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Identification of Road User related Risk Factors

Deliverable 4.1

Identification of Road User related Risk Factors

Work package 4, Deliverable 4.1

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Project Coordinator:
Professor Pete Thomas, Transport Safety Research Centre, Loughborough Design School, Loughborough University, Ashby Road, Loughborough, LE11 3TU, UK

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Loughborough University, UK

Report Author(s):
Talbot, R., Filtness, A. (LOUGH), United Kingdom
Aigner-Breuss, E., Kaiser, S., Braun, E. Eichhorn, A., Pilgerstorfer, M., Rußwurm, K., Soteropoulos, A. (KFV), Austria
Alfonsi, R. (CTL), Italy
Hay, M., Etienne, V., Gabaude, C., Paire-Ficout, L. (IFSTTAR), France
Goldenbeld, C., Van Schagen, I., (SWOV), Netherlands
Jänsch, M. (MHH), Germany
Leblud, J. (BRSI), Belgium
Leskovšek, B. (AVP), Slovenia
Ziakopoulos, A., Theofilatos, A., Papadimitriou, E., Yannis, G. (NTUA), Greece
Sandin, J., Strand, N. (SAFER, VTI), Sweden

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Executive summary

Safety CaUsation, Benefits and Efficiency (SafetyCube) is a European Commission supported Horizon 2020 project with the objective of developing an innovative road safety Decision Support System (DSS). The DSS will enable policy-makers and stakeholders to select and implement the most appropriate strategies, measures, and cost-effective approaches to reduce casualties of all road user types and all severities.

This document is the first deliverable (4.1) of work package 4 which is dedicated to identifying and assessing human related risk factors and corresponding countermeasures as well as their effect on road safety. The focus of deliverable 4.1 is on identification and assessment of risk factors and describes the corresponding operational procedure and corresponding outcomes. The following steps have been carried out:

- Identification of human related risk factors – creation of a taxonomy
- Consultation of relevant stakeholders and policy papers for identification of topic with high priority ('hot topics')
- Systematic literature search and selection of relevant studies on identified risk factors
- Coding of studies
- Analysis of risk factors on basis of coded studies
- Synopses of risk factors, including accident scenarios

The core output of this task are synopses of risk factors which will be available through the DSS. Within the synopses, each risk factor was analysed systematically on basis of scientific studies and is further assigned to one of four levels of risk (marked with a colour code). Essential information of the more than 180 included studies were coded and will also be available in the database of the DSS. Furthermore, the synopses contain theoretical background on the risk factor and are prepared in different sections with different levels of detail for an academic as well as a non-academic audience. These sections are readable independently.

It is important to note that the relationship between road safety and road user related risk factors is a difficult task. For some risk factors the available studies focused more on conditions of the behaviour (in which situations the behaviour is shown or which groups are more likely to show this behaviour) rather than the risk factor itself. Therefore, it cannot be concluded that those risk factors that have not often been studied or have to rely more indirect and arguably weaker methodologies, e.g. self-reports , do not increase the chance of a crash occurring.

The following analysed risk factors were assessed as 'risky', 'probably risky' or 'unclear'. No risk factors were identified as 'probably not risky'.

Risky	Probably risky	Unclear
• Influenced driving – alcohol • Influenced Driving – drugs (legal & illegal) • Speeding and inappropriate speed • Traffic rule violations – red light running • Distraction – cell phone use (hand held) • Distraction – cell phone use (hands free) • Distraction – cell phone use (texting) • Fatigue – sleep disorders – sleep apnea	• Risk taking – overtaking • Risk taking – close following behaviour • Insufficient knowledge and skills • Functional impairment – cognitive impairment • Functional impairment – vision loss • Diseases and disorders – diabetes • Personal factors – sensation seeking • Personal factors – ADHD • Emotions – anger, aggression • Fatigue – Not enough sleep/driving while tired • Distraction – conversation with passengers • Distraction – outside of vehicle • Distraction – cognitive overload and inattention	• Functional impairment – hearing loss (few studies) • Observation errors (few studies) • Distraction – music – entertainment systems (many studies, mixed results) • Distraction – operating devices (many studies, mixed results)

The next step in SafetyCube's WP4 is to identify and assess the effectiveness of measures and to establish a link to the identified risk factors. The work of this first task indicates a set of risk factors that should be centre of attention when identifying corresponding road safety measures (category 'risky').

1 Introduction

1.1 SAFETYCUBE

Safety CaUsation, Benefits and Efficiency (SafetyCube) is a European Commission supported Horizon 2020 project with the objective of developing an innovative road safety Decision Support System (DSS) that will enable policy-makers and stakeholders to select and implement the most appropriate strategies, measures and cost-effective approaches to reduce casualties of all road user types and all severities.

SafetyCube aims to:

1. develop new analysis methods for (a) Priority setting, (b) Evaluating the effectiveness of measures (c) Monitoring serious injuries and assessing their socio-economic costs (d) Cost-benefit analysis taking account of human and material costs
2. apply these methods to safety data to identify the key accident causation mechanisms, risk factors and the most cost-effective measures for fatally and seriously injured casualties
3. develop an operational framework to ensure the project facilities can be accessed and updated beyond the completion of SafetyCube
4. enhance the European Road Safety Observatory and work with road safety stakeholders to ensure the results of the project can be implemented as widely as possible

The core of the project is a comprehensive analysis of accident risks and the effectiveness and cost-benefit of safety measures focusing on road users, infrastructure, vehicles and injuries framed within a systems approach with road safety stakeholders at the national level, EU and beyond having involvement at all stages.

Work Package 4

The objective of work package 4 is to analyse data, implement developed methodologies (WP3) concerning accident risk factors and road safety measures related to the road users. It examines accident risks and safety measures concerning all types of road users including Vulnerable Road Users (VRU). Personal as well as commercial transportation aspects are taken into account. Therefore, various data sources (macroscopic and in-depth accident data) and knowledge bases (e.g. existing studies) will be exploited in order to:

- Identify and rank risk factors related to the road use
- Identify measures for addressing these risk factors
- Assess the effect of measures

The work on human related risks and measures in road traffic is done according to the methodologies and guidelines developed in WP3 (Martensen et al., 2017) and uniform and in parallel with the work packages dealing with infrastructure (WP5) and vehicle (WP6) related risks and measures. Furthermore, the latter process is monitored and steered by WP8.

All main results of WP4 will be integrated into the DSS and linked with each other (risk factors and measures) and with outcomes of other work packages (WPs 5, 6, and 7[1]).

[1] WP7 is dealing with serious injuries.

1.2 PURPOSE OF THIS DELIVERABLE

This deliverable reports on the work in Task 4.1. The overall aim of Task 4.1 was to identify road user related risk factors. However, it comprises additional tasks like in-depth accident analysis and the identification of knowledge gaps in order to get to the bottom of contributing road accident factors and as a basis for the next step of identifying related countermeasures.

This deliverable is dedicated to present the process of identifying, selecting, analysing and assessing road safety risk factors related to humans and their behaviour as well as its outcomes. The following steps were taken towards achieving the common purpose of SafetyCube and are described in detail in this deliverable:

- Identification of human related risk factors – creation of a taxonomy
- Consultation of relevant stakeholders for 'hot topic' identification
- Systematic literature search and selection of relevant studies on identified risk factors
- Coding of studies
- Analysis of risk factors on basis of coded studies
- Synopses of risk factors (including accident scenarios)

The main results of deliverable 4.1 will be a variety of systematically analysed risk factors, documented in risk factor 'synopses' which will be incorporated into the Safety Cube DSS and linked to corresponding road safety measures and cost-benefit-analyses of certain measures. As the synopses are very comprehensive, they form individual documents appended to this one and will be made available separately via the project website (www.safetycube-project.eu/) and on the DSS when it is launched. However, an overview of the risk factor-synopses can be found in this deliverable as well as all related abstracts.

It is crucial to note that the overall approach of SafetyCube – to quantify risk factors and assess measures quantitatively – is challenging to apply when human decision making and behaviour come into play. Human related risk factors are often not directly observable (e.g. a personality trait or fatigue) or have similar characteristics that make it difficult to distinguish between them. This requires the presence of such 'unobservable' risk factors to be inferred. Furthermore, human road safety risk factors tend not to occur as a singular phenomenon but in interaction with other (human) factors. Thus, the methods to determine them are manifold and sometimes vary considerably making it difficult to compare the outcomes. We are frequently dealing with studies which are investigating the effect of a risk factor on Safety Performance Indicators (SPI) such as self-reported behaviour or driving simulator measures, as opposed to the direct link between the risk factor and accidents. While the considered SPIs are either assumed or known to be linked to road safety, the relationship is sometimes indirect and cannot always be quantified. Taking all this into account makes it vital to provide qualitative information for each risk factor or road safety measure alongside the quantitative assessment.

2 Identification and prioritisation of risk factors

This chapter explains the process of deriving a taxonomy of human related risk factors in road traffic for SafetyCube's purpose. To ensure the relevance of this, the risk factors have been further prioritized by considering valuable input from practitioners and stakeholders. Moreover, the chapter shows how human risk factors are delineated from road safety measures within this project as well as how vulnerable road users were taken into consideration.

2.1 WHAT IS A RISK FACTOR?

Within the SafetyCube project 'risk factor' refers to any factor that contributes to the occurrence or the consequence of road accidents. Risk factors can have a direct influence on the risk of an accident occurring or more indirectly by influencing a Safety Performance Indicator (SPI). All elements of the road system can hold an accident risk factor. WP4 is dealing with those that are related to the road users and their behaviour in road traffic.

2.2 TAXONOMY OF HUMAN RELATED RISK FACTORS

As a first step towards assessing behavioural risk factors in a comprehensive manner, a list of known human related risks in road traffic has been created with broad categories. An important aim was to consider all individual modes of transport (pedestrians, cyclists, powered two-wheelers, car drivers) and all kinds of road users (children, elderly etc.). The taxonomy is furthermore the basis for linking risk factors with their corresponding measures.

While there have been various classifications of road safety risks developed already, mostly for accident causation analysis within former projects such as SafetyNet (Wallén Warner et al., 2008) or TRACE (Naing et al., 2007), none of them exactly suited the needs of SafetyCube since each of these tools was developed with a very specific aim. Therefore it was decided to create a new, made-to-measure taxonomy, although the accident causation classifications formed a useful starting point.

The topics, only categorized roughly at that point, like 'speeding', 'distraction', or 'fatigue', have been assigned to all partners involved in Task 1 according to their expertise and preference. Partners then further refined and differentiated their topics - based on literature search and their expertise - on two sublevels in an iterative process to arrive at a three-level taxonomy. This three-level structure is uniform across the analytical WPs and that is how the topics will also appear within the web-based DSS. Proposals of classifications have been circulated within the WP for feedback of others and consolidated centrally.

During this process the creation of a draft taxonomy of human related road safety measures has been started in parallel to use resources for the first literature screening as effectively as possible (for the taxonomy of behavioural measures see deliverable 4.2 – available from Aug 2017). Figure 1 shows an example of the three-level classification for the topic of driving under the influence. The full taxonomy of road user related risk factors can be found in appendix A.

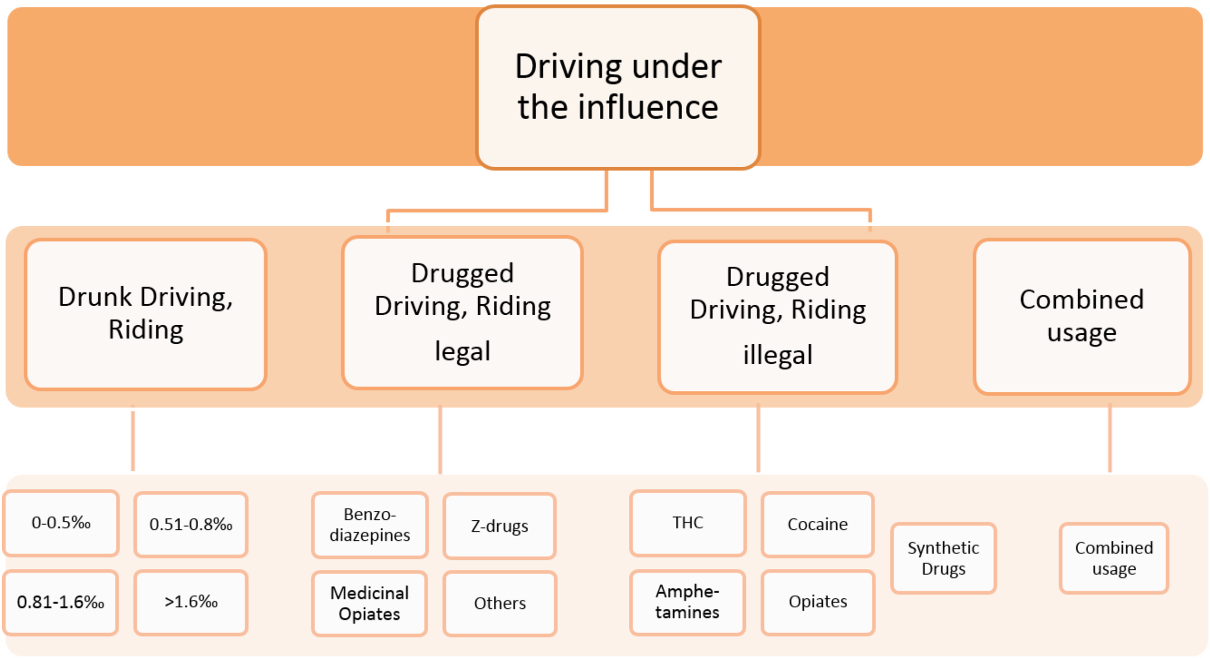

Figure 1: SafetyCube's three-level taxonomy using the example of driving under the influence.

In the course of establishing the risk factor taxonomy in parallel with the WPs dealing with infrastructure and vehicles, it was not always clear right away how to separate certain factors from each other. As the three areas - behaviour, infrastructure, and vehicle - are of course interrelated in the traffic system as a whole, some division between topics had to be made purely for the reason of splitting project work - not suggesting a division content-wise. On the one hand, there has been some overlap with WP6 (vehicles). For example, the lack of maintenance of a car or a powered two-wheeler, which clearly is risky for road safety, can be interpreted as belonging to the sphere of vehicles but also relates to human behaviour. However, it has been decided in accordance with WP6 and 8 to assign all risk factors to WP6 that are physically tied to the vehicle like checking tire pressure or car maintenance in general.

Similarly, it is debatable whether certain behaviours are interpreted as risks or as measures. Not using a bicycle helmet (or any other safety device) is a risk in terms of severity of injury in the case of an accident. Using the helmet in turn is a measure to mitigate injury outcomes. In the end, safety devices will be dealt within the next task which is to prioritize and assess measures targeting unsafe human behaviour (see deliverable 4.2, available August 2017).

While road safety research shows clearly that certain age groups are more at risk than others (e.g. young males, children, elderly), it is inappropriate to claim that 'age' is a risk factor per se. Therefore, age groups will not be treated as a separate risk factor but tackled within the other risk factors (e.g. functional impairment and elderly). A focus will be put on these groups that are at risk when it comes to identifying and selecting measures for assessment. However, the topic of age appears in the WP4-taxonomy as a separate topic for practical reasons. Whenever an included study deals with a certain risk of a certain age group, it is assigned primarily to that risk factor and then to the age group to make it traceable for the DSS-user (e.g. cognitive impairment among elderly, lack of knowledge among children etc.).

Several adaptations of the taxonomy had to be made in an iterative process since it was not possible to anticipate all aspects of all topics prior to conducting a systematic literature search which was the next step. As the DSS is designed to be a living rather than a static system, the taxonomies of road safety risks and measures do not claim to be exhaustive.

2.3 HOT TOPICS AND PRIORITIES IN ROAD SAFETY

During the task of creating a list of risk factors, policy makers and other stakeholders were consulted and various policy documents were reviewed to identify research and policy priorities. The close engagement of various stakeholders including EU bodies, member states, road and vehicle industry but also e.g. the health sector is crucial throughout the project to ensure a high level of impact of SafetyCube's DSS. The stakeholders' consultations in the form of two workshops were organised and lead by the dissemination WP (2) and were designed to cover the focus of all WPs. Additionally, stakeholders had the opportunity to contribute at any time via an 'Interactive Stakeholders' Platform' (see Deliverable 2.4). Furthermore, various policy papers and outcomes of research projects have been screened for highlighted topics and priorities in road safety work.
The consideration of stakeholders' opinion, policy papers and research outcomes did not only help to prioritize but also to make sure the most pressing issues are covered within SafetyCube beyond the obvious human related risk factors. The following sources have been collected and further systematically processed:

- **Stakeholder workshops** (A list of participants is available in appendix C)
  - Brussels, June 17th 2015
  - Ljubljana, October 14th 2015
- **Projects**
  - PROS (Urban, 2014)
  - Rosee (Štaba & Možina, 2014)
- **Policy papers**
  - Towards a European road safety area: policy orientations on road safety 2011-2020 (EC, 2010)
  - Towards Zero Deaths: A National Strategy on Highway Safety (Zegeer et al., 2010)
  - Towards safer roads in Europe (FERSI, 2014)
- **Individual expert consultation**
  - FERSI representative
  - Project consortium

Processing of stakeholders' input and policy and research outcomes

All statements and topics mentioned in the screened papers on various road user related risk factors were counted and recorded. The identified hot topics are within different levels of the WP4 taxonomy. Some nominations are very explicit like 'distraction due to cell phone use' and some are on a very global level like 'driving under the influence'. Furthermore, there had not always been a separation between risks and measures. The input on priorities of measures will be used for the next task of assessing road safety measures. The outcome of this procedure can be found in appendix A (colour highlighting).

In conclusion, the following are considered to be 'hot topics' (minimum of three nominations):

- Speed choice
- Drunk driving/riding
- Drugged driving/riding (legal, medicine)
- Fatigue
- Cell phone use & operation other devices (e.g. in-vehicle information systems)
- Cognitive Impairment
- Aggression and anger
- Elderly road users

- Young adult road users
- Children

The identified hot topics are widely covered in the work reported in this deliverable. However, also various other risk factors from the taxonomy were selected and included in the further analysing process to cover a wider range of topics:

- Drugged driving/riding (illegal drugs)
- Risk taking – overtaking and close following
- Insufficient skills and knowledge
- Functional impairment – vision loss and hearing loss
- Diseases and disorders – diabetes
- Personal factors – sensation seeking and ADHD
- Distraction through conversation with passengers, music/entertainment systems and outside of vehicle
- Observation errors

Vulnerable road users

Generally the term 'vulnerable road users' (VRU) either refers to the modes of transport that provide the least protection for the road user or a certain age group. The latter is considered vulnerable due to their physiology or potentially limited task capability. Resilience is also a factor that distinguishes between vulnerable road users and others (SWOV, 2012). VRU are defined in the SafetyCube project to be pedal cyclists, pedestrians, powered two-wheelers, children, and elderly. Even though the number of fatalities on EU's roads decreased in the decade to 2010 (45% reduction in fatalities, 30% reduction of all injured, EuroStat, 2012), in 2010 more than 50% of all fatally injured were VRU (EC, 2010).

As mentioned earlier, rather than declaring a whole group of VRU, such as elderly, a risk factor, they require high attention when it comes to designing and selecting effective road safety measures. SafetyCube will therefore put an emphasis on these groups in the next task when dealing with road safety measures. All studies included in the DSS on risk factors that have a look at a VRU group will be assigned to both the specific risk factor and the age group or mode of transport (e.g. cognitive impairment of elderly, insufficient skills and children, or young males and speeding). Consequently, DSS users will be able to find the information by either searching for the risk factor and for the VRU group respectively.

3 Study selection and coding

This chapter provides an overview of the process of searching and selecting studies on human related risk factor estimates that have been included in SafetyCube's repository and will be available through the DSS.

The aim was to collect information of studies dealing with the effect of risk factors on road safety in a uniform manner (as far as possible). Therefore, a standard methodology was developed by WP3. This included a literature search strategy, a coding scheme to record key data and metadata from individual studies and guidelines for summarising the findings per risk factor. Copies of these documents and the associated instructions and guidelines can be found in Martensen et al. (2017).

3.1 LITERATURE SEARCH

For each of the identified and selected risk factor topics a standardised literature search was conducted in order to identify relevant studies to include in the DSS and to form a basis for a concluding summary (synopsis) and further analyses. A standardised procedure was developed in WP3 and applied for each examined risk factor in SafetyCube (within WPs 4, 5, 6, 7). The closer look at each risk factor in terms of the literature search resulted in the need for several adaptations of the risk factor taxonomy, especially on the second and third, more detailed levels. The literature search was documented according to the Guidelines of WP3 in a standard template to make the gradual reduction of relevant studies transparent. This documentation of each search is included in the corresponding supporting documents of the synopses (see Appendix D). The databases used in WP4 are the following:

- Scopus
- Google Scholar
- Web of Science
- Science Direct
- Dok Dat[2]
- PubMed

3.2 STUDY SELECTION

Accident counts versus Safety Performance Indicators as Outcome

The initial aim was to find studies that provided an estimate of the risk of being in an accident due to the presence of the risk factor. However, while the actual occurrence of accidents can be seen as the ultimate measure for road safety, in recent years more and more often, Safety Performance Indicators (SPI) have been taken into consideration to quantify the road safety level (Gitelman et al., 2014) - like driving behaviour, such as speed choice, drink driving or seat belt use. In addition, attitudes and intentions can be utilised as SPI given that a link between attitudes and behaviour can be established by psychological theory (Martensen et al., 2017).

SPIs such as attitudes or driving behaviour are often used to test the impacts of, for example, campaigns or enforcement strategies (e.g. their effect on speeding or driving under influence). When considering road user related risks, it is especially important to also have a look at studies that

[2] Internal database of Austrian Road Safety Board

report on SPIs such as self-reported behaviour or cognitive diagnostic measures. That is because the presence of a human related risk factor in an accident is far less easy to determine than the presence or absence of a safety feature in a vehicle or the presence or absence of an infrastructural element. However, it is important to note that the effect of a given risk factor on accidents via a SPI is indirect and often the relationship between an SPI and accident involvement is a missing link in road safety knowledge.

Studies have been considered which either assess the effect of a risk factor on accidents (fatal, injured, material damage) or on one or several SPIs. The following measurement variables have been included in WP4:

- Accident and injury data, statistics
- Self-reported accident history
- Near miss or critical event data (self-reported, observed)
- Directly observed or measured behaviour (e.g. red light running, speeding)
- Self-reported behaviour (e.g. speeding, risk taking etc.)
- Real world driving (Naturalistic, driving test on road)
- Driving test in simulator (e.g. reaction time, lane deviation etc.)
- Attitudes towards unsafe behaviours
- Outcomes of psychological diagnostic assessment

Studies that compared two different kinds of (variations of) risk factors are not suitable in terms of risk factors assessment and have been excluded for that reason. Studies with no control or comparison group (e.g. group not exposed to risk factor) were also excluded.

Prioritising

Since the study design and the outcome variables are just basic criteria, for some risk factors the literature search resulted in a large amount of studies, so further selection criteria were required. Furthermore, on major and well-studied human risk factors meta-analyses were available and these were prioritised. While the aim was of course to include as many studies as possible for as many risk factors as possible, it was simply not achievable to examine all available studies for all risk factors and their variants. The criteria for the prioritisation of studies were the following (no obligatory application):

- Key meta-analyses (studies already included in the key meta-analysis were not coded again)
- Most recent studies
- Quality of studies
- Country origin: Europe before US/Australia/Canada before other countries
- Importance: number of citations
- Language: English
- Peer-reviewed journals

According to the level of detail of the topic and the history of research in the field, the number of studies that were eligible for 'coding' varied (see synopses for the number of studies included per topic). To keep track of the number of studies per risk factor topic and to avoid double-coding of different partners with overlapping topics, a document was kept and updated where partners recorded all of their studies.

A challenge within the task of identifying studies to be included in the repository of risk factor studies was to distinguish between risk factors and countermeasures. For example, studies dealing with speeding are often designed to record e.g. accidents before and after the establishment of a certain speeding measure (e.g. section control). So the study is at the same time assessing the risk factor and the corresponding measure.

3.3 STUDY CODING

Within the aim of creating a database of estimates of risk factors and safety effects, a template was developed (WP3) that determined what information per study had to be provided and offered the opportunity to report this information uniformly across topics and WPs.
Guidelines were also made available for the task of coding with detailed instructions on how to use the template. The design of the coding template accommodates the variety and complexity of different study designs. A workshop was organised to train coders on how to use the template.

The following information is provided per study and will also be retrievable in the DSS:

- Road system element (Road User, Infrastructure, Vehicle) and level of taxonomy so that users of the DSS will be able to find information on topics they are interested in
- Basic information of the study (title, author, year, source, origin, abstract, etc.)
- Road user group examined
- Study design
- Measures of exposure to the risk factor
- Measures of outcome (e.g. number of injury crashes)
- Type of effects
- Effects (including corresponding measures such as confidence intervals)
- Biases
- Summary

For the full list of information provided per study see Martensen et al. (2017). Completed coding files were uploaded to the web-based DSS. In total, more than 180 studies on human related risk factors have been coded within WP4.

Quality control for coding task

Even though the instructions for coding were very detailed, there is sometimes still room for interpretation e.g. which design describes the study the best (if not mentioned by author), which estimates to include or exclude, what are the main weak points of the study etc. Therefore, a quality control procedure was established. Every coded study was checked by a second person (within or outside the same organisation) and at least one study per organisation was checked by the WP leader. Furthermore, coders had the opportunity to have more than one study checked if they were uncertain.

Iterative process and adaptation of taxonomy and coding template

The structure of this deliverable suggests a sequential approach of creating a risk factor taxonomy, identifying studies that assess the risk in terms of quantitative measures, and coding all these studies. However, the actual process was rather more iterative: creating a draft taxonomy, finding few suitable studies, adapting the taxonomy according to that, filling in a draft coding template, feedback to the methodology developers (WP3), adaptation of the template, refining the taxonomy, searching for suitable studies etc. This process was necessary since it was not possible to anticipate all methodological details of all studies, neither was is possible to establish a suitable taxonomy of risk factors and measures without going into detail in terms of a literature review of each topic. This approach required tight cooperation between WP3 and the executing WPs 4, 5, and 6. Several adaptations of the taxonomy and the coding template were necessary.

4 Analysis and summary

This chapter describes how the information from the coded studies and additional in-depth crash data was analysed and summarized. For many risk factors this analysis and summary will be available through the DSS in the form of a risk factor 'synopsis'. The audience of the synopses will be varied – both academic and non-academic stakeholders e.g. policy makers. Thus, risk factor synopses are structured in different sections, for different target groups, that can be read independently.

The DSS will provide information for all coded studies (see above) for various risk factors and measures. The synthesis of these studies will be also be available, in the form of a 'synopsis' indicating the main findings for a particular risk factor derived from meta-analyses or another type of comprehensive synthesis of the results (e.g. vote-count table).

Synopses were created for the identified hot topics and furthermore for several other risk factors of the taxonomy (for measures see deliverable 4.2, available from August 2017) on different levels of the risk factor taxonomy, thus, for different levels of detail. Whether a synopsis was created for the first, second, or third level of the taxonomy was decided during the task of searching literature (see 3.1) by the responsible partner, mainly dependent on the availability of studies for a certain topic. All synopsis for individual risk factors are presented in the appendix D. Moreover, the synopses contain context information for each risk factor from literature that could not be coded (e.g. literature reviews or qualitative studies). On the other hand, not all the coded studies that will populate the DSS are included in the analysis documented in the synopsis.

The synopses aim to facilitate different end users: decision-makers looking for global estimates vs. scientific users interested in result and methodological details. Therefore, the synopses contain sections for different end user groups that can be read independently. Moreover, the structure of the synopses is differentiated into three distinct parts:

a. **Summary:** A two-page document reporting the key aspects of the topic, the main results, and transferability conditions. This part addresses users, who need a short overview of the topic and the main results, such as policy makers.
b. **Scientific overview:** A four to five page document including a short synthesis of the literature, an overview of the available studies, a description of the analysis methods, and an analysis of the effects by condition. This section aims to describe the way the reported effects have been estimated, with a full analysis of the methods and results, in order to give the user all the necessary information to understand the results and assess their validity.
c. **Supporting document**: This section describes the literature search, compares the available studies in detail (optional) etc. It aims to provide the most detailed information for the scientific reader and interested user (no initial page limit).

A colour code was assigned to each synopsis to give an indication about the evidence that the risk factor(s) covered has a negative effect on road safety (see chapter 5.1).

4.1 HUMAN RELATED IN-DEPTH CRASH DATA

To enrich the background information in the synopsis, in-depth accident data from The German In-Depth Accident Study (GIDAS) has been used for those risk factors, which are sufficiently represented in the corresponding database. The analysis of accident causes in GIDAS was conducted by GIDAS researchers and used the Accident Causation Analysis System (ACAS) which particularly focuses on the identification of human failures. The theoretical framework for the analysis of these human causes is a hierarchical classification scheme of five categories of basic human functions in which errors are identified. More detailed information about GIDAS and ACAS can be found below. The codes of the accident analysis system ACAS widely covers the identified risk factors of the WP4 taxonomy which made it possible to gain more knowledge about the relation of the factor in question with other important characteristics of accidents, such as the type of road user involved, their age, the time of the day or the week, the type of the road, etc.
As an example, Figure 2 gives an overview of the distribution of accident locations for crashes in which either distraction or speeding was a contributory factor and for all crashes together respectively. It is clear that each contributory factor has a distinctive 'footprint' with distraction accidents taking place exclusively on straight road segments and in curves, while speeding crashes are underrepresented on straight roads and overrepresented in curves and also at crossings.

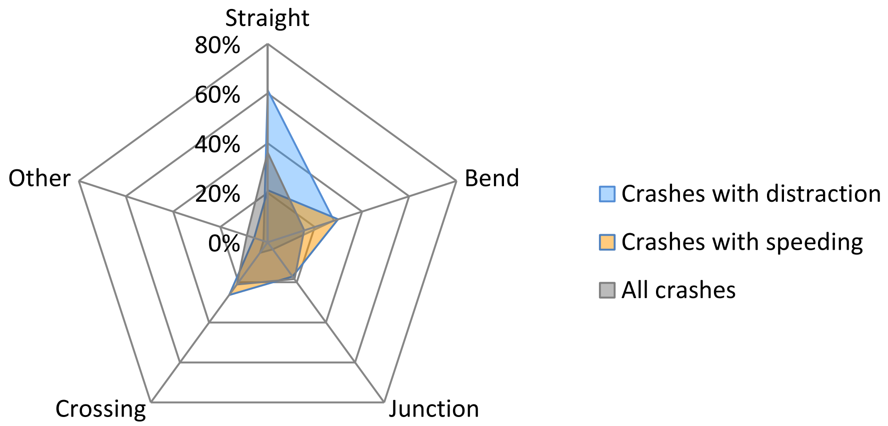

Figure 2: Radar plot of distribution of accident sites from the GIDAS database for crashes with distraction and speeding involved, and all crashes respectively.

About GIDAS

The German In-Depth Accident Study (GIDAS) is a joint venture between Federal Highway Research Institute (BASt) and the German Association for Research in Automobile Technology (FAT), initiated in July 1999. It is the largest in-depth accident study project in Germany and based on the work of the BASt-founded investigation team at the Hanover Medical School (MHH), in co-operation with the investigation team of the Technical University Dresden. Approximately 2,000 accidents involving personal injury are recorded in the area of Dresden and Hannover annually (Otte et al., 2003).

In GIDAS, road traffic accidents involving personal injury are investigated using the "on the scene" approach and are collected according to a statistical sampling process. This means that teams are called promptly after the occurrence of any kind of road traffic accidents with at least one injured person which occurred in determined time shifts. Comparisons with the official accident statistics

are made regularly and weighing factors are applied (to avoid biases). Investigation areas were chosen accordingly to represent the German national road network and built-up areas.
The detailed documentation of the accidents is performed by survey teams consisting of specially trained students, technical and medical staff. The documentation scope obtained reaches up to 3,000 encoded parameters per accident. The data scope includes technical vehicle data, crash information, road design, active and passive safety systems, accident scene details, and cause of the accident. Surveyed factors include impact contact points of passengers or vulnerable road users, environmental conditions, information on traffic control, and other parties (road users) involved. To collect detailed injury and accident causation information individual interviews of the involved accident participants are followed by detailed surveying of the accident scene based on existing evidence. All information available retrospectively is collected in close collaboration with police, hospitals and rescue services and each documented accident is reconstructed in a simulation program (entire course of the accident).

About ACAS

The analysis of the accident causes at the investigation team at MHH is conducted using ACAS (Accident Causation Analysis System). It was developed to aid the on-scene accident research team, GIDAS to analyse and collect relevant factors of causes of accidents. ACAS focuses especially on the identification of human failures (Otte et al., 2009). Within the ACAS-methodology causation factors of traffic accidents are identified and collected using a code of 4 numbers. For each accident participant multiple codes may apply.
The causation factors of traffic accidents can be divided in to three different groups (first number of the code):

- Group 1. Human causation factors
- Group 2. Factors from the technical nature of vehicles and
- Group 3. Factors from the range of the infrastructure and nature.

Each causation factor group consists of specific categories which are subdivided into different criteria and within Group 1 (Human causation factors) the criteria are further subdivided into different indicators of each criteria, see Figure 3.

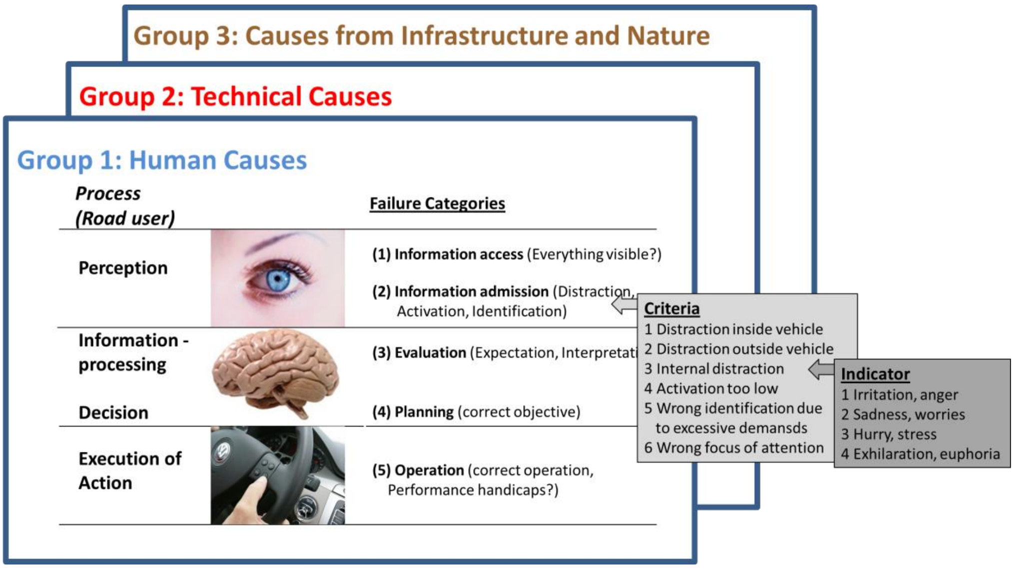

Figure 3: Structure of causation codes in ACAS (example from Group 1 – human factors)

The analysis of the human factors is achieved by describing the human participation factors - and failures of these - in a chronological sequence from perception to concrete action/operation. This is done by considering the logical sequence of five basic human functions which the road user continuously engages in when participating in the road traffic system. These functions provide the 5 categories of human factors (group 1) and are the core of the causation analysis system. The full list of ACAS codes can be found in the appendix B.

CARE database

The Care CADaS database was also looked at to describe the relationship between a human related risk factor and crashed. The database contained information for some risk factors like alcohol or distraction by devices but the data was only available for some countries for some years with an uncertain quality. For this reason, the data was not analysed further.

5 Risk factor synopses - Abstracts

This chapter provides an overview of all human related risk factor synopses that have been written as of October 2016 and these will be available through the DSS when it is launched in 2017. However, since these are very comprehensive documents, only the abstracts and the corresponding colour code - which indicates the level of evidence for a given risk factor (see section 5.1) - will be provided in this chapter. The synopses are intended to be periodically updated to reflect new research or in some cases to expand their scope. The full text of the synopses in their current form (v1.0) can be found in Appendix D and any future updates or additions will be available on the project website (http://www.safetycube-project.eu/) and the DSS.

Full list of Synopses: [3]

- Influenced driving - alcohol
- Influenced driving - drugs (legal & illegal)
- Speeding and inappropriate speed
- Traffic rule violations - red light running
- Risk taking - overtaking
- Risk taking - close following behaviour
- Distraction - cell phone use - hand held
- Distraction - cell phone use - hands free
- Distraction - cell phone use - texting
- Distraction - music - entertainment systems
- Distraction - operating devices
- Distraction - cognitive overload, inattention
- Distraction - conversation with passengers
- Distraction - outside of vehicle
- Fatigue - not enough sleep, sleepy at wheel
- Fatigue - sleep disorders - sleep apnea
- Insufficient knowledge and skills
- Observation errors
- Functional impairment - cognitive impairment
- Functional impairment - hearing loss
- Functional impairment - vision loss
- Diseases and disorders - diabetes
- Personal factors - sensation seeking
- Personal factors - ADHD
- Emotions - aggression, anger

[3] The titles of the synopses are not always in line with the wording of the corresponding topics in the taxonomy. Some specific topics have been summarised in one synopsis. Sometimes the chosen synopsis title was better suitable corresponding to the content and literature respectively.

5.1 COLOUR CODE EXPLANATION

A colour code was assigned to each synopsis to give an indication about the evidence that the risk factor(s) covered has a negative effect on road safety. [Adapted from Martensen et al., 2017]

Red (risky)

Red was used when the study results were relatively consistent showing an increased risk upon exposure to the risk factor in question.

- Good number of studies (at least 3 per relevant condition, at least 5 in total)
- Fair quality (at least for a number of studies showing the result)
- Consistency across studies & conditions
- Good indictor (proven relation with accidents)

Yellow (probably risky)

Yellow was used when there was some indication that exposure to the risk factor increases the accident or injury risk, but the results were not consistent. This could either be due to conditions under which the risk factor has been shown to be unproblematic, or because the study results are inconsistent (but with the majority of studies pointing to an increased risk).

- Few studies (of sufficient quality)
- Inconsistent results (but majority showing risk effect)
- Weak indicator (unsure relation to accidents)

Grey (unclear)

If several of the above issues listed in the yellow category were applicable (few studies with inconsistent results, or few studies with weak indicators or an equal amount of studies with no (or opposite) it was concluded that the evidence for the effect of the risk factor on road safety was 'unclear' and so was assigned the category 'grey'

- No studies that investigate effect
- Mixed results
- Insufficient quality & quantity of studies that might show a risk effect

Green (probably not risky)

This colour was selected to indicate that studies suggest that the 'risk factor' was probably not risky or actually had a positive effect on road safety. The absence of a risk effect is a null-effect which is notoriously difficult to "prove", therefore this category was only chosen if there were a reasonably large number of studies with fair quality – such that one could expect a risk effect (if it existed) to become apparent in them.

- Sufficient quantity and quality of studies
- Large majority of studies show null-effect or opposite effect
- Meta-analysis on a large number of studies shows no significant effect or opposite effect

5.2 INFLUENCED DRIVING - ALCOHOL

Colour code: Red

Driving under the influence of alcohol generally has a significantly increased risk of crashes and poor driving performance. There is a common understanding that driving under the influence of alcohol is associated with higher risk of being involved in crashes with injuries and possible fatalities as the outcome. Alcohol is a depressant. It slows down the brain and affects the body's responses. At the same time, if you have been drinking, you are more likely to take risks. Combined, these reactions increase the likelihood of accidents happening.

Abstract

Drinking and driving is one of the main causes of road crashes worldwide. Efforts to deter drunken driving have a long history as evidenced by enforcement of statutory blood-alcohol concentration (BAC) limits of 0.20, 0.50 or 0.80 g/L (20, 50 or 80 mg/100 mL) in most nations. In high-income countries, about 20% of fatally injured drivers have excess alcohol in their blood, while in some low- and middle-income countries these figures may be up to 69%. Although injuries and fatalities related to road accidents have decreased in recent decades, the prevalence of drunk driving among drivers killed in road accidents has remained stable, at around 25% or more during the past 10 years. In the context of driving, it is relevant to distinguish between drivers who exceed the BAC limit only once, and those who do it repeatedly (recidivists). Driving under the influence (DUI) laws, enforcement and penalties vary between countries and have been implemented at different historical moments. In addition, the driver's knowledge and respect for the DUI laws vary; therefore, the incidence of driving under the influence of alcohol or drugs and the involvement of alcohol and drugs in fatal crashes varies.

5.3 INFLUENCED DRIVING - DRUGS (LEGAL & ILLEGAL)

Colour code: Red

Legal and illegal drugs generally have a significant negative effect on crashes and driving performance. The crash risk is increased with most drug types. When combined with other drugs or alcohol, the effect on road safety is even worse than when taken alone.

Abstract

'Drugs' is a very common term which refers to countless numbers of substances. It can have positive or negative effects on efficiency, reflexes, concentration, sleeping etc. More specifically, substances having physiological effects on the human body and behaviour are defined as psychoactive drugs. In the context of road safety, they could be a major danger when driving a vehicle. In this synopsis the main types of drugs were assessed to determine their impact on road safety. Legal drugs studied were divided into benzodiazepine and medicinal opioids. Illegal drugs were divided into amphetamines, cocaine, opioids, and cannabinoids. The literature study firstly highlighted that driving under the influence of drugs is a well-studied subject, with hundreds of papers found. It also showed that the main legal and illegal drugs have a negative impact on road safety. They increase the crash risk, injury severity, fatal crash rate, but also the general ability to drive. When combined with alcohol or other drugs, their effects are even worse. Considering that more than 10% of fatal accidents could be linked to drug use, it is important to systematically monitor their use and increase the enforcement.

5.4 SPEEDING AND INAPPROPRIATE SPEED

Colour Code: Red

Research shows that there is a very strong statistical relationship between speed and road safety. When speed increases, the number of accidents and the number of injured road users rises. When speed goes down, the number of accidents and the number of injured road users decreases.

Abstract

Speed is a well-known risk factor. Studies documented a strong statistical relationship between speed and road safety. If the (mean) speed of traffic is reduced, the number of accidents and the severity of injuries decrease. The relationship between changes in speed and changes in road safety can be described by the Power Model – developed by Nilsson in 1981. Mainly case-control, cross-

sectional and observational study designs are used for investigating the effect of speeding. Studies mainly compare speeders and non-speeders, drivers with and without crashes, or analyse accident outcomes regarding the proportion of speeders. However, studies on speeding often reveal several limitations like availability of a control group or completeness of data.

5.5 TRAFFIC RULE VIOLATIONS - RED LIGHT RUNNING

Colour code: Red

Red light running can lead to two basic types of traffic conflicts at intersections: right-angle and left turn-opposed conflicts. Red light running is a traffic violation that is associated with very serious crash outcomes (fatality or serious injury). Red-light-running related crashes compose a substantial part of urban road safety. It has been estimated that when a pedestrian crosses an intersection at red light his relative crash risk is eight times higher compared to a legal crossing at green (or amber) light.

Abstract

Red light running is a risky traffic violation leading to traffic conflicts at intersections that may result in death or serious injury. It has been estimated that pedestrians' relative crash risk is eight times higher when they cross an intersection at red light instead of green (or yellow) light. Relative risk estimates for red light running by drivers and cyclists have not yet been made. Red light running is fairly scarce amongst drivers (a few drivers per 1,000 vehicles), but fairly frequent among cyclists and pedestrians (percentages may run up to over 50% at specific days, times and locations). Red light running is influenced by several factors, including age and gender, static and dynamic intersection characteristics, day and time, and weather. Most research has been done in busy, large metropolitan city areas in China, Europe, and the USA.

5.6 RISK TAKING - OVERTAKING

Colour Code: Yellow

Research shows compared to other vehicle manoeuvres (risky) overtaking tends to increase accident severity. Regarding accident frequency however it seems that only a small share of crashes occurs while overtaking another vehicle. In addition, some situational factors (traffic volume, speed) and driver characteristics (age, gender) seem to influence (the frequency of) risky overtaking.

Abstract

Overtaking is known as one of the most complex manoeuvres for road users. From studies in the international literature, it appears indeed that compared to other vehicle manoeuvres, (risky) overtaking significantly increases accident severity, however regarding accident frequency – although associated with a higher crash risk in one study – it seems that only a small share of crashes occurs while overtaking another vehicle. Moreover, studies indicate that various situational factors and driver characteristics – especially age – seem to influence (the frequency of) risky overtaking: younger drivers tend to be more likely to engage in risky overtaking manoeuvres, than older drivers. This seems to be also the case for other situational factors (traffic volume, speed) and driver characteristics (gender).

5.7 RISK TAKING - CLOSE FOLLOWING BEHAVIOUR

Colour Code: Yellow

Although following too closely is seen as one of the main reasons for rear end crashes, studies that evaluate the risk of this behaviour in connection to accidents are rare. However, if headway distances are so short that it is no longer possible to stop in time in the case of an emergency stop, it can be presumed as risky. Quite a proportion of drivers engage in such a behaviour. Results of one study indicate a higher crash risk for short headways.

Abstract

Headway is the distance from a following vehicle to a lead vehicle in a traffic following situation. A minimum headway distance of two seconds to the vehicle in front is generally recommended as safe. Considerably shorter headways for a longer period are seen as risky and addressed as tailgating. Headway distance is mainly measured in seconds (time headway), which is independent from velocity, or meters (headway distance). The prevalence of close following behaviour in traffic differs considerably depending on the location, traffic situation, time of the day and type of measurement (prevalence of risky drivers, prevalence of driving time). Studies which evaluate the risk of this behaviour in connection to accidents are rare. One naturalistic driving study shows an increased crash risk for close following behaviour with a low prevalence of this behaviour present in the driving condition. Several driving characteristics and situational factors such as age, personality, weather and presence of roadworks seem to have an effect on the choice of headway distance.

5.8 DISTRACTION - CELL PHONE USE - HANDHELD

Colour code: Red

The effects of handheld cell phone use for conversation have long related to accidents, with a very large number of literature studies presenting findings to support that. Those studies have good levels of quality, and are overall consistent in their results. Finally, study results and professional practice indicate that handheld cell phone use has a proven relation with accidents.

Abstract

The use of handheld cell phones induces a level of distraction to the person driving. This distraction translates to slower reaction times to events, increased percentages of time with eyes off the road, speeding, increased number of crashes and near misses and also increased crash injury severities. Thirteen high quality studies, including four meta-analyses, regarding various related topics were coded. On a basis of both study and effect numbers, it can be argued that handheld cell phone use creates negative impacts on road safety, with most factors being statistically significant. There were cases, however, that reported no statistically significant relation of cell phone use to various road safety variables (including behavioural factors) or even positive effects from overcompensation. The presence of meta-analyses makes the results generally transferable.

5.9 DISTRACTION - CELL PHONE USE - HANDS-FREE

Colour Code: Red

The effects of hands-free cell phone use for conversation have long related to accidents, with a large number of literature studies presenting findings to support that. Those studies have good levels of quality, and are overall consistent in their results. Finally, study results and professional practice indicate that hands-free cell phone use has a proven relation with accidents.

Abstract

The use of hands-free cell phones induces a level of distraction to the person driving. This distraction translates to slower reaction times to events, increased percentages of time with eyes off the road, speeding, increased crashes and near misses, and also increased crash injury severities. Nine high quality studies regarding various hands-free cell phone topics were coded. On a basis of both study and effect numbers, it can be argued that hands-free cell phone use creates negative impacts on road safety, with most factors being statistically significant. There were cases, however,

that reported no statistically significant impact to various road safety variables (including behavioural factors). The presence of meta-analyses makes the results generally transferable.

5.10 DISTRACTION - CELL PHONE USE - TEXTING

Colour code: Red

The effects of texting have long been related to accidents, with a large number of literature studies presenting findings to support that. Those studies have good levels of quality, and are overall consistent in their results. Finally, study results and professional practice indicate that texting has a proven relation with accidents.

Abstract

The use of cell phones for texting induces a level of distraction to the person driving. This distraction translates to an increase of; accidents and near misses, injury severities, reaction times to events, percentage of time with eyes off the road, speeding, and to inconsistencies in driving behaviour. Eight high quality studies regarding various texting topics were coded. On a basis of both study and effect numbers, it can be argued that texting via cell phones or other devices creates negative impacts on road safety, with most factors being statistically significant. There were cases, however, that reported no statistically significant relation of texting to various road safety variables (including behavioural factors). The presence of meta-analyses makes the results generally transferable.

5.11 DISTRACTION - MUSIC - ENTERTAINMENT SYSTEMS

Colour code: Grey

The effects of listening to music while driving have been suspected to link to accidents, and thus many relevant scientific studies have been conducted to investigate the matter. The coded studies have good levels of quality, however they fail to settle to a common conclusion for the effects of this risk factor, or in some cases even reach opposite results. As there is a balance between positive and negative effects, and a lot of uncertainties, the overall impact of music is characterised as grey (unclear).

Abstract

The employment of music for entertainment while driving induces a level of distraction to the person driving. The specific impacts of these distractions vary, but in general music has an unclear impact on road safety. While in absolute numbers a lot of the effects of this risk factor are detrimental, there are many beneficial impacts as well, and a considerable number of variables remain statistically non-significant (not sufficiently related) to music. Driver behaviour variables such as speed and (lateral) positioning are affected. There is evidence to support that overcompensation occurs by certain drivers, but whether the overall, collective effects of this risk factor are negated is still unclear. The results of the analysis are generally transferable. The majority of the studies were quasi- or experimental studies with the capability to investigate various behavioural variables.

5.12 DISTRACTION - OPERATING DEVICES

Colour code: Grey

The effects of operating devices while driving have been suspected to link to accidents, and thus many relevant scientific studies have been conducted to investigate the matter. The coded studies have good levels of quality, however they fail to settle to a common conclusion for the effects of these risk factors, or in some cases to even reach consistent and significant results. As there is a presence of several positive and negative effects, and a lot of uncertainties, the overall impact of operating devices is characterised as grey (unclear).

Abstract

The use or operation of various devices (generally IVIS) while driving induces many distractions to the person driving. The specific impacts of these distractions vary, but in general it can be assumed that driver behavioural variables are affected. Six high quality studies regarding various IVIS topics were coded. On a basis of both study and effect numbers, it can be argued that operating devices have an unclear impact on road safety, with most factors not being statistically significant. There were cases, however, that reported increased crash counts and reaction times to events (e.g. bicycle appearance) when distracted by IVIS. The results are moderately transferable.

5.13 DISTRACTION - COGNITIVE OVERLOAD, INATTENTION

Colour code: Yellow

The effects of the risk factor of inattention (daydreaming and distraction through state of mind (pondering etc.)) and cognitive overload while driving have been suspected to link to accidents, and thus investigated accordingly. The coded studies have good levels of quality and decent consistency, though there are some unclear areas. As there are more detrimental effects than beneficial ones to road safety, the overall impact of inattention is characterised as yellow (probably risky).

Abstract

The inattention of drivers through loss of focus, daydreaming or state of mind induces a level of distraction to the person driving. On a basis of both study and effect numbers, it can be argued that the risk factor of inattention while driving has a likely detrimental effect on road safety. The specific impacts of these distractions vary, but they are negative and in general it can be assumed that driver behavioural variables such as perception and braking performance are affected. There are some positive results that show reduced injury severity or increased perception, but these occur mainly due to overcompensation and effects and are limited. The results of the analysis are generally transferable with caution. The majority of the studies were observational/case control studies which investigated past accident data.

5.14 DISTRACTION - CONVERSATION WITH PASSENGERS

Colour Code: Yellow

The meta-analyses carried out showed that conversation with other passengers (both adults and children) corresponds to a significant proportion of road accidents. There is also evidence to support that this distraction activity slows reaction times and increases injury severity, but more studies are needed to further support this statement.

Abstract

Conversation and other interactions with passengers induce a level of distraction to the person driving. This distraction translates to slower reaction times to events or to increased severity of driver injuries in accidents. On a basis of both study and effect numbers, it is observed that a consistent non-negligible proportion of road accidents are caused by driver conversation with other passengers in the vehicle. The results of the meta-analyses carried out confirmed this trend and showed that this proportion is significant. In general, findings for this risk factor are generally transferable, though caution and care against oversimplification are always required.

5.15 DISTRACTION - OUTSIDE OF VEHICLE

Colour Code: Yellow

The effects of distraction outside the vehicle while driving have been suspected to link to accidents, and thus investigated accordingly. The coded studies encompass several topics and have good levels of quality and consistency, though there are some unclear areas. As all statistically significant effects are detrimental effects to road safety, the overall impact of outside factors is characterised as yellow (probably risky).

Abstract

The engagement with various factors that can be present outside the vehicle induces a level of distraction to the person driving. The specific impacts of these distractions vary, but they are negative and in general it can be assumed that accident numbers and various driver behavioural variables such as lateral control and speeding are affected. Twelve high quality studies regarding various outside factors were coded. On a basis of both study and effect numbers, it can be argued that outside factors create mostly negative impacts on road safety, with all statistically significant effects being detrimental. There were cases, however, that reported no statistically significant relation of distraction outside of the vehicle to various road safety variables (including behavioural factors). The results seem generally transferable.

5.16 FATIGUE - NOT ENOUGH SLEEP, DRIVING WHILE TIRED

Colour Code: Yellow

Although studies suggest that in general sleepiness/fatigue increases the risk of road traffic accidents, the wide range of methodologies used makes it difficult to compare results and findings are not always consistent across studies.

Abstract

Fatigue is examined in terms of drivers who have not had enough sleep or more generally driving while feeling tired irrespective of how this was caused. Fatigue and road traffic accident risk is studied and measured in a variety of different ways in the scientific literature. This includes both directly observing fatigue symptoms and more commonly using self-report methodologies to capture information on sleep habits and sleepiness while driving. Both accidents and near miss events are focussed on and participants have been recruited directly following a road traffic accident or at a stop point during a journey. There appears to be relatively strong evidence for sleepiness at the wheel/not having enough sleep increasing the risk of professional drivers being involved in safety critical events. For car drivers, when participants report actually falling asleep at the wheel (or display drowsy behaviour), the risk of having a road traffic crash is substantially higher. However differences between sleepy and alert drivers are sometimes small or non-significant and the variation in methodologies make comparisons between studies problematic.

5.17 FATIGUE: SLEEP DISORDERS - SLEEP APNEA

Colour Code: Red

Studies consistently show that untreated Obstructive Sleep Apnea is associated with increased risk for road traffic accidents.

Abstract

Fatigue is examined in terms of drivers who have not had enough sleep or more generally driving while feeling tired irrespective of how this was caused. Fatigue and road traffic accident risk is studied and measured in a variety of different ways in the scientific literature. This includes both directly observing fatigue symptoms and more commonly using self-report methodologies to capture information on sleep habits and sleepiness while driving. Both accidents and near miss events are focussed on and participants have been recruited directly following a road traffic accident or at a stop point during a journey. There appears to be relatively strong evidence for sleepiness at the wheel/not having enough sleep increasing the risk of professional drivers being involved in safety critical events. For car drivers, when participants report actually falling asleep at the wheel (or display drowsy behaviour), the risk of having a road traffic crash is substantially higher. However differences between sleepy and alert drivers are sometimes small or non-significant and the variation in methodologies make comparisons between studies problematic.

5.18 INSUFFICIENT KNOWLEDGE AND SKILLS

Colour Code: Yellow

The influence of insufficient skills and knowledge on crash risk is not properly identified. The concepts are often combined without a clear picture of the specific contribution of each of them. The issue is often treated in studies covering larger topics (e.g. age, personal factors) and consequently its effect turns out to be confounded with that of other risk factors. Furthermore, the number of studies is limited. Results, mainly constituting of the outcome of correlation analysis, show a general negative contribution to road safety in terms of crash risk and risky behaviour, although not always statistically significant.

Abstract

Insufficient skills and knowledge identify a lack of technical and theoretical functions in relation to different elements (vehicle properties and functions, traffic conditions, trip characteristics and life goals/personal tendencies), which is expected to increase the risk for road users of being involved in road accidents. Studies show, in this condition, a general tendency to be involved in road accidents or to commit violations, as well as to assume specific risky behaviours. Nevertheless, findings are almost entirely related to the issues of personal goals/tendencies and vehicle properties/functions, and it is not always feasible to separately identify the contribution of skills or knowledge. Moreover, they are mainly focused on young drivers and the effect of some personal characteristics is likely to be confused with that of other risk sources like "age" or "personal factors".

5.19 OBSERVATION ERRORS

Colour Code: Grey

In depth accident data shows that observation errors in traffic are often the causes of accidents. However little has been found in literature on observation errors that are related to a wrong strategy of observation e.g. "looked but failed to see".

Abstract

Next to other factors like distraction or a low activation, observation errors of road users are responsible for a failure in the processing of relevant information when navigating in traffic and potentially lead to an accident. Observation errors mostly occur due to a wrong focus of attention where the attention was not aimed towards the relevant objects at the right time, or immediate relevant information was missed (e.g. looked but failed to see). Observation errors are among the most frequent failures in the human task of information admission when driving.

5.20 FUNCTIONAL IMPAIRMENT - COGNITIVE IMPAIRMENT

Colour code: Yellow

Depending on the type of cognitive impairment considered (neurocognitive disorders, depression or other psychiatric disorders), results on crash risk are inconsistent. Neurocognitive disorders do not seem to increase the pedestrians' crash risk, but increase drivers' crash risk. Depression significantly increases the risk of injury but results related to crash responsibility are inconsistent (no significant effect or increase of the crash risk). Depression also decreases the road mobility among men and their risk for crash involvement. Regarding the other psychiatric disorders, results are also inconsistent: psychological distress decreases crash risk, whereas psychiatric disorders increase it.

Abstract

Cognitive impairment is characterized by a deterioration of cognitive functions such as attention, memory or executive functions. The reviewed studies focused on the effect of neurocognitive disorders (dementia, Alzheimer's or Parkinson's diseases), depression, and other psychiatric disorders on crash risk or on driving performances. Case-control, cross- sectional and observational study designs were mainly used to investigate the effect of cognitive impairment on road safety. The reviewed studies have mostly been conducted on car drivers from the United States and the European Union. Studies generally indicated a higher risk of crash or driving errors for mild to severe neurocognitively impaired drivers. Discrepant findings about depression and other psychiatric disorders have been revealed. Studies on cognitive impairment presented several limitations: i) small sample size, ii) medical conditions difficult to control and often self-reported, and iii) analyses performed on self-reported crash data or on driving simulator performance.

5.21 FUNCTIONAL IMPAIRMENT - HEARING LOSS

Colour code: Grey

Reduced hearing, or hearing loss, is generally not considered to reduce road safety, but there is limited and inconsistent research on the subject. There is a lack of studies that can quantify the effect of hearing loss on road safety in terms of crash risk, and overall they cannot show a clear association between hearing loss and increased crash risk.

Abstract

Hearing loss is one of the most frequent sensory deficits, of which prevalence increases with age. Hearing loss is generally not considered to reduce road safety, but there is limited and inconsistent research on the subject. There is a lack of studies that can quantify the effect of reduced hearing on road safety in terms of crash risk, and overall they cannot show a clear association between reduced hearing and increased crash risk. The studies have used approaches similar to case-control, which means that the crash rates of individuals with hearing loss (cases) are compared with crash rates of individuals without hearing loss (controls).

5.22 FUNCTIONAL IMPAIRMENT - VISION LOSS

Colour code: Yellow

The current knowledge about visual impairments and crash risk suggests that visual acuity is very weakly associated with crash risk, while contrast sensitivity, visual field, and in particular cognitive aspects of vision have better evidence for their relevance to road safety.

Abstract

The current knowledge about visual impairments and elevated crash risk suggests that visual acuity (generally tested during application for a driving license) is very weakly associated with crash risk, while contrast sensitivity, visual field, and cognitive aspect of vision have some, or thorough, evidence for their relevance to road safety. Impaired vision is much correlated with increased age and the elderly. Therefore, several studies focus on road users 50 years of age or older. With advanced age, other medical and functional co-morbidities follow that are potential confounders in the relationship between vision and road safety – in particular cognitive impairments. The majority of studies have used case-control approaches, usually meaning that the crash rates of individuals with vision impairments (cases) are compared with crash rates of individuals without vision impairment(s) (controls).

5.23 DISEASES AND DISORDERS - DIABETES

Colour code: Yellow

Studies generally show a (small) elevated crash risk. However, effects are not always statistically significant. Many studies have low quality, e.g. because they did not adjust for exposure or mileage. Furthermore, the results are possibly compromised by national countermeasures, e.g., some countries impose driving restrictions on drivers with insulin-treated diabetes. When the higher risk diabetes drivers are not allowed to participate in traffic, this will affect the overall risk of diabetes identified in that country.

Abstract

This chapter discusses the effect of diabetes on road safety. Diabetes mellitus is a group of metabolic diseases characterised by defects in insulin secretion, insulin action, or both. Studies generally show a (slightly) higher risk for drivers with diabetes, although differences are often not statistically significant. Two main approaches have been used to study the relationship between diabetes and crash risk. The most common approach compares crash rates of individuals with diabetes with crash rates of individuals without diabetes. The less common approach first distinguishes between drivers who have and who have not been involved in a crash, and then compares the prevalence of diabetes in these two groups. Most research has been done in the USA, Canada, and Europe. Most of the research is on private drivers; very few studies are on commercial drivers.

5.24 PERSONAL FACTORS - SENSATION SEEKING

Colour code: yellow

Studies generally show an association between sensation seeking and self-reported risky driving and self-reported crashes. In a number of studies the association remains significant after statistical control for various demographic and other related personality variables. This suggests that sensation seeking has an independent effect on risky driving behaviour. However, the independent effect of sensation seeking is generally small, and the causal relationship is not always clear. Moreover, in nearly all studies the association may be inflated by research biases and, hence, overestimated.

Abstract

Sensation seeking is a personality trait that steers people at "varied, novel, complex, and intense sensations and experiences" and at accepting the physical, social, legal, and financial risks for the sake of such experiences. Sensation seeking can have an immediate, direct effect on driving behaviour and crashes because sensation seekers are more inclined to look for new, exciting and intense sensations of, for example, driving fast and recklessly. Generally, the results show that sensation seeking is associated with self-reported risky driving behaviours such as speeding, risky driving, alcohol-impaired driving, driving with multiple passengers and self-reported crash-involvement. Various studies show that this effect is robust after control for demographic and other personality variables. However, the independent effect of sensation seeking is generally small, its causal interpretation is not always clear, and in nearly all survey research the reported association may be inflated or exaggerated by research biases. In summary, although there is fairly consistent evidence that sensation seeking is linked to risky driving behaviour and road crashes, the independent, direct effect of sensation seeking is rather small and may be overestimated.

5.25 PERSONAL FACTORS - ADHD

Colour code: Yellow

Even though few studies investigated the crash risk related to ADHD (only six reviewed studies), a consensus on its negative effect on road safety has arisen. More precisely, ADHD appears to significantly increase the risk of crash and near-crash involvement, and the risk of traffic violations. However, results about the negative effect of ADHD on the risk of injury and crash responsibility were inconsistent. Additional studies have to be conducted to further explore this issue.

Abstract

Attention deficit hyperactivity disorder (ADHD) is a behavioural disorder characterized by inattention, hyperactivity, and impulsivity. A review of the literature was conducted to investigate the crash risk related to ADHD. Six studies were included in this literature review, one meta-analysis, three cross-sectional studies, one longitudinal study and one case-control study. Most of the reviewed studies have been carried out in the United States and in the European Union, and have been conducted on car drivers. The effect of ADHD on road safety has been measured by the analysis of self-reported crashes, patient registry, or by simulated driving performances. Most of the reviewed studies showed a negative effect of ADHD on road safety, with an increased risk of crash involvement and traffic violations. Inconsistent results have been found regarding the risk of crash responsibility and injuries. The main limitation of the reviewed studies concerns the diagnosis of ADHD, often based on subjective evaluation instead of based clinically.

5.26 EMOTIONS - ANGER, AGGRESSION

Colour Code: Yellow

The relationship between emotion and crash risk varies depending on the mode of measurement (simulator, questionnaires, different decision making tests, self-reported crashes etc.). Moreover, emotion is induced in different ways (pictures and videos, emotional recall, traffic events etc.) and its exposure can only be concluded from self-ratings. Therefore, results are inconsistent but show a tendency to an elevated crash risk, though, not always statistically significant.

Abstract

There is no consensus about an unambiguous definition for emotion. However, in common speech, it is any relatively brief mental experience with intensity and a high degree of pleasure or displeasure (Cabanac, 2002). Most research in this field is based on the appraisal theory. According to appraisal theory, the particular judgments about a stimulus cause emotion (Scherer et al., 2001). Studies generally indicate a (slightly) higher risk for drivers that show emotion, typically anger or aggression, while driving, although differences are often not statistically significant. Most research has been done in Europe and USA and was conducted at universities with students as participants. Only car drivers have been investigated. There is no information on VRU. Due to the kind of study interests, studies with control groups (in the sense of "neutral" emotions) are rare.

6 Conclusions

6.1 DISCUSSION OF RESULTS

As shown in Table 1, out of the 25 risk factor synopses presented here, eight were given the colour code 'Red' indicating that studies consistently show that the risk factor has a negative effect on road safety. A further 11 concluded that there is some evidence that the risk factor(s) has a negative effect on road safety but there are some problems in terms of mixed results, study design, or number of studies available. Four synopses were assigned the code 'grey' indicating that there was not enough evidence to draw valid conclusions about its effect on road safety.

Table 1: Human Behaviour related risk factor synopses by colour code. Risk factors highlighted bold were identified as hot topics in a previous step.

Risky	Probably risky	Unclear
• **Influenced driving – alcohol** • Influenced Driving – drugs (legal & illegal) • **Speeding and inappropriate speed** • Traffic rule violations – red light running • **Distraction – cell phone use (hand held)** • **Distraction – cell phone use (hands free)** • **Distraction – cell phone use (texting)** • **Fatigue – sleep disorders – sleep apnea**	• Risk taking – overtaking • Risk taking – close following behaviour • Insufficient knowledge and skills • **Functional impairment – cognitive impairment** • Functional impairment – vision loss • Diseases and disorders – diabetes • Personal factors – sensation seeking • Personal factors – ADHD • **Emotions – anger, aggression** • Fatigue – Not enough sleep/driving while tired • Distraction – conversation with passengers • Distraction – outside of vehicle • Distraction – cognitive overload and inattention	• Functional impairment – hearing loss (few studies) • Observation errors (few studies) • Distraction – music – entertainment systems (many studies, mixed results) • **Distraction – operating devices (many studies, mixed results)**

It is worth noting at that the 'risks' in the red category can be directly observed and/or measured. Some risks in the yellow category (e.g. emotions) are more difficult to measure and therefore links between the experience of the risk factor and accident risk are more difficult to make. Other risks however are in the yellow category because studies only found a weak association with negative road safety outcomes (e.g. diabetes). Studies were included in the grey category because either too few studies were identified (e.g. hearing loss) or that the subject area is well researched but the results were a mixture of positive, negative and none significant effects (e.g. music – entertainment systems)

Limitations

As previously discussed evaluating the relationship between road safety and road user related risk factors is a difficult task. For some risk factors the available studies focused more on conditions of the behaviour (in which situations the behaviour is shown or which groups are more likely to show this behaviour) rather than the risk factor itself. Therefore it cannot be concluded that those risk factors that have not often been studied or have to rely more indirect and arguably weaker methodologies, e.g. self-reports , do not increase the chance of a crash occurring.

Due to the lack of studies or difficulties of finding relevant studies and the need for focusing on some of the topics, it was not possible to evaluate the effects on road safety of all risk factors listed in the taxonomy or cover all conditions and road users in each synopsis.

6.2 CONCLUSIONS AND NEXT STEPS

The next task of SafetyCube is to begin the task of identifying measures that will counter the identified risk factors, in this case those that relate to road user behaviour. Methodological guidance has been provided for this task:

> **Selecting risk factors for treatment**
> A list of risk factors that contribute to accidents or injuries can be sorted according to many criteria. The importance of a risk factor is just one of these. Not all risk factors are equally amenable to treatment by means of road safety measures. An attempt should be made to establish a link between risk factors and road safety measures that can be applied to treat the risk factors. It is important to understand that an effective treatment of a risk factor related to a specific element of the road system may not always be related to that element, but may be related to a different element. As an example, drinking-and-driving is a behavioural problem related to the driver, but the solution may be a technical device, alcohol ignition interlocks.
>
> (Martensen et al., 2017)

The synopses indicate a set of risk factors that should be a focus when searching for road safety measures (red category). The priority of risk factors in the yellow category will depend on why they were assigned that category. Topics such as 'diabetes' which have a lot of studies but with limited evidence of a negative effect on road safety should be less of a priority than studies that are in the yellow category because there are many different ways of measuring them, e.g. fatigue, or have to utilise weaker study designs (self- report) as the primary method of measuring exposure to the risk e.g. sensation seeking.

The next steps will be to identify the measures that can counter the risks identified in this document and to establish the links between them. As the road user is part of a road traffic system, interventions that relate to other elements of that system will be examined (Infrastructure, vehicle) as well as those aimed at the road user. In addition, attention will be given to the interrelationship of measures, i.e., complementary measures that have found to strengthen the effect of a measure (e.g. enforcement to support regulation or publicity to support enforcement).

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List of Abbreviations

AADT	Annual Average Daily Traffic
ACAS	Accident Causation Analysis System
ANOVA	Analysis of Variance
CaDaS	Common Accident Data Set
CARE	Community database on Accidents on the Roads in Europe
CMF	Crash Modification Factor
DSS	Decision Support System
DUI	Driving Under the Influence
ETSC	European Transport Safety Council
GIDAS	German In-Depth Accident Study
HGV	Heavy Goods Vehicle
ISA	Intelligent Speed Adaption
IVIS	In-Vehicle Information System
MANCOVA	Multivariate Analysis of Covariance
OECD	Organisation for Economic Cooperation and Development
SPI	Safety Performance Indicator
TRACE	Traffic Accident Causation in Europe
VRU	Vulnerable Road User(s)
WP	Work Package

Appendix A: Taxonomy and prioritisation ('hot topics') of human related risk factors

This table represents the taxonomy of human related road safety risk factors in SafetyCube and includes furthermore the indication of 'hot topics'. Risk factors named by stakeholders or are mentioned in policy papers and research reports three times and more are highlighted in dark blue. Bright blue flagged risk factors were named twice and are considered a second level priority.

Topic	Subtopic	Specific Risk Factor
Speed choice	Speeding	Built-up areas
		Rural roads
		Motorways
	Inappropriate speed	Too fast weather-related
		Too fast traffic related
		Too slow
Influenced driving - alcohol	Drunk driving or drunk riding (cyclists/mopeds)	0-0,5‰
		0,51-0,8‰
		0,81-1,6‰
		> 1,6‰
Influenced driving - drugs	Drugged driving/riding, legal (medicine)	Benzodiazepines
		Z-drugs
		Medicinal opiate
		Others (antidepressants etc.)
	Drugged driving/riding, illegal	THC
		Cocaine
		Amphetamines
		Illegal opiate
		Synthetic drugs
	Combined usage	Combined usage

Risk taking	Risky overtaking	Risky overtaking: wrong side
		Without adequate visibility
		Without warning others
		Into oncoming traffic
	Headway distance	Misjudgement
		Tailgating
Fatigue	Not enough sleep	Not enough sleep
		Sleeping disorders
	Driven a long time	Driven a long time
Distraction and inattention	Distraction within vehicle or within the riding or walking situation	Conversation with person, passenger/codriver
		Music, entertainment systems
		Cell phone use - talking - handheld mode
		Cell phone use - talking - hands-free mode
		Cell phone use - texting
		Operating devices (IVIS, navigation systems etc.)
		Animals, insects, others
		Consummation of goods (eating, drinking, smoking)
	Distraction outside vehicle	Watching persons, situations
		Static objects (advertisement, traffic management information etc.)
		Sun, other vehicles' lights
	Distraction through state of mind and cognitive overload	Distraction through state of mind (pondering etc.) and cognitive overload
	Inattention	Inattention, daydreaming
Functional impairment	Reduced vision (adaptation, visual field, visual acuity, contrast perception)	Night time driving
		Safety margins
		Pedestrian detection
		Road sign recognition
		Driving out of a tunnel
		Maneuvering

		Permanent impairment (physical condition)
	Reduced hearing	Decreased driving performance under presence of distractors
		Missing out auditive information of other road users
		Permanent impairment (physical condition)
	Cognitive impairment	Dementia
		Alzheimer disease
		Mild cognitive impairment
		Parkinson's disease
		Depressive symptoms
		Other psychiatric disorders
Insufficient skills	Skills (motor etc.), operating errors	Vehicle manoeuvring related (control of speed and position, shifting etc.)
		Traffic situation related (communication, speed adjustment, observation etc.)
		Trip related (planning the trip)
		Control over how life goals and personal tendencies affect driving behaviour
Insufficient knowledge	Knowledge	Knowledge about effects of vehicle properties
		Traffic situation related (knowledge of traffic regulations)
		Trip related (knowledge of location, effects of time pressure in car etc.)
		Knowledge about life goals and personal tendencies affect driving behaviour
Emotions and stress	Intrinsic stress	Overburdened
	extrinsic stress (time pressure)	Time pressure
	Positive emotions	Euphoria
	Negative emotions	Aggression, anger
		Fear, anxiety
Misjudgement and obserservation errors	Misjudgement of oneself	Underestimate of own speed
		Misjudgement of braking distance, acceleration

		Misjudgement of behaviour of own car or two-wheeler (dynamic, stability etc.)
		Misinterpretation of driver assistance information
	Misjudgement of others, situation	Speed
		Distance
		Development of situation
		Misunderstanding between road users
	Observation errors	Missed
		Late
		False
Traffic rule violations	Red light running	Red light running
	Disregard of right of way	Not yielding for pedestrians at ped. crossing
		Running stop sign, yielding sign
	Disregard of obligatory usage of car devices	Not using vehicle light when dark
		Not indicating direction
	Wrong way driving	One-way roads
		Wrong side of road
	Using road lane dedicated to other road user or for other function	Bus lanes
		Truck lanes
		Emergency lanes
		Cycle lanes
Personal factors	Sensation seeking	Sensation seeking
	Type A personality (impatience, time urgency, and hostility)	Type A personality (impatience, time urgency, and hostility)
	ADHD, ADD etc.	ADHD, ADD etc.
	Locus of control	Locus of control
	Introversion, extraversion	Introversion, extraversion
Age	Children (0-12 years)	Children (0-12 years)
	Adolescents (12-18 years)	Adolescents (12-18 years)
	Young people (18 -24 years)	Young people (18 -24 years)

	Elderly (65+)	Elderly (65+)
Diseases and disorders	Diabetes	Typ A
		Typ B
	Epilepsy	Epilepsy
	Influenza	Influenza
	Psychiatric disorders	Anxiety disorder
		Mood disorder
		Psychotic disorder
		Personality disorder
		Impulse control disorders
	Sudden illness	Heart attack, stroke
		Fainting

Appendix B: ACAS code list of human causation factors

Group 1: Human causation factors

The human causation factors describe situative influences, i.e. solely causation factors are coded, which were effective at the moment of the accident emergence. Failures which were made for example before departure (iced windows, wrong vehicle loading) or during the trip before the accident are not relevant. Outlasting factors like influence of alcohol or tiredness are coded, when they show effect in the situation of the accident emergence (Example: Influence of alcohol → Attention lowered 1-2-04-2)

1st no.	2nd number (Category)	3rd number (Criteria)	4th number (Indicator)
(1) Situational human factors	**(1) Information access** *Code if the participant did not have access to relevant information at the emergence of the accident. An available piece of information cannot be perceived if it was covered / hidden by objects inside or outside the vehicle of if it could not be registered due to physical conditions or disease.*	**01 Information not perceivable due to disease or physical condition**	(0) Not. Specified (8) Other (9) Multiple (1) seeing problem. \ / *wrong or not corrected* (2) hearing probl. / \ *problems with eyes or ears*
		02 Information hidden/covered by objects outside the vehicle *Applies for objects which are not connected with the vehicle*	(0) N.s. (8) Other (9) Multiple (1) Buildings (2) Plants (3) Parking vehicles (4) Standing or moving vehicles
		03 Information hidden/covered by objects inside the vehicle *This also includes trailers and external objects fixed to the vehicle*	(0) N.s. (8) Other (9) Multiple (1) Passengers (2) vehicle-load (3) steamed-up / frosted windows (4) Retrofit devices (mobile GPS-navigation) (5) bodywork pillars and other components
		04 Information-masking *By atmospheric conditions or lack of contrast*	(0) N.s. (8) Other (9) Multiple (1) Darkness (2) Heavy rain (3) Fog (4) Dazzle (Sun, other vehicles) (5) superimposition of relevant information (other light sources, similarity of colour) (6) sound overlapped by noise
	(2) Information admission *When the relevant information could have been acquired by the participant, however it was not acquired in time or at all. The participant could have been able to gather the information by reason of adequate perception conditions, however failed to do so.*	**01 Distraction from inside the vehicle**	(0) N.s. (8) Other (9) Multiple (1) Operation of devices (2) by passengers (3) On the phone / Music (4) Animals
		02 Distraction from traffic environment	(0) N.s. (8) Other (9) Multiple (1) Posters, showcases etc. (2) People
		03 Internal distraction (thoughts / emotions)	(0) N.s. (8) Other (9) Multiple (1) Irritation, anger (2) Sadness, worries (3) Hurry, stress (4) Exhilaration, euphoria
		04 Activation too low *Attention hindered/reduced due to physiological conditions. Resulting in a reduction of information admission*	(0) N.s. (8) Other (9) Multiple (1) physical stress, fatigue (2) Alcohol (3) Drugs (4) Disease / Medicine (5) Blackout (Heart attack, seizure) (6) Due to age/retarded development (*Children, mentally disabled people*)
		05 Wrong identification due to excessive demands *„Information overload“*	(0) N.s. (8) Other (9) Multiple (1) Complex Information (*stimulus satiation*) (2) Complexity (*not the amount of Information, but the arrangement*)
		06 Wrong focus of attention *When observing the traffic situation the attention was aimed towards the relevant objects, but the immediate relevant information (e.g. Collision opponent) was missed*	(0) N.s. (8) Other (9) Multiple (1) Focus on other road user *(Looking towards other road users and Missing the relevant road user)* (2) Focus on traffic signal (*traffic lights, traffic sign*) (3) Wrong strategy of observation (*failed reorientation or missed reassuring view*)

Group 1: Human causation factors

1st no.	2nd number (Category)	3rd number (Criteria)	4th number (Indicator)
(1) Situational human factors	**(3) Information evaluation** *The participant has ingested the all relevant information but has misjudged or misinterpreted it.*	01 **Wrong expectation concerning the accident place or the behaviour of other road users due to false assumption**	(0) N.s. (8) Other (9) Multiple (1) Communication failure (*between Road users*) (2) lack of knowledge of the place (3) Inappropriate confidence due to habits / experience (*A Frequent experience of a traffic situation leads to a wrong information Interpretation. E.g. „Never before someone came out of there*“)
		02 **Misjudgement of speed or distance of other road users**	(0) N.s. (8) Other (9) Multiple (1) Misjudgement of speed of other road user (2) Misjudgement of distance of other road user
		03 **Misjudgement concerning the own vehicle** (Misjudgement of the driving state or the vehicle reaction in a critical situation)	(0) N.s. (8) Other (9) Multiple (1) Underestimation of own speed (2) Vehicle behaviour (dynamics, stability) (3) Misjudgement of the breaking or accelerating power of the vehicle (4) Misinterpretation of driver assistance systems (displays, signals)
	(4) Planning *The information was ingested and evaluated correctly however the participant drew wrong conclusions concerning the action to manage the situation. This concerns no reflexful actions - the participant must have had enough time for planning. A further form is the conscious action against well-known traffic rules*	01 **Decision error** The participant had enough time to select an action strategy but has chosen the wrong action alternative	(0) N.s. (8) Other (9) Multiple (1) Wrong manoeuvre planned (*e.g. evasion manoeuvre instead of breaking*) (2) Wrong assumption concerning the development of a situation (*Movement of other road user was assumed incorrectly*)
		02 **Intentional breach of rules** Refers only to a situational intentional breach of rules; not due to lack of information. Driving under influence of alcohol is not applicable here.	(0) N.s. (8) Other (9) Multiple (1) neglecting of right of way (2) driving above speed limit (3) wrong overtaking (4) wrong turning manoeuvre (5) too little distance to vehicle ahead (6) Problematic driving motive (*Suicide, murder, fleeing from police*) (7) Irregular use of roadway (*e.g. cycling on a pedestrian path*)
	(5) Operation *Errors or difficulties arose during the execution of the planned action. This can cover too late, wrong, omitted or reflexful actions. Code only if the incorrect action was causal for the accident*	01 **Mix-up error or operation error** (e.g. mix-up of brake pedal and accelerator pedal)	(0) N.s. (8) Other (9) Multiple (1) Pedals (mix-up, slip off) (2) gear shift (3) operating controls
		02 **Reaction error**	(0) N.s. (8) Other (9) Multiple (1) too week braking (2) too late braking (3) too strong braking/ over-braking (4) Steering too week / too late / not at all (5) Overreaction steering (6) Omitted reaction – no action.

Important:
If detailed information to a causation factor is not determinable, then it is also possible to code only the first number, only the first two numbers or only the first three numbers of the code.
Example: It is only known that a participant did not see/recognize another road user, it was determinable why. Here the following may be coded:
1 - 0 - 00 - 0 (unknown human influence)
1 - 2 - 00 - 0 (human factor - information admission – n.s. – n.s.)
9 - 0 - 00 - 0 (influence given however no distinction regarding the group is possible)
0 - 0 - 00 - 0 (this participant did not contribute to the emergence of the accident)

Appendix C: Stakeholder workshops – list of participants

17th June 2015, Brussels

- Peter Saleh, AIT
- Veronique Verhoeven, BRSI
- Koen Peeters, BRSI
- John Doyle, Department for Transport
- Concetta Durso, ERF
- Ceri Woolsgrove, European Cyclists' Federation
- Graziella Jost, ETSC
- Jeannot Mersch, FEVR
- Ingeborg Hesjevoll, Institute of Transport Economics
- Veronique Feypell, OECD
- Dagmar Köhler Polis, European Cities and Regions networking for innovative transport solutions
- Jac Wismans, SAFER
- Freddy Gazan, SPF Justice
- Werner De Dobbeleer, VSV
- Pascal Lammar, Afdeling BMV - Dept MOW

14th October 2015, Ljubljana

- Ahmed Bardan, CNPAC
- Niels Bos, SWOV
- Justyna, Wacowska-Slezak, ITS
- Dovile Adminaite, ETSC
- Lucia Pennisi, ACI
- Manca Carman, AVP
- Andraz Murkovic, AVP
- Riikka Rajamäki, Trafi
- Camilla Sloth Andersen, Aalborg University
- Susanne Schönebeck, BASt
- Ruth Bergel Hayat, IFSTTAR
- Steffen Niemann, bfu
- Philippe Bapst, ASTRA
- Alexander Tratsky, IRSA
- Anil Bhagat, DfT

Appendix D: Road User Behaviour Synopses version 1.0

This appendix includes all the road user behaviour synopses that are available in October 2016. These will be available through the DSS when it is launched in 2017. The synopses are intended to be periodically updated to reflect new research or in some cases to expand their scope. Future updates or additions to the synopses will be available on the project website (http://www.safetycube-project.eu/) and the DSS.

Full list of synopses:

- Influenced driving - alcohol
- Influenced driving - drugs (legal & illegal)
- Speeding and inappropriate speed
- Traffic rule violations - red light running
- Risk taking - overtaking
- Risk taking - close following behaviour
- Distraction - cell phone use - hand held
- Distraction - cell phone use - hands free
- Distraction - cell phone use - texting
- Distraction - music - entertainment systems
- Distraction - operating devices
- Distraction - cognitive overload, inattention
- Distraction - conversation with passengers
- Distraction - outside of vehicle
- Fatigue - not enough sleep, sleepy at wheel
- Fatigue - sleep disorders - sleep apnea
- Insufficient knowledge and skills
- Observation errors
- Functional impairment - cognitive impairment
- Functional impairment - hearing loss
- Functional impairment - vision loss
- Diseases and disorders - diabetes
- Personal factors - sensation seeking
- Personal factors - ADHD
- Emotions - aggression, anger

Influenced Driving - Alcohol

Driving/riding a vehicle following the consumption of Alcohol

1 Summary

Leskovšek, B., July 2016

1.1 COLOUR CODE: RED

Driving under the influence of alcohol generally has a significantly increased risk of crashes and poor driving performance. There is a common understanding that driving under the influence of alcohol is associated with higher risk of being involved in crashes with injuries and possible fatalities as the outcome. Alcohol is a depressant. It slows down the brain and affects the body's responses. At the same time, if you have been drinking, you are more likely to take risks. Combined, these reactions increase the likelihood of accidents happening.

1.2 KEY-WORDS

Alcohol, hangover, driving, drunk driving, driving under the influence, alcoholic beverages consumption, traffic violations, road traffic accidents, driving performance, crash risk, crash culpability, car drivers, impairment, attention, sleepiness, cognition, traffic fatalities, recidivism, SDLP, driving licence, BAC, 0-0,5 ‰, 0,51-0,8‰, 0,81-1,6‰, >1,6‰.

1.3 ABSTRACT

Drinking and driving is one of the main causes of road crashes worldwide. Efforts to deter drunken driving have a long history as evidenced by enforcement of statutory blood-alcohol concentration (BAC) limits of 0.20, 0.50 or 0.80 g/L (20, 50 or 80 mg/100 mL) in most nations. In high-income countries, about 20% of fatally injured drivers have excess alcohol in their blood, while in some low- and middle-income countries these figures may be up to 69%. Although injuries and fatalities related to road accidents have decreased in recent decades, the prevalence of drunk driving among drivers killed in road accidents has remained stable, at around 25% or more during the past 10 years. In the context of driving, it is relevant to distinguish between drivers who exceed the BAC limit only once, and those who do it repeatedly (recidivists). Driving under the influence (DUI) laws, enforcement and penalties vary between countries and have been implemented at different historical moments. In addition, the driver's knowledge and respect for the DUI laws vary; therefore, the incidence of driving under the influence of alcohol or drugs and the involvement of alcohol and drugs in fatal crashes varies.

1.4 BACKGROUND

Driving under the influence (DUI), or driving while intoxicated (DWI), is the crime of driving a motor vehicle while impaired by alcohol or other drugs (including recreational drugs and those prescribed by physicians), to a level that renders the driver incapable of operating a motor vehicle safely. People who receive multiple DUI offenses are often people struggling with alcoholism or alcohol dependence.[1]

[1] https://en.wikipedia.org/wiki/Driving_under_the_influence

How is it measured?

With alcohol, a drunk driver's level of intoxication is typically determined by a measurement of blood alcohol content or BAC; but this can also be expressed as a breath test measurement, often referred to as a BrAC. A BAC or BrAC measurement in excess of the specific threshold level, such as 0.08%, defines the criminal offence with no need to prove impairment. In some jurisdictions, there is an aggravated category of the offense at a higher BAC level, such as 0.12%, 0.15% or 0.25%.

A breathalyser is a device for estimating BAC from a breath sample. BAC is most conveniently measured as a simple percent of alcohol in the blood by weight. Research shows an exponential increase of the relative risk for a crash with a linear increase of BAC. BAC does not depend on any units of measurement. In Europe, it is usually expressed as milligrams of alcohol per 100 millilitres of blood. However, 100 millilitres of blood weighs essentially the same as 100 millilitres of water, which weighs precisely 100 grams. Thus, for all practical purposes, this is the same as the simple dimensionless BAC measured as a percent. The 'per mille' (promille) measurement, which is equal to ten times the percentage value, is used in Denmark, Germany, Finland, Norway and Sweden.

What is the effect of drunk driving on road safety?

Consuming alcohol prior to driving greatly increases the risk of car accidents, highway injuries, and vehicular deaths. When the amount of alcohol in the blood exceeds a certain level, the respiratory (breathing) system slows down markedly. It can even cause a coma or death, because oxygen no longer reaches the brain. Studies show that a high BAC increases the risk of accidents, whereas it is not clear if a BAC of 0.01% - 0.05% slightly increases or decreases the risk. Some studies suggest that a BAC of 0.04 - 0.05% would slightly increase the risk whereas other studies suggest that a BAC of 0.01 - 0.04% would slightly lower the risk, possibly due to the drivers being more cautious.

Traffic accidents are predominantly caused by driving under the influence for people in Europe between the age of 15 and 29. It is one of the main causes of mortality. According to the National Highway Traffic Safety Administration, alcohol-related crashes cause approximately $37 billion in damages annually.[2] Every 51 minutes someone dies from an alcohol-related crash. When it comes to risk-taking there is a larger male to female ratio as personality traits, anti-social behaviour and risk-taking are taken into consideration, factors that are all involved in DUIs (Anum et al, 2014).

Prevalence of alcohol in accidents

Drinking and driving is one of the main causes of road crashes worldwide. According to the World Health Organization, in high-income countries, about 20% of fatally injured drivers have excess alcohol in their blood, while in some low- and middle-income countries these figures may be up to 69%. Road traffic injuries are a major but neglected public health challenge that requires concerted efforts for effective and sustainable prevention. Of all the systems with which people have to deal every day, road traffic systems are the most complex and the most dangerous. Worldwide, an estimated 1.2 million people are killed in road crashes each year and as many as 50 million are injured. According to WHO projections indicate that these figures will increase by about 65% over the next 20 years unless there is new commitment to prevention.

Main conclusions

Drunk driving is one of the most risky factors when dealing with traffic safety. Accident risk increases when blood alcohol level increases. There is a lot of ongoing research being conducted on the matter of driving under the influence. The number of research projects and people involved in the collection of contributive DUI data is multiplying. This includes technological advances that lead

[2] http://www.nhtsa.gov/Impaired

to more advanced tools for alcohol detection, and devoted organisation's statistical reports revealing the success and failures of prevention programs. Studies will expand our collective capability to prevent drink driving, stop drink driving-related accidents, and save lives.

2 Scientific Overview

2.1 LITERATURE REVIEW

Several studies have been conducted on the use of alcohol in traffic worldwide. However, definitions of drink-driving and research methods applied differ from country to country. This makes it difficult to make a fully accurate comparison of the prevalence of drink-driving. Despite the differences the studies nevertheless still provide a clear picture on the overall situation and general differences between countries.

The European research project DRUID (Driving Under the Influence of Drugs, Alcohol, and Medicines) was conducted between 2007 and 2011. DRUID included 13 national studies on the prevalence of psychoactive substances (including alcohol), which were conducted according to a uniform study design. Data on alcohol use was collected during all times of the day and all days of the week to get a representative sample of psychoactive substances use in national traffic. All data were collected using a uniform protocol and using the same cut-off levels. Some large European countries did not participate in these studies (United Kingdom, Germany, France). Additionally, some roadside surveys suffer from large shares of non-response, which makes the data less reliable. The results of these studies show that alcohol is the most commonly used psychoactive substance in European traffic. It was estimated that on average 1.65% of all drivers in European traffic are driving with a blood alcohol concentration (BAC) of 0.5 g/L or higher. For alcohol levels above 0.1 g/L the estimated prevalence was 3.85%.

Another European study, SARTRE (Social Attitudes to Road Traffic Risk in Europe), focused on attitudes, opinions and perceptions of road users regarding several traffic safety issues, such as drink-driving. The study has provided data for 17 European countries on the frequency with which drivers have driven above the legal limit in the past month. Of all asked drivers, 31% reported to have driven a car in the past month after taking an amount of alcohol. The study found that countries with low legal limits (0.0-0.2 g/L) all have a relatively low share of self-reported drink-driving. Self-reported drink-driving in countries with a legal BAC limit of 0.5 g/L was significantly higher (see **Table 1**).

Table 1: Self-reported drink-driving behaviour

Country	Legal limit	Drink-driving above the legal limit in the past month	Drink-driving with any amount of alcohol in the past month
BE	0.5 g/L	26%	39%
CZ	0.0 g/L	12%	14%
DE	0.5 g/L	10%	33%
EE	0.2 g/L	4%	11%
EL	0.5 g/L	14%	38%
ES	0.5 g/L	26%	42%

FR	0.5 g/L	19%	45%
IE	0.5 g/L	9%	19%
IT	0.5 g/L	33%	59%
CY	0.5 g/L	34%	51%
HU	0.0 g/L	5%	5%
NL	0.5 g/L	7%	32%
AT	0.5 g/L	20%	43%
PL	0.2 g/L	2%	2%
SI	0.5 g/L	11%	34%
FI	0.5 g/L	2%	13%
SE	0.2 g/L	2%	8%

Source: SARTRE

2.2 CRASH DATA

Alcohol affects driving performance in three levels that can be active at the same time and can influence each other: strategic level, tactical level and control level. The strategic level defines the general planning stage of a trip, including the determination of trip goals, route and modal choice, plus an evaluation of the costs and risk involved. Deciding on whether or not to drive when one has consumed alcohol, or even when one is planning to consume alcohol, falls within this category. At the tactical level drivers exercise manoeuvre control, allowing them to negotiate the prevailing circumstances. It involves tasks in relation to route navigation, the interaction with other traffic and adherence to the rules of the road. The control level consists of tasks at an operational level. These tasks are the basic actions to operate vehicle control functions and keep speed and course. Extensive research has shown that the many skills involved in driving are not all impaired at the same Blood Alcohol Content (BAC) levels.

Compared to studies on the impact of alcohol on the performance of a driver at the control and tactical levels, the impact at the strategic level has been studied far less. This is probably because skills and actions at this level cannot be studied in driving simulators or instrumented vehicles. Nevertheless, it is well known that after having consumed alcohol, self-control becomes less stringent and even when a little drunk, people are more inclined to think that they are still able to drive safely. From this we can conclude that alcohol has a significant negative impact on the strategic level.

An analysis was conducted of the German In-Depth Accident Study (GIDAS) database. The GIDAS database details those accidents which occurred on a public road where at least one person was injured. The accidents are collected according to a statistical sampling process to ensure a high level of representativeness of the actual accident situation in the sample regions (Hannover and Dresden). The data collection is conducted using the "on the scene" approach where all factors which were present at a crash are recorded. The analysis of 'alcohol' used the data from the Hannover accidents of the GIDAS data (GIDAS Hannover accidents; years 2008-2014 with ACAS-codes; data basis: 2599 accidents) was done using the ACAS codes which describe (mostly human) causation factors which led to the accident occurrence. The following three figures describe the results.

Drunk driving depends on a range of different factors such as road type, location, road user type, time of the day etc. The following charts show their correlation, it is apparent from the first graph that most drink driving is recorded on urban roads.

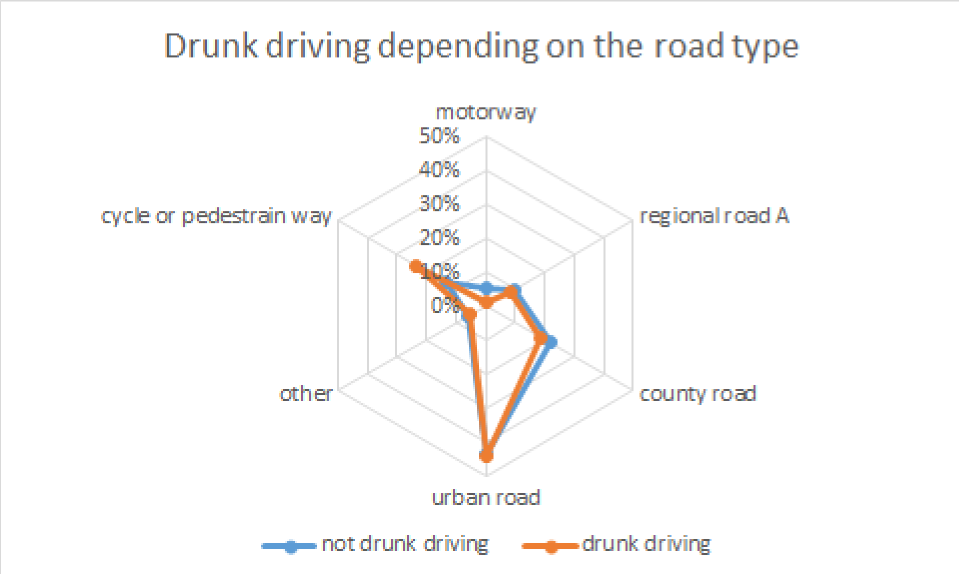

Figure 1: Drunk driving depending on the road type. Source: GIDAS, 2016.

The odds of getting into a driving accident increase during periods when there are more cars on the road, such as rush hour, or when driving conditions are less than optimal, as during periods of inclement weather. The majority of studies show that most accidents occur during "rush hour," between 3 p.m. and 6 p.m. Saturday is the most dangerous day of the week to drive, primarily because there are more cars – and more drunk drivers – on the road than any other day. Various studies have shown that the most of the fatal drunk-driving accidents occur on the weekend, and the highest number of drunk drivers on the road is between midnight and 3 a.m.

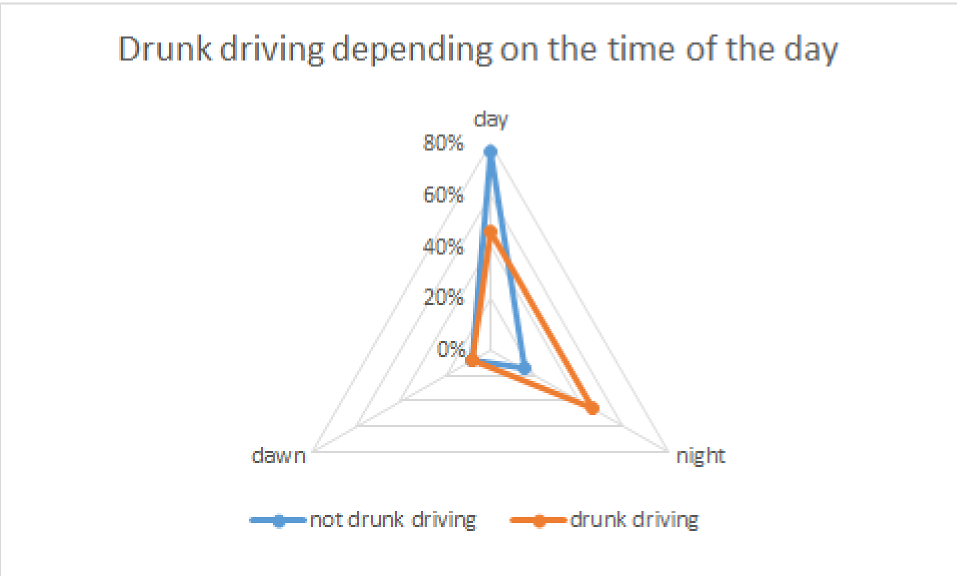

Figure 2: Drunk driving depending on the time of the day. Source GIDAS, 2016.

Drunk driving also depends on the road user type, as seen in **Figure 3** below.

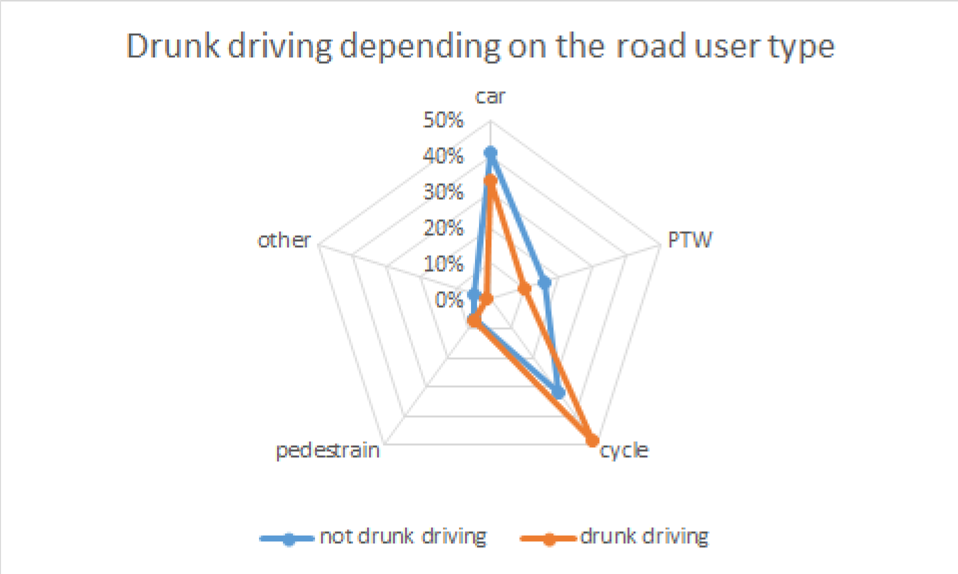

Figure 3: Drunk driving depending on the road user type. Source GIDAS, 2016.

2.3 DESCRIPTION OF STUDIES

Driving under the influence of alcohol is an important factor in road fatalities in Europe. Alcohol is the most frequently detected psychoactive substance in the driving population as well as in the seriously injured and killed drivers in Europe. According to DRUID project, alcohol alone, where BAC ≤ 0.1 g/L, is the most frequently detected substance in most countries.
Coded studies on driving under the influence of alcohol have considered:

- impairment of driving ability for different BACs;
- searching and identifying the best performance tests for initial screening of skills related to car driving;
- analysing the link between fatal traffic accidents and driving under different BAC levels;
- the impact of different BAC levels on drivers who are already under the influence of drugs;
- the impact of low levels of alcohol on driving performance in the condition of partial sleep deprivation;
- effects of alcohol hangover on simulated highway driving performance; with the relationship between unemployment and drunk driving in correlation to fatal traffic accidents;
- differences between non-drunk drivers, drunk driving non-recidivists and drunk driving recidivists with respect to their socio-economic characteristics, road accident involvement and other traffic or non-traffic related law violations;
- analysing possible reasons for the differences in compliance with the DUI law in different countries with the same legal limit for alcohol.

Table 2gives an overview of each study and their results.

Table 2: Description of analysis of coded studies

Author, Year, Country	**Exposure variable**	**Outcome variable**	**Effects for Road Safety**	**Main outcome – description**
Verster, J. C., Bervoets, A. C., de Klerk, S., Vreman, R. A., Berend O., Roth, T., Brookhuis, K. A. (2014) USA	Alcohol hangover.	Effects on driving performance.	↗	Driving performance was significantly impaired during alcohol hangover. Subjects reported their driving quality to be significantly poorer and less safe. Subjects further reported being significantly more tense while driving, and more effort was needed to perform the driving test. Total sleep time has a significant impact on the magnitude of driving impairment.
Dubois, S., Mullen, N., Weaver, B., Bedard, M. (2015) USA	Combined use of alcohol and cannabis.	Combined influence of low levels of alcohol (BAC ≤ 0.08) and cannabis on crash risk.	↗	Drivers positive for both agents had greater odds of making an error than drivers positive for either alcohol or cannabis only. Further research is needed to better examine the interaction between cannabis concentration levels, alcohol, and driving.
Jongen, S., Vuurman, E., Ranaekers, J., Vermeeren, A. (2014) Netherlands	Alcohol calibration (Twenty-four healthy volunteers participated in a double blind, four-way crossover study. Treatments were placebo and three different doses of alcohol leading to blood alcohol concentrations (BACs) of 0.2, 0.5, and 0.8 g/L.).	Determination of preferable tests to measure drunk-induced impairment.		The preferable tests for initial screening are the DAT and the PVT, as these tests were most sensitive to the impairing effects of alcohol and being considerably valid in assessing potential driving impairment.
Ahlner, J., Holmgren, A., Jones, A.W. (2014) Sweden	This retrospective 4-year study (2008–2011) used a forensic toxicology database (TOXBASE) from drivers killed in road-traffic crashes.	Evaluation of the concentrations of alcohol and other drugs in blood samples.	↗	The high median BAC in fatally injured drivers speaks strongly towards alcohol-induced impairment as being responsible for the crash. The victims BAC exceeded Sweden's statutory alcohol limit for driving (0.2 g/L) in 21% of all fatalities, whereas the median BAC was more than 8 times higher (1.7 g/L). In 76% of fatalities, the autopsy BAC was over 1.0 g/L, which gives convincing evidence that these drivers were impaired at the time of the crash.
Moller, M., Haustein, S., Prato, C.G. (2015) Denmark	Drunk driving.	Profiling drunk driving recidivists.		The differences identified with regard to socio-economic characteristics between persons with 0, 1, or more than 1 drunk driving incident(s) indicate that drunk driving recidivism is more likely to occur among people in situations involving socio-economic disadvantage, including living alone, low income and low education. In addition, recidivists are involved in more traffic, as well as non-traffic-related, law violations, which, together with their socio-economic characteristics, may suggest a marginalised life situation.
Veldstra, J.L., Brookhuis, K.A., de Waard, D., Molmans, B.H.W., Verstraete, A.G., Skopp, G., Jantos,	Drunk driving in combination with drugged driving.	The study was designed to establish the extent of driver impairment as a consequence of	↗	Alcohol and ecstasy mainly influenced automated driving performance such as lateral and speed control. Small to no effects were found on more complex driving behaviour. Overall, variance within the different driving measures was high, especially when participants were treated with

R. (2012) Netherlands		ecstasy or combined ecstasy and alcohol use as compared to driving under the influence of 0.3‰, 0.5‰ and 0.8‰ alcohol.		3.4-methylenedioxy-methamphetamine (MDMA) and alcohol. Combined use might lead to impaired driving, but not necessary for all drivers. Participants rated their own performance to be slightly worse than normal in both studies. Their driving was actually seriously deteriorated.
Banks, S., Catcheside, P., Lack, L., Grunstein, R.R., McEvory, R.D. (2004) Australia	Drunk driving.	Effects of low BAC (<0.05 g/dL on driving performance in subjects who were partially sleep deprived (driving early in the morning).	↗	Alcohol at legal BACs appears to increase sleepiness and impair performance and the detection of crash risk following partial sleep deprivation. When partially sleep deprived, women appear to be either more perceptive of increased crash risk or more willing to admit to their driving limitations than are men. Alcohol eliminated this behavioural difference.
Gjerde H., Sousa T.R., De Boni R., Christophersen A.S., Limberger R.P., Zancanaro I., Oiestad E.L., Normann P.T., Morland J., Pechansky F. (2014) Brasil, Norway	Weekends drink driving.	A comparison of alcohol and drug use by random motor vehicle drivers in Brazil and Norway.		High participation rates (94–97%) were obtained in both countries. The weighted prevalence of driving with alcohol concentrations in breath or oral fluid equivalent to BAC above 0.2 g/L was 2.7% in Brazil and 0.2% in Norway. The difference in the prevalence of alcohol may be related to the fact that Norway has implemented steps to reduce drunk driving since 1936, whereas Brazil has attempted to do the same for only a few years.
Kruger N.C. (2013) Sweden	Drunk driving.	Socio-economic determinants of road accident risk.	↗	Resources for safety measures should not be spent uniformly across time and space. Safety measures should be concentrated to areas with a high share of young people and to periods with low unemployment. Factors other than increased mileage during booms contribute to the higher rate of fatalities during good times.

Key: ↗ Increased risk

3 Supporting Document

3.1 LITERATURE SEARCH STRATEGY

The literature search was conducted in March 2016. It was carried out in three databases with separate search strategies.

Database: Scopus **Date:** 31th of March 2016

search no.	search terms / operators / combined queries	hits
#1	("influenced driving" OR "drunk driving" OR "driving under alcohol")	962
#2	AND ("road safety" OR road crash" OR "road casualties" OR "traffic accident" OR "collision" OR "road fatalities")	286
#3	AND ("BAC" OR "blood alcohol content")	38
#4	Limitations/ Exclusions (years, language, countries)	12

Optional but recommended: Limitations/ Exclusions:

- Search field: TITLE-ABS-KEY
- published: 1990 to current
- Document Type: "Review" and "Article"
- Language: "English" and "German"
- Source Type: "Journal"
- Exclusion of several countries
- Subject Area: "Engineering")

Database: Scopus **Date:** 31th of March 2016

search no.	search terms / operators / combined queries	hits
#1	("influenced driving" OR "drunk driving" OR "driving under alcohol")	962
#2	AND ("BAC" OR "blood alcohol content")	97
#3	AND ("road safety" OR "road fatalities" OR "road crash")	10
#4	Limitations/ Exclusions (years, language, countries)	10

Database: Scopus **Date:** 31th of March 2016

search no.	search terms / operators / combined queries	hits
#1	("influenced driving" OR "drunk driving" OR "driving under alcohol")	962
#2	AND ("road safety" OR "legislation")	117
#3	AND ("BAC" OR "blood alcohol content")	20

#4	Limitations/ Exclusions (years, language, countries)	17

Database: Web of Science **Date:** 31th of March 2016

search no.	search terms / operators / combined queries	hits
#1	("influenced driving" OR "drunk driving" OR "driving under alcohol")	166,743
#2	AND ("road safety" OR "road fatalities" OR "road crash")	446
#3	AND ("BAC" OR "blood alcohol content")	34
#4	*Limitations/ Exclusions (years, language, countries)*	14

Database: Science Direct **Date:** 31th of March 2016

search no.	search terms / operators / combined queries	hits
#1	("influenced driving" OR "drunk driving" OR "driving under alcohol")	77,673
#2	Limitations/ Exclusions (years, language, countries)	417
#3	AND ("road safety" OR road crash" OR "road casualties" OR "traffic accident" OR "collision" OR "road fatalities")	231

Results Literature Search

Database	Hits
Scopus (remaining papers after several limitations/exclusions)	17
Web of Science	14
ScienceDirect	231
Total number of studies to screen title/ abstract	**262**

Screening

Total number of studies to abstract	262
De-duplication	87
Exclusion not the right topic	53
Exclusion focus on other than risk factor	24
Exclusion only relevant countries	19
Remaining studies	58
Not clear (full-text is needed)	20
Studies to obtain full-texts	**78**

Eligibility

Total number of studies to screen full-text	78
Full-text could be obtained	47
Reference list examined Y/N	No
Eligible papers	**47**

Prioritising Coding

1. Meta-analysis
2. Recent studies
3. Clear experimental design

3.2 ANALYSIS OF STUDY DESIGN AND METHODS

In the coded studies, a variety of methods have been used. Johan Ahlner used the Swedish forensic toxicology database to evaluate the concentrations of alcohol and other drugs in blood samples from drivers killed in road traffic crashes for the period 2008 - 2011. In a similar study from the USA, authors used data from the Fatality Analysis Reporting System, complied by the National Centre for Statistics, and Analysis of the National Highway Traffic Safety Administration. They analysed data for the period 1991 – 2008. From the dataset, they derived the proxy measure of responsibility (presence of one or more unsafe driver actions), cannabis and alcohol exposure, and driver age, sex, medication usage, and driver history. They examined the prevalence of driving under the influence of alcohol for drivers involved in a fatal crash. Adjusted odds ratios of committing an unsafe driving action (UDA) for alcohol effect were computed via logistic regression and adjusted for a number of potential confounders.

In a study from the Netherlands, the author's aim was to determine which performance tests are useful to measure drug-induced impairment. He used effects of alcohol to compare the psychometric quality between tests and as benchmark to quantify performance changes in each test associated with potentially impairing drug effects. Volunteers (aged 18 – 30 years) were invited to participate in a double blind, four-way crossover study. Some inclusion criteria had to be met for participation: drinking at least three but no more than 21 glasses of alcohol per week and a Body Mass Index (BMI) between 19 and 29 kg/m^2. There were also some additional exclusion criteria: pregnancy or lactation, any history of psychiatric or medical illness, history of or current drug or alcohol abuse, current use of psychoactive medication, inability to stay abstinent during the study, excessive caffeine use and smoking more than seven cigarettes a week.

Treatments were placebo and three different doses of alcohol leading to blood alcohol concentrations (BACs) of 0.2, 0.5 and 0.8 g/L. The placebo dose consisted of a glass of orange juice with a small amount of alcohol floating on the surface of the beverage. Volunteers participated in two treatment days. In a first day a dose to achieve a low BAC (0.0 – 0.2 g/L) was administered. The second dose was to achieve a high BAC (0.5 – 0.8 g/L). The order of test days was balanced over participants. The washout period was at least 1 week. Participants were individually trained to perform the behavioural tests prior to the first test day. During participation in the study, alcohol intake was not allowed from 24 hours prior to each dosing until discharge. On treatment days, participants fasted for 4 hours before arrival at the lab.

There is another double blind, placebo-controlled four-way crossover design study from the Netherlands, which was designed to establish extent of driver impairment as a consequence of drug or combined drug and alcohol use, as compared to driving under the influence of 0.3, 0.5 and 0.8 promille alcohol. Only 17 participants with an average age of 23.6 years were analysed in the alcohol reference study. Participants were experienced drivers who had held their driving licence for at least 3 years and drove at least 5,000 km per year. The participants were instructed to abstain from alcohol in the 24 hours prior to the experiment and to refrain from caffeinated beverages on the morning of the experiment. They were tested during 5 separate testing days, starting with a screening by questioning them about their lifestyle in relation to alcohol and drug use. Further, they were trained in the simulator for 30 minutes.

Figure 4: Driving simulator

On the other 4 testing days, participants were given beverages containing vodka filled up with orange juice until the intended BAC was reached or only orange juice with a spray of alcohol on top as a placebo. The amount of administrated alcohol was dependent on the weight, height and gender of the participant and was calculated using the Widmark formula (Widmark, 1932). The test was paused every 20 minutes to do a breath analysis and administer extra alcohol when necessary. All statistical analyses were conducted by means of SPSS 16 for Windows. Normally distributed data were subjected to a general linear model univariate repeated measures analysis with alcohol level as the main within-subjects factor.

An experimental study from Australia hypothesized that while low blood alcohol concentration (<0.05 g/L) may not significantly increase crash risk, the combination of partial sleep deprivation and low blood alcohol concentration would cause a significant drop in performance. There were 20 volunteers participating in the study, mean age 22.9 years. At the first visit to the lab, the subjects were introduced to the testing equipment and driving simulator. They had three 10-minute practice sessions. Subjects underwent driving simulator testing at 1 am on 2 nights a week apart. On the night preceding simulator testing, subjects were partially sleep deprived (5 hours in bed). Alcohol consumption was randomized to 1 of the 2 test nights, and blood alcohol concentrations were estimated using a calibrated Breathalyser. During the driving task subjects were monitored continuously with electroencephalography for sleep episodes and were prompted every 4.5 minutes for answers to 2 perception scales - performance and crash risk.

Participants were required to keep a detailed diary of their sleep habits and to wear an activity monitor which measured sleep-wake activity for 1 week prior to the experimental conditions. This was done to verify the subjects had regular sleep habits in the week prior to testing, that they followed the sleep deprivation protocols, and that they did not nap during the day of testing. In sleep deprivation conditions subjects were restricted to 5 hours in bed on the night prior to testing.

The study examined mean steering deviation (deviation from the subject's median position on the road averaged every 40 milliseconds, excluding crashes), mean speed deviation (deviation from the safe speed zone 60-80 km/h), braking reaction time (in response to trucks on the road ahead), and mean number of driving-simulator crashes (off-road, truck collision, or stoppage events).

A study from Denmark included all persons in the register-based data of Statistics Denmark aged 18 or older in the year 2008 (4,260,306 persons). To all those persons the following demographic variables were connected: gender, age, civil status, household type, number of children in the household, place of residence, immigration status and country of origin, highest level of education, income, yearly rate of unemployment and job-related position. For each person, the number of drunk driving offences and other violations of traffic laws or non-traffic laws for the years 2008–2012 were retrieved from the national crime database maintained by Statistics Denmark. Additionally, the number of accidents involving injuries as the driver of a vehicle that requires a driver's licence in the years 2008–2012 and information on the BAC at the time of each accident was added from the national accident database that is maintained by the Road Directorate and constructed on the basis of police registered road accidents.

First, persons that were involved in only one drunk driving incident in the year 2008 were compared with those who were involved in at least one additional drunk driving incident within the study period, according to selected demographic and socio-economic characteristics. The significance of the differences between recidivists and non-recidivists was tested via Chi-square tests and t-tests. Persons without drunk driving incidents throughout the study period served as a comparison group. A logistic regression model was estimated to examine the likelihood of becoming a recidivist within the study period 2008–2012 for persons involved in a drunk driving incident in 2008 based on their socio-demographic characteristics in 2008, the year of the first offence. Finally, the analysis focused on accident involvement and other traffic and non-traffic law violations of persons with 0, 1, or more than one drunk driving incident(s) during the study period.

Another study from Sweden investigated connections between fatal traffic accidents and socioeconomic status. The study uses both regional panel data and national time series data combined with filtering techniques to determine what factors influence the number of accidents, the accident outcome and detected drunk driving. The author used two methods: time-scale decomposition techniques and panel-regression techniques. Time series data can be examined in two basic ways, either by analysing how a variable changes over time or by analysing what frequencies the variable covers. For a single time series, the time domain-based analysis can reveal trends over time and dependence in the data across time. Frequency domain analysis can reveal what periodicities are present in a time series. One common use is to reveal the seasonal properties of a time series, often a non-trivial issue because of different overlapping seasonality's, non-regular periodicities and stochastic errors. Since both time and frequency domain approaches have merits as well as drawbacks, there have been efforts to combine them. A simple strategy is to perform frequency domain analysis for different periods along the time axis, so that we are better able to detect changing periodicities that might occur due to structural breaks or regime shifts. One way to recombine the time and frequency dimensions is to use a certain class of function called "wavelets" in order to filter the data. The purpose of filtering the data is to analyse the data for different periodicities. By using wavelets, the data is filtered so that the data is represented in different independent time scales. The different time scales therefore represent independent information of the underlying variable (seen for different periodicities) without changing the information content of the data. Whereas time series analysis is the only way to unravel the dynamics of a variable (or a set of variables), time series analysis cannot, largely, control for the multitude of factors that could be important. Multivariate time series analyses, like vector autoregressive models, are in general difficult to interpret. Cross-sectional data is a rather limited alternative, since omitted variables might bias the results. A feasible and superior approach is to combine the time series and cross-sectional data that are often available, for example, for different regions. Using panel analysis, which combines the informational content from time series and cross-sectional data, gives us the opportunity to more thoroughly examine the impact of socioeconomic factors on traffic fatalities. A panel model can control for omitted variable bias to some extent, in contrast to pure cross-sectional or time series analysis.

3.3 EXPLORATORY ANALYSIS OF RESULTS

In a 4-year (2008-2011) retrospective study from Sweden, authors (J. Ahlner et al.) used a forensic toxicology database (TOXBASE) to evaluate the concentrations of alcohol and other drugs in blood samples from drivers killed in road traffic crashes. The mean age of all victims (N=895) was 48 ± 20 years, and the majority were male (86%). In 504 drivers (56%), the results of toxicological analysis were negative and these victims were older; mean age (± SD) 47 ± 20 years, than alcohol positive cases (35 ± 14 years) and illicit drug users (34 ± 15 years). In 21% of fatalities, blood-alcohol concentration (BAC) was above the statutory limit for driving (0.2 g/L), although the median BAC was appreciably higher (1.72 g/L). The high median BAC in fatally injured drivers speaks strongly towards alcohol-induced impairment as being responsible for the crash. The study verified that overconsumption of alcohol and drunkenness was much more common in fatally injured drivers compared with use of other drugs. Of the 21% of drivers who's BAC was above the statutory limit, 76% had a BAC > 1.0 g/L. When alcohol use and crash statistics were consolidated over a 12-year period the results were remarkably consistent, showing 20%–22% of drivers above the statutory limit of 0.2 g/L.

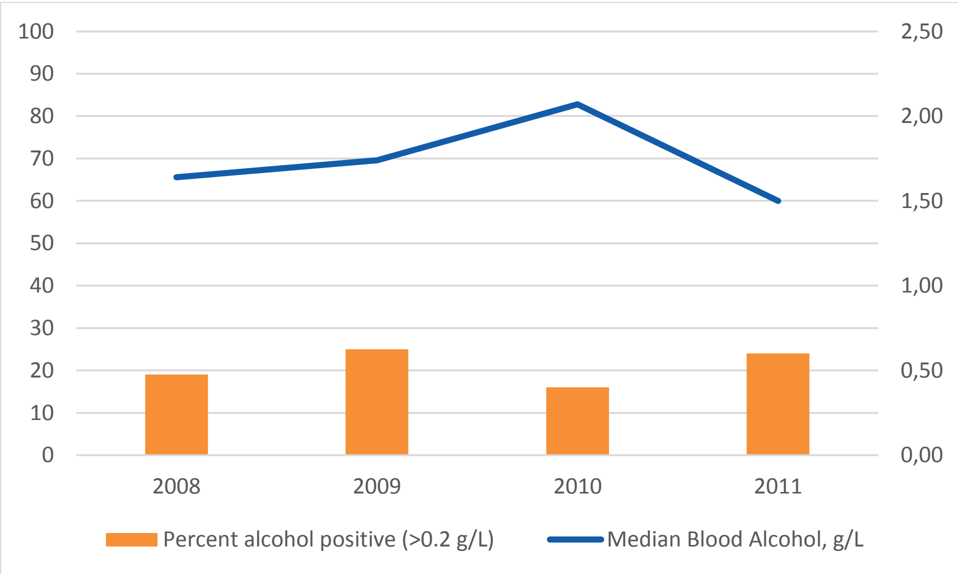

Figure 5: Graph (2008–2011), showing percentages of drivers killed in road-traffic crashes in Sweden with blood-alcohol concentration (BAC) above the statutory limit for driving (0.2 g/L); Source: Ahlner et al (2014).

The median BAC was appreciably higher (1.7 g/L), which gives convincing evidence that the driver was impaired by alcohol at the time of the crash.

Another study investigating the prevalence of driving under the influence, for drivers involved in a fatal crash, comes from the USA. Authors (S. Dubois et al.) examined the period from 1991-2008. In this case-control study, drivers aged 20 years or older who had been tested for both drugs and alcohol after involvement in a fatal crash during the chosen period were examined. Cases were drivers with at least one potentially unsafe driving action (UDA) recorded in relation to the crash. Drivers with no recorded UDAs were considered not to have contributed to crash initiation. Driver crash data were drawn from the Fatality Analysis Reporting System (FARS) complied by the National Center for Statistics and Analysis of the National Highway Traffic Safety Administration. For inclusion in the study, drivers were required to have a valid blood alcohol content obtained by blood test (FARS recorded range: 0 thru 0.94 BAC grams per decilitre). To control for high risk driving habits, authors also included variables containing the drivers' past three-year driving records, which included crashes, recorded convictions for driving while impaired, speeding convictions, other harmful moving violation convictions and licence suspensions or revocations. Descriptive statistics were used to present drivers' age, sex, previous driving history and drug status by alcohol and THC exposure. The Pearson chi-square test was used to compare driver characteristics by alcohol/THC exposure. To examine the effects of alcohol, THC and their combination, logistic regression was used.

Between 1991 and 2008 there were 834,328 drivers of cars involved in a fatal crash. Of these, 150,010 drivers were blood tested for both alcohol and drugs and comprise the sample used for analysis. Of the 150,010 tested drivers 87,280 were alcohol and THC free. 53,992 (36%) drivers were positive for alcohol only, 3,387 tested positive for THC only and 4,347 (3%) tested positive for both THC and alcohol. Drivers testing positive for alcohol tended to be younger, male, and have a poorer driving record compared to those drivers testing negative. Both alcohol and THC increased the odds of committing an UDA. Results showed that when BAC increases from 0.0 to 0.1 the odds of an UDA increases by 11%. The statistically significant BAC quadratic term indicated that each 0.01 BAC increment was slightly lower than the previous unit's increase. Age and sex interacted significantly with alcohol. The age-term had the greatest impact on increasing the odds of an UDA for the youngest and oldest drivers. The odds of committing an UDA preceding a fatal crash were increased from age 20 until around the age of 40. At that point odds began to decrease. Driver sex did interact significantly with driver age. Males had greater predicted odds of committing an UDA compared to females. Given the curvilinear relationship between age and UDAs, this difference was most pronounced in the youngest and oldest drivers.

Drivers at typical BAC legal limits of 0.05 and 0.08 had greater odds of committing an UDA of 66% and 117%, respectively, compared with sober drivers. When combined with THC these odds increased to 81% and 128%, respectively. Combination effect was most pronounced at the lowest levels of BAC. As BAC levels increases the impairing effects of alcohol dominate the relationship between THC and alcohol.

The dissociation between subjective perceptions and objective performance decrements are important notions for traffic safety. An experimental study from the Netherlands (J.L.Veldstra et al.) was designed to establish the extent of driver impairment as a consequence of ecstasy or combined ecstasy and alcohol use as compared to driving under the influence of 0.3 promille, 0.5 promille and 0.8 promille alcohol. For this reason, a double blind, four-way, crossover alcohol reference study was initially performed. In this study the influence of three levels of alcohol were tested against placebo condition on a set of measures within specifically developed scenarios. The placebo looked and smelled like an alcoholic beverage but contained no alcohol.

17 volunteers with a mean age of 23.6 years were analysed. Those were all experienced drivers (driving licence held for at least 3 years). They drove at least 5,000 km per year. Participants were required to complete test rides in a driving simulator of a mock-up car with original controls linked to a computer, registering driver behaviour. They had a 180° view of the road environment. The virtual environment consisted of urban, rural and motorway road types. Under automated driving performance average speed and SDSP were assessed. In addition, to measure tracking errors, road tracking was monitored on two rural roads of approximately 10 km. Complex driving performance was assessed using car following test, gap acceptance tasks to asses risk taking in traffic, running red lights test, driver's reaction to unexpected events, total number of crashes during the entire ride.

Subjective performance was also assessed: *Karolinska sleepiness scale* to assess the participant's own feeling of alertness before and after driving; *Rating scale mental effort* to assess whether there was a difference in the mental effort participants had to invest during the driving session for the different alcohol conditions; *Driving quality scale* for participants to judge their own performance.

The results indicated that alcohol mainly influenced automated driving performance. Speed on urban roads increased when BAC was above 0.5 promille. This increase was small and did not exceed the posted speed. Participants were weaving increasingly more as they were under the influence of higher alcohol levels. No effects of alcohol on any of the car following measures were found. Therefore, effects on automated driving performance were the main parameters that served as references for the second study on the influence of MDMA (ecstasy – 3.4-methylenedioxy-methamphetamine) and alcohol on driving performance. When comparing self-assessment of driving performance with the automated driving results in case of alcohol consumption, the self-evaluation led to the wrong conclusions. Participants rated their performance before and after driving under the influence as the same (slightly worse than normal). Their driving was actually seriously deteriorated. Therefore, this conclusion was a falsely positive assessment of the situation. For MDMA, the opposite was the case. The driving performance of the MDMA users was better than their self-assessment.

In Europe, a study which was a part of the Driving Under the Influence of Drugs, alcohol and medicines (DRUID) project, reported an estimated prevalence of alcohol use of 3.48% in the general population of drivers (Houwing et al. 2011). The most widely used benchmark drug for assessing drug-induced driving impairment is alcohol. Most studies found that risks of being involved in fatal crash increase exponentially with BACs of 0.5 g/L and higher. In line with this, the legal BAC limit for driving a car is set at a BAC of 0.5 g/L in most countries. Despite the fact that legal limits are societal issues, it is generally agreed that the impairment produced by BACs of 0.5 g/L and higher is clinically relevant. Therefore, a BAC of 0.5 g/L can be used to calibrate changes in tests measuring driving skills. That was also the case in alcohol calibration study by S.Jongen et al.. The aim of the study was to determine which performance tests are useful to measure drug-induced impairment. The main objective was to compare the relative sensitivity of exhaustive list of tests, measuring driving-related and drug-induced impairment, for the dose-dependent effects of alcohol. A secondary objective was to establish the mean performance changes in each test associated with three increasing doses of alcohol resulting in BACs of 0.2, 0.5 and 0.8 g/L for future reference and interpretation of the clinical relevance of drug effects, which could provide a comparison of full range of driving-related skills. Eight tests were included measuring various skills related to driving, such as psychomotor speed (CTT, ANT, PVT, DSST, DAT), divided attention (DAT), sustained attention (PVT), spatial attention (ANT), executive attention (ANT, CST), memory span (DST) and postural balance (PBT). 24 participants (aged 18 – 30 years) completed the study.

All tests except the DST and CST showed statistically significant effects of alcohol intoxication. The largest and strongest dose-dependent effects of alcohol were found on performance in the PBT, PVT and DAT. Only three tests showed significant impairment at a BAC of 0.5 g/L. Effect sizes for reaction time in the DAT and PVT were moderate (i.e., 0.39 and 0.29) at a BAC of 0.5 g/L and large (i.e., 0.65 and 0.70) at BAC of 0.8 g/L. Results also showed that performance in the DAT, PVT and PBT is sensitive to low or moderate BACs. Several previous studies support that result. The failure of the CST to show any effects of alcohol is also in line with findings of similar studies – performance in a similar test was only impaired at a very high BAC but not at lower BACs as used in the present study. DSST showed impairment at BAC of 0.8 g/L, but not below. This result is also in line with most previous studies. CTT showed impairment at a BAC of 0.2 and 0.8 g/L, but not at a BAC of 0.5 g/L. This failure was unexpected. Participants were extensively trained in the current study, but a learning effect could have occurred in participants who completed the 0.5 g/L condition at the end of the second testing day.

One of the reasons why PVT and DAT are more sensitive to impairment may be related to their longer duration. The duration of the PVT and DAT is 10 and 12 minutes. Many other tests take no more than 2 or 3 minutes to complete. In shorter tests, a temporary increase of effort may compensate the impairing effects.

The limitation of the study represents the fact that not all available tests measuring driving-related skills could be included to compare all these tests in one study – more studies are needed comparing other tests.

According to this study, the preferable tests for initial screening are DAT and the PVT. They were most sensitive to the impairing effects of alcohol and they are considerably valid in assessing potential driving impairment because of sedation or drowsiness.

Alcohol hangover is the most frequently reported consequence of heavy drinking. Joris C. Verster et al. examined the effects of alcohol hangover on simulated highway driving performance. The hangover is characterized by a feeling of general misery that may last up to 20 hours after alcohol consumption (Verster et al. 2010). It develops when blood alcohol concentration returns to zero. The hangover state has a negative impact on memory and cognitive and psychomotor functioning. The study had a naturalistic design. That means that participants consume alcohol unsupervised at a place, time and drinking speed of their own choice. Participants sleep at home and visit the laboratory for testing the following morning at a predetermined time. On a control day, participants consume no alcohol. The standardized highway-driving test was conducted in the STISIM driving simulator. 42 non-smoking social drinkers aged 21-35 years who have a valid driver's licence for at least 3 years and who drive at least 4,000 km/year participated in the study.

For the test day, subjects were instructed to consume their usual amount of alcohol in a place of choice or not to consume alcohol on the night before the test day. The subjects themselves scheduled the alcohol day. There were no behavioural restrictions in this naturalistic design – except to refrain from nicotine and drug use. Subjects were not allowed to consume caffeinated beverages on the test days. At the start of each test day, urine drug screening was performed and a hangover symptom severity questionnaire was completed. Previous night activities and alcohol consumption were assessed by self-report. Subjects indicated whether in total they slept more or less than 6 hours. The test lasted for 1 hour. Participants were instructed to drive with a steady lateral position in the right traffic lane while maintaining a steady speed of 95 km/h. The primary outcome measure of the test was standard deviation of lateral position (SDLP, cm). Secondary outcome measures were the standard deviation of speed (SDS, km/h) and number of collisions. Mean lateral position (MLP, cm) and mean speed (MS, km/h) were control variables. To examine hangover severity, 21 commonly reported symptoms were scored on a 10-point scale ranging from 0 to 10.

The mean and SD were computed for each variable. A normal distribution of the data and difference scores was confirmed with the Kolmogorov-Smirnov test for normality. Data of the hangover and control day were compared using paired t-tests and ANOVA, GLM for repeated measures (two-tailed) with gender as the between-subjects factor. Differences were considered significant if $p<0.05$.

The mean number of alcoholic drinks in the hangover condition was 10.2. The evening before the hangover test day, 11 subjects stayed at home and 31 went to the pub or party. On the control day, all subjects stayed at home. 22 subjects reported sleeping less than 6 hours on the night before the hangover. Mean sleep quality scores were significantly higher in the hangover condition (5.4) when compared to the control day (2.5).

This study showed that driving performance is significantly impaired during alcohol hangover. This was expressed both in an elevated SDLP and in increased number of lapses. The analyses of subsequent 10-km segments of the driving test showed that the effects of hangover on driving were most pronounced in the second half of the driving test. About four out of every ten drivers showed an SDLP increment >+2.4 cm during hangover. The data further showed that the magnitude of driving impairment during hangover was impacted by total sleep time on the night after the drinking. Those with a sleep duration of 6 h or less showed significantly increased SDLP, whereas the difference between hangover and control was not significant for those, sleeping more than 6 h. A limitation of the study is that it was performed in a driving simulator. Several differences have been noted between simulator research and on-road driving (the artificial environment, the absence of the risk of having crashes with real consequences). It is therefore understandable that a participants' state of mind is different when performing a simulator test when compared to driving in actual traffic on a public highway.

Driving is significantly impaired during alcohol hangover. Total sleep time has a significant moderating effect on the magnitude of the driving impairment.

While driving with a high BAC or after total sleep deprivation is recognized to constitute a serious risk for an accident, driving after one or two drinks while partially sleep deprived is much more common, particularly among young drivers. The primary aim of the study, conducted by S. Banks et al., was to test the effects of low BAC (<0.05 g/L) on driving performance in subjects who were partially sleep deprived and driving close to the circadian nadir (early hours of the morning). 20 subjects (aged 18-30 years) underwent driving simulator testing at 1 am on two nights a week apart. On the night preceding simulator testing, subjects were partially sleep deprived (5 hours in bed). Alcohol consumption (2-3 standard alcohol drinks over 2 hours) was randomized to one of the two test nights, and blood alcohol concentrations were estimated using a calibrated Breathalyser. During the driving task subjects were monitored continuously with electroencephalography for sleep episodes and were prompted every 4.5 minutes for answers to 2 perception scales—performance and crash risk. At the first visit to the laboratory, the subjects were introduced to the testing equipment and driving simulator. The subjects took home an activity monitor and a sleep diary to be completed in the week prior to testing. Subjects were not required to obtain a specific amount of sleep during the testing period. The AusEd driving simulation task used in this study was a computer program devised to monitor a number of performance variables. Subjects were asked to maintain their position in the left-hand lane on the road, to keep their speed within 60 to 80 km/h, and to react by braking firmly and as quickly as possible to any trucks that appeared ahead in the driving lane. The simulator was programmed to present four trucks at approximately 10-minute intervals during the 70-minute task. The subjects were required to keep a detailed diary of their sleep habits and to wear an activity monitor, which measured their sleep-wake activity for 1 week prior to the experimental conditions. In the partial sleep-deprivation condition, subjects were restricted to 5 hours' time in bed on the night prior to testing. BAC levels below 0.05 g/dL were targeted. Subjects started the 70-minute driving simulation at 1:00 AM, and they were prompted every 4.5 minutes during the driving task to answer the perception probes.

This study examined mean steering deviation, mean speed deviation, braking reaction time and mean number of driving-simulator crashes. The mean number of crashes was determined for each 4.5-minute bin. The EEG during the driving simulation task was assessed for the appearance of microsleeps. The subjects' mean BAC on the alcohol night at the start and end of the 70-minute driving simulation were 0.037 ± 0.011 g/dL and 0.021 ± 0.009 g/dL. These values are well below the Australian legal limit for driving of 0.05 g/dL. The consumption of alcohol significantly increased mean steering deviation (P = .05) and the number of driving-simulator crashes (P = .02). Both variables showed a significant increase with time on task (P < .001 and P = .02, respectively). Speed variability was not affected by alcohol (P = .07) but increased with time on task (P < .001). Braking reaction time to trucks increased after alcohol (P = .01) but not with time on task (P = .09). Overall, subjects showed less insight about crash risk in the combined partial sleep deprivation and alcohol condition (38% compared to 64% in the partial sleep deprivation alone condition. The principal finding of this study was that the addition of a low BAC to the presence of partial sleep deprivation caused increased sleepiness while driving and impaired driving performance, without subjects appreciating the extent of their impairment. Even a small amount of alcohol combined with sleep loss appears to be sufficient to dramatically impair subjects' ability to 'drive' safely. The amount of sleep deprivation and alcohol consumed are not only within the legal driving limits for most countries, but also at a level that many individuals would consider safe to drive. This is the first study to assess such a combination. Overall subjects did not realize the full extent of their performance impairment and were poorer at assessing crash risk in the partial sleep deprivation and alcohol condition. Subjects' ability to accurately assess potentially dangerous situations was affected by alcohol, and this may in part explain the increased accident risk associated with drunk driving.

It is well known that DUI laws, enforcement and penalties vary between countries and have been implemented at different historical moments. H. Gjerde et al. conducted roadside surveys to compare the use of alcohol, illegal drugs and psychoactive medicinal drugs among random drivers in Brazil and Norway. Those are two countries with the same legal limit for drunk driving, but with marked differences in legislation history, enforcement and penalties for DUI. Surveys were conducted on Fridays and Saturdays between noon and midnight. Samples of oral fluid were collected for analysis of drugs, whereas alcohol was determined by breath testing or by analysis of oral fluid. Brazil and Norway had the same legal limit for alcohol of 0.2 g/L at the time of this study (2008–2009). Drivers were recruited for this study using stratified multi-stagecluster sampling procedures between August 2008 and September 2009 in Brazil and between April 2008 and March 2009 in Norway. In the first stage, geographical districts were chosen. In the second stage, random road sites and time intervals were selected. The third stage consisted of randomly stopping and interviewing drivers who were older than 18 years of age and consented to participate in the studies.

The sampling was divided into four time periods: 1: Friday12:00–17:59; 2: Friday 18:00–24:00; 3: Saturday 12:00–17:59; and 4: Saturday 18:00–24:00. Possible differences in substance use between the two countries were investigated with binomial logistic regression. Type of country was used as a covariate (with two categories: 0 = Brazil, 1 = Norway), and each substance or substance group was included as a dependent variable (also with two categories: 0 = negative, 1 = positive). In all statistical tests, the conventional critical 5% level was used to assess whether the obtained odds ratio (OR) significantly deviated from 1.

The refusal rates among those who were asked to participate in the study were 3% in Brazil and 6% in Norway. In total, 3,326 drivers were included in Brazil and 2,038 drivers in Norway. The most significant difference was observed for alcohol; only 0.2% of Norwegian drivers had BACs above 0.2 g/L, whereas 2.7% of Brazilian drivers had BACs above this limit. The median BAC was 0.41 g/L for Norwegian drivers and 0.42 g/L for Brazil drivers with BAC ≥0.2 g/L. Logistic regression analysis found significant differences between the two countries (OR = 0.09, 95% CI 0.03–0.27) when including gender, age group and time period as covariates in the statistical analysis. The low prevalence of drunk driving in Norway is probably related to the fact that Norway has had a strict DUI law since 1936 with strong enforcement and hard sentences for a long time period, whereas Brazil has only seriously attempted to modify this relationship in the last five years. Overall, it may take a generation or more for these changes and implementations to be expressed in a substantial reduction of figures in countries such as Brazil and other low and middle-income countries, which face the same reality.

In the context of drunk driving, it is relevant to distinguish between drivers who exceed the BAC limit only once, and those who do it repeatedly: the so-called recidivists. In a Danish study (M. Moller et al.), authors aimed at identifying the differences between non-drunk drivers, drunk driving non-recidivists and drunk driving recidivists with respect to their demographic and socio-economic characteristics, road accident involvement and other traffic and non-traffic-related law violations. This study presents a robust design by focusing on the entire population aged 18 or older in Denmark, while examining a 5-year period between 2008 and 2012 to measure recidivism. Persons were identified in the database of Statistics Denmark. In addition to demographic variables, for each person, the number of drunk driving offences and other violations of traffic laws or non-traffic laws for the years 2008–2012 were retrieved from the national crime database maintained by Statistics Denmark. Finally, the number of accidents involving injuries as the driver of a vehicle that requires a driver's licence in the years 2008–2012 and information on the BAC at the time of each accident was added.

Persons that were involved in only one drunk driving incident in the year 2008 were compared with those who were involved in at least one additional drunk driving incident within the study period, according to selected demographic and socioeconomic characteristics. The significance of the differences between recidivists and non-recidivists was tested via Chi-square tests and t-tests. A logistic regression model was estimated to examine the likelihood of becoming a recidivist within the study period 2008–2012 for persons involved in a drunk driving incident in 2008 on the basis of their socio-demographic characteristics in 2008, the year of the first offence. Finally, the analysis focused on accident involvement and other traffic and non-traffic law violations of persons with 0, 1, or more than 1 drunk driving incident(s) during the study period.

In each of the years included in this study, between 0.18% and 0.21% of the Danish population above 18 years of age was registered for drunk driving. Among persons who had (at least) one drunk driving incident in 2008, 17% were apprehended again within the study period: this can be regarded as the 5-year-prevalence for recidivism in Denmark. Recidivists differed significantly from people having only one drunk driving incident in most demographic categories. The vast majority (95%) of recidivists were male drivers. Recidivists were most likely to be between 30 and 50 years of age. Gender and age play a significant role in the reduction of the probability of becoming a recidivist, which is reduced by 57% for female drunk drivers, 41% for young drivers below 30 years old and 58% for drivers over 60 years old.

The differences identified with regard to socio-economic characteristics between persons with 0, 1, or more than 1 drunk driving incident(s) indicate that drunk driving recidivism is more likely to occur among people in situations involving socio- economic disadvantage, including living alone, low income and low education. In addition, recidivists are involved in more traffic, as well as non-traffic-related, law violations, which, together with their socio-economic characteristics, may suggest a marginalised life situation.

In recent years, a considerable number of papers have examined factors influencing the number and the outcome of traffic accidents. A Swedish study by Niclas A. Krüger used both regional panel data and national time series data combined with filtering techniques to determine what factors influence the number of accidents, the accident outcome and detected drunk driving.

A higher traffic density and other factors like stress may contribute to a higher risk of traffic fatalities during economic expansions. We use wavelets to cut up the data into variations across different and independent time scales. Scale 1 captures variation with a period of 2-4 years, scale 2 captures variation with a period of 4-8 years and scale 3 captures variation with a period of 8-16 years. GDP fluctuations are positively correlated with traffic fatalities per capita over all time scales. Traffic fatalities increase significantly during short-term economic shocks. Traveling more by car increases the risk of severe accidents. There is a comparably strong connection between mileage fluctuations and traffic fatalities per capita. A drop in unemployment by 1 percentage unit is associated with an increase of fatalities by 1 percent and serious injuries by 3 percent. The share of young people aged 18–30 years is correlated with higher traffic injuries, possibly reflecting inexperience and higher risk tolerance. Using panel data, we find that traffic fatalities decrease with unemployment, whereas personal injuries increase on a per capita basis with youth and the number of cars. There is some evidence that drunk driving mostly affects pedestrians and not car drivers and passengers. The results of the time series analysis suggest that factors other than increased mileage during booms affect the higher rate of fatalities during good times. Increased risk taking, such as drunk driving, might be an explanatory factor.

3.4 DETAILS OF RESULTS

Across all the coded studies, results have highlighted that driving under the influence of alcohol is linked with a higher chance of having a fatal crash.

Studies showed that driving performance is significantly impaired already during alcohol hangover. Hangover presents a significant increased risk of clinically important impaired driving. The magnitude of driving impairment during alcohol hangover is comparable to a BAC between 0.05 and 0.08 %, i.e., over the legal limit for driving in many countries. The data further show that the magnitude of driving impairment during hangover is impacted by total sleep time on the night after drinking.

A few studies investigated effects of combined use of alcohol and different drugs. Over the past two decades, the prevalence of THC and alcohol in car drivers involved in a fatal crash has increased. Studies showed that drivers positive for both alcohol and cannabis had greater odds of making an error than drivers positive for either alcohol or cannabis only. Further research is needed to better examine the interaction between cannabis concentration levels, alcohol and driving. A study from Sweden showed that the high median BAC in fatally injured drivers speaks strongly towards alcohol-induced impairment as being responsible for the crash. The legal drug alcohol topped the list of psychoactive substances identified in blood samples from fatally injured drivers. The victim's BAC exceeded Sweden's statutory alcohol limit for driving (0.2 g/L) in 21% of all fatalities, where the median BAC was more than 8 times higher (1.7 g/L). In 76% of these fatalities, the autopsy BAC was over 1.0 g/L, which gives convincing evidence that these drivers were impaired at the time of the crash. Alcohol and ecstasy mainly influenced automated driving performance (such as lateral and speed control). Equivalence testing showed that combined use might lead to impaired driving for some, but not all, drivers. It could lead to impairment that is equivalent to BAC 0.5% or even BAC 0.8% since the upper limit of 95% confidence interval associated with the mean SDLP (standard deviation of lateral position) change in the combined treatment clearly exceeded the pre-established margin of both alcohol levels. Participants in the study did tend to vary their speed more when treated with alcohol only as compared to the placebo, but only when driving on the rural road. SDSP decrease when under the influence of ecstasy only, which would be expected since ecstasy increases feelings of alertness and vigilance.

The difference in the prevalence of alcohol in different countries might be related to the fact that DUI laws enforcement and penalties vary between countries and have been implemented at different historical moments. In addition, the driver's knowledge and respect for the DUI laws vary. Differences for drugs may be related to different patterns in the use of stimulants, cannabis and medicines.

A study from Denmark aimed at identifying the differences between non-drunk drivers, drunk driving non-recidivists and drunk driving recidivists with respect to their demographic and socio-economic characteristic, road accident involvement and other traffic and non-traffic-related law violations. The results revealed a significant relation between recidivism and the drunk drivers' gender, age, income, education, receipt of an early retirement pension, household type, and residential area. Recidivists are found to have a higher involvement in alcohol-related road accidents, as well as other traffic and non-traffic related offences. Results indicated that drunk driving recidivism is more likely to occur among persons who are in situations of socio-economic disadvantage and marginalization.

In a study from the USA alcohol consumption to a BAC considered in most jurisdictions to be safe, when combined with sleep loss, increased EEG-defined sleepiness, impaired driving-simulator performance and reduced subjects' ability to detect impairment in driving performance and assess crash risk. Women appeared to be more perceptive of increased crash risk or more willing to admit to their driving limitations under partial sleep-deprivation conditions.

The number of traffic fatalities increases per person kilometre travelled during economic booms. Studies also showed that traffic fatalities decrease with unemployment, whereas personal injuries increase on a per capita basis with youth and the number of cars. There is some evidence that drunk driving mostly affects pedestrians and not car drivers and passengers. In contrast to property crimes, drunk driving decreases during economic contractions. It seems reasonable not to spend resources for measures uniformly across time and space, but to concentrate actions in areas with a high share of young people and periods with low unemployment.

Driving under the influence of alcohol is a factor that not only affects the probability of being involved in a traffic accident, but also the severity of injuries sustained consequently. Therefore, it is important to have reliable data that allow for the impact of initiatives intended to reduce this risky behaviour and that contribute, with valuable information, to design tailored campaigns for the most exposed groups, to be assessed.

3.5 REVIEW TYPE ANALYSIS

Table 3: Overview of results of coded studies

Author, Year, Country	Sample, method/design and analysis	Risk group/ Cases	Control group/ Controls	Research conditions/ control variables
Verster, J. C., Bervoets, A. C., de Klerk, S., Vreman, R. A., Berend O., Roth, T., Brookhuis, K. A. (2014) USA	Driving performance was tested the morning following an evening of consuming on average 10.2 (SD=4.2) alcoholic drinks (alcohol hangover) and on a control day (no alcohol consumed). Subjects performed a standardized 100-km highway-driving test in the STISIM driving simulator. In addition to the standard deviation of lateral position, lapses of attention were examined. Inclusion criteria: non-smoking social drinkers, aged 21-35 years, experienced with consuming more than 5 alcoholic drinks on a single occasion, driver's licence for at least 3 years and regular driver (>4,000 km/year).	Social drinkers, hangover; driving simulator + self-reporting (n = 42).		Self-reported driving quality and driving style were scored, as well as mental effort to perform the test, sleepiness before and after driving, and hangover severity.
Dubois, S., Mullen, N., Weaver, B., Bedard, M. (2015) USA	Drivers aged 20 years or older who had been tested for both drugs and alcohol after involvement in a fatal crash in the United States (1991–2008) were examined using a case–control design. Cases were drivers with at least one potentially unsafe driving action (UDA) recorded in relation to the crash controls had none recorded. The prevalence of driving under the influence of alcohol, cannabis, and both agents, for drivers involved in a fatal crash was examined. Adjusted odds ratios of committing an UDA for alcohol alone, THC alone, and their combined effect were computed via logistic regression and adjusted for a number of potential confounders. To control for high risk driving habits, we also included variables containing the drivers' past three-year driving records (crashes, recorded convictions for driving while impaired, speeding convictions, other harmful moving violation convictions, and license suspensions and revocations.	Drivers, positive on alcohol (n = 53,992).	Drivers positive on alcohol and THC (n = 4,347).	For inclusion in this study, drivers were required to have a valid blood alcohol content (FARS recorded range: 0 thru 0.94 BAC grams per decilitre) obtained by blood test. Further, all drivers had at least one confirmed blood drug test. Analyses were limited to drivers of passenger vehicles, sport-utility vehicles and light trucks (pickup trucks) only. Drivers aged less than 20 were excluded as they would not have had sufficient time to acquire a driving history.
Jongen, S., Vuurman, E., Ranaekers, J., Vermeeren, A. (2014) Netherlands	Volunteers (ages 18 – 30 years) participated in a double blind, four-way crossover study. Treatments were placebo and three different doses of alcohol leading to blood alcohol concentrations (BACs) of 0.2, 0.5, and 0.8 g/L. Inclusion criteria: social drinking, defined as drinking at least three but no more than 21 glasses of alcohol, per week; and a Body Mass Index (BMI) between 19 and 29 kg/m2. Exclusion criteria included pregnancy or lactation; any history of psychiatric or medical illness; history or current drug or alcohol abuse; current use of psychoactive medication; inability to stay abstinent during the study; excessive caffeine use, defined as drinking six or more cups of coffee per day; and habitual smoking, defined as smoking more than seven cigarettes a week.	n = 24 participants (12 men, 12 women); a high BAC (0.5 – 0.8 g/L).	n = 24 participants (12 men, 12 women); a low BAC (0.0 – 0.2 g/L).	The study was conducted according to a double blind, placebo-controlled, four- way crossover design. Volunteers participated in two treatment days during which two doses of alcohol were administered each day. Alcohol was administered orally. The alcohol-dosing regimen was developed to reach BACs of 0.0, 0.2, 0.5, and 0.8 g/L. To verify this, breath samples were obtained with an alcohol breathalyser. Tests were always administered according to the same order: i.e., Concept Shifting Test, Critical Tracking Test, Divided Attention Test, Psychomotor Vigilance Test, Digit Symbol Substitution Test, Digit Span Test, Attention Network Test, and Postural Balance Test.

Ahlner, J., Holmgren, A., Jones, A.W. (2014) Sweden	This retrospective 4-year study (2008–2011) used a forensic toxicology database (TOXBASE) to evaluate the concentrations of alcohol and other drugs in blood samples from drivers killed in road-traffic crashes.	Drivers, killed in road traffic crashes (n = 895); BAC above the statutory limit (0.2 g/L).	Drivers, killed in road traffic crashes (n = 895); no alcohol in blood.	The concentration of ethanol in blood was determined by a well-established method based on headspace gas chromatography (HS-GC). Aliquots of blood (0.1 mL) were diluted 1+10 with t-butanol (0.05 g/L) as an internal standard, transferred into glass vials (22 mL) and made airtight with a rubber stopper and a crimped-on aluminium cap. All determinations of ethanol were done in duplicate on two chromatographic systems and the mean concentration reported.
Møller, M., Haustein, S., Prato, C.G. (2015) Denmark	This study is based on register-data from Statistics Denmark and includes information from 2008 to 2012 for the entire population, aged 18 or older, of Denmark. For each person, the number of drunk driving offences and other violations of traffic laws or non-traffic laws for the years 2008–2012 were retrieved from the national crime database maintained by Statistics Denmark. Finally, the number of accidents involving injuries as the driver of a vehicle that requires a driver's licence in the years 2008–2012 and information on the BAC at the time of each accident was added from the national accident database that is maintained by the Road Directorate and constructed on the basis of police registered road accidents.	N = 4,260,306 1) Identify persons, involved in only one driving incident (in the year 2008). 2) Identify persons, involved in more than 1 drunk driving incident within the study period.	N = 4,260,306 Identification of persons without drunk driving incidents throughout the study period.	The present study aims at identifying differences between drunk driving recidivists and non-recidivists with respect to their demographic and socio-economic characteristics, road accident involvement, and other traffic and non-traffic-related law violations. This study presents a robust design by focusing on the entire population aged 18 or older in Denmark, while examining a 5-year period between 2008 and 2012 to measure recidivism.
Veldstra, J.L., Brookhuis, K.A., de Waard, D., Molmans, B.H.W., Verstraete, A.G., Skopp, G., Jantos, R. (2012) Netherlands	The study was conducted according to a double blind, placebo-controlled, four-way crossover design with treatment orders counterbalanced. Participants were presented with alcoholic drinks leading up to a BAC of 0.3% 0.5% or 0.8% and a placebo which looked and smelled like an alcoholic beverage but contained no alcohol.	n = 17 (9 males, 8 females) experienced drivers, who held their driving licence for at least 3 years. 0.3% <BAC> 0.8%	n = 17 (9 males, 8 females) experienced drivers, who held their driving licence for at least 3 years. BAC < 0.3%	The participants were instructed to abstain from alcohol in the 24 h prior to the experiment and to refrain from caffeinated beverages on the morning of the experiment. They were then tested during five separate testing days. Each test day started between 1 p.m. and 3 p.m. First day: questionnaire + training on simulator. Other 4 days: driving test under simulated BAC condition.
Banks, S., Catcheside, P., Lack, L., Grunstein, R.R., McEvory, R.D. (2004) Australia	Experimental study on effects of low BAC on driving when a driver is in a condition of partial sleep deprivation. Subjects were excluded if they had a sleep disorder (e.g., self-reported snoring or difficulty sleeping), if they were taking any forms of medication, and if they suffered motion sickness. The subjects were required to keep a detailed diary of their sleep habits and to wear an activity monitor, which measured their sleep-wake activity for 1 week prior to the experimental conditions. In the partial sleep-deprivation condition, subjects were restricted to 5 hours' time in bed on the night prior to testing.	n = 20 healthy volunteers (18 – 30 years old) Condition: partial sleep deprivation + alcohol (mean BAC was 0.035+/-0.015g/L).	n = 20 healthy volunteers (18 – 30 years old) Condition: partial sleep deprivation.	In order to assess the relationship between the perception scores and actual performance, the driving simulator and EEG were analysed in fifteen 4.5-minute bins. This study examined mean steering deviation, mean speed deviation, braking reaction time and mean number of driving- simulator crashes. The mean number of crashes was determined for each 4.5-minute bin.
Gjerde H., Sousa T.R., De Boni R., Christophersen A.S.,	Roadside surveys were conducted on Fridays and Saturdays between noon and midnight. Samples of oral fluid were collected for analysis of drugs, whereas alcohol was determined by breath testing or by analysis	n = 3,326 drivers in Brazil analysing 4 time periods	n = 2,038 drivers in Norway analysing 4 time periods	In the first stage, geographical districts were chosen. In the second stage, random road sites and time intervals were selected. The third stage consisted of

Limberger R.P., Zancanaro I., Oiestad E.L., Normann P.T., Morland J., Pechansky F. (2014) Brasil, Norway	of oral fluid. Drivers were recruited for this study using stratified multi-stage cluster sampling procedures between August 2008 and September2009 in Brazil and between April 2008 and March 2009 in Norway.	between August 2008 and September 2009.	between August 2008 and March 2009 (part of European DRUID Project).	randomly stopping and interviewing drivers who were older than 18 years of age and consented to participate in the studies. The sampling was divided into four time periods: 1: Friday12:00–17:59; 2: Friday 18:00–24:00; 3: Saturday 12:00–17:59; and 4: Saturday 18:00–24:00.
Krüger N.C. (2013) Sweden	This paper uses both regional panel data and national time series data combined with filtering techniques to determine what factors influence the number of accidents, the accident outcome and detected drunk driving. Panel data for Swedish regions: 1976 – 2007. Time series data can be examined in two basic ways, either by analysing how a variable changes over time or by analysing what frequencies the variable covers. Using panel analysis, which combines the informational content from time series and cross-sectional data, gives us the opportunity to more thoroughly examine the impact of socioeconomic factors on traffic fatalities.	Impact of unemployme nt on drunk driving.	Impact of GDP on traffic fatalities.	A higher traffic density and other factors like stress may contribute to a higher risk of traffic fatalities during economic expansions. We use wavelets to cut up the data into variations across different and independent time scales. Fluctuations in GDP and mileage around trend growth significantly affect road accident deaths. Still, the income effect on car usage is not enough to explain this relationship. In contrast, goods transported by road do not affect the death risk.

3.6 FULL LIST OF STUDIES

Table 4: Final list of coded studies, and reason to exclude studies that should have been coded

Authors	Title	Year	Country	Status	Reason of exclusion
Ahlner, J., Holmgren, A., Jones, A.W.	Prevalence of alcohol and other drugs and the concentrations in blood of drivers killed in road traffic crashes in Sweden	2014	Sweden	Coded	
Albalate, D.	Lowering Blood Alcohol Content Levels to Save Lives: The European Experience	2008	International	Not coded	Not a risk factor study
Anund, A., Antonson, H., Ihlstrom, J.	Stakeholders' Opinions on a Future In-Vehicle Alcohol Detection System for Prevention of Drunk Driving	2014	Sweden	Not coded	Not a risk factor study
Assum, T., Sorensen, M.	Safety Performance Indicator for alcohol in road accidents—International comparison, validity and data quality	2010	International	Not coded	Not relevant
Banks, S., Catcheside, P., Lack, L., Grunstein, R.R., McEvory, R.D.	Low Levels of Alcohol Impair Driving Simulator Performance and Reduce Perception of Crash Risk in Partially Sleep Deprived Subjects	2004	Australia	Coded	
Bjerre, B.	Primary and secondary prevention of drink driving by the use of alcolock device and program: Swedish experiences	2005	Sweden	Not coded	Not a risk factor study
Bjerre, B., Thorsson, U.	Is an alcohol ignition interlock programme a useful tool for changing the alcohol and driving habits of drink-drivers?	2008	Sweden	Not coded	Not a risk factor study
Castillo-Manzano, J.I., Castro-Nuno, M.	Driving licenses based on points system: Efficient road safety strategy or latest fashion in global transport policy?	2012	International	Coded	Not a risk factor study
Cestac, J., Kraiem, S., Assailly, J.-P.	Cultural values and random breath tests as moderators of the social influence on drunk driving in 15 countries	2016	International	Not coded	Not a risk factor study
Chang, K., Wu, C.-C., Ying, Y.-H.	The effectiveness of alcohol control policies on alcohol-related traffic fatalities in the United States	2012	USA	Not coded	Not a risk factor study
Dubois, S., Mullen, N., Weaver, B., Bedard, M.	The combined effects of alcohol and cannabis on driving: Impact on crash risks	2015	USA	Coded	
Elder, R.W., Shults, R.A., Sleet, D.A., Nichols, J.L., Thompson, R.S., Rajab, W.	Effectiveness of Mass Media Campaigns for Reducing Drinking and Driving and Alcohol-Involved Crashes A Systematic Review	2004	International	Not coded	Not a risk factor study
Erke, A., Goldenbeld, C., Vaa, T.	The effects of drink-driving checkpoints on crashes—A meta-analysis	2009	International	Not coded	Not a risk factor study
Freeman, D.G.	Drunk driving legislation and traffic fatalities: new evidence on BAC 08 laws	2007	USA	Not coded	Not a risk factor study
Gjerde, H., Sousa, T.R., De Bon,i R., Christophersen, A.S., Limberger, R.P.,	A comparison of alcohol and drug use by random motor vehicle drivers in Brazil and Norway	2014	Brazil, Norway	Coded	

Zancanaro, I., Oiestad, E.L., Normann, P.T., Morland, J., Pechansky, F.					
Glendon, A.I., Cernecca, L.	Young drivers responses to anti-speeding and anti-drink-driving messages	2003	Australia	Not coded	Not a risk factor study
Goss, C.W., Van Bramer, L.D., Gliner, J.A., Porter, T.R., Roberts, I.G., Diguiseppi, C.	Increased police patrols for preventing alcohol-impaired driving (Review)	2008	International	Not coded	Not a risk factor study
Hong, I.-K., Ryu, J.-B., Cho, J.-H., Lee, K.-H., Lee, W.-S.	Development of a driving simulator for virtual experience and training of drunk driving	2011	Korea	Not coded	Not relevant
Jia, K., Fleiter, J., King, M., Sheehan, M., Ma, W., Ali, J., Zhang, J.	Alcohol-related driving in China: Countermeasure implications of research conducted in two cities	2016	China	Not coded	Not a risk factor study
Jongen, S., Vuurman, E., Ranaekers, J., Vermeeren, A.	Alcohol calibration of tests measuring skills related to car driving	2014	Netherlands	Coded	
Krüger, N.C.	Fatal connections–socioeconomic determinants of road accident risk and drunk driving in Sweden	2013	Sweden	Coded	
Mathijssen, M.P.M.	Drink driving policy and road safety in the Netherlands: a retrospective analysis	2005	Netherlands	Not coded	Not a risk factor study
Meesmann, U., Martensen, H., Dupont, E.	Impact of alcohol checks and social norm on driving under the influence of alcohol (DUI)	2015	Belgium	Not coded	Not a risk factor study
Missoni, E., Božić, B., Missoni, I.	Alcohol-Related Road Traffic Accidents Before and After the Passing of the Road Traffic Safety Act in Croatia	2012	Croatia	Coded	Not a risk factor study
Møller, M., Haustein, S., Prato, C.G.	Profiling drunk driving recidivists in Denmark	2015	Denmark	Coded	
Phillips, R.O., Ulleberg, P., Vaa, T.	Meta-analysis of the effect of road safety campaigns on accidents	2011	International	Coded	Not a risk factor study
Rothschild, M.L., Mastin, B., Miller, T.W.	Reducing alcohol-impaired driving crashes through the use of social marketing	2006	USA	Not coded	Not a risk factor study
Trejo, A.C., Leenen, I.	If You Drink, Don't Drive: Drunk Drivers in Guadalajara and León, Mexico	2014	Mexico	Coded	Not a risk factor study
Veldstra, J.L., Brookhuis, K.A., de Waard, D., Molmans, B.H.W., Verstraete, A.G., Skopp, G., Jantos, R.	Effects of alcohol (BAC 0.5‰) and ecstasy (MDMA 100 mg) on simulated driving performance and traffic safety	2012	Netherlands	Coded	
Verster, J. C., Bervoets, A. C., de Klerk, S., Vreman, R.	Effects of alcohol hangover on simulated highway driving performance	2014	USA	Coded	

A., Berend O., Roth, T., Brookhuis, K. A.					
Willis, C., Lybrand, S., Bellamy, N.	Alcohol ignition interlock programmes for reducing drink driving recidivism (Review)	2009	Australia	Not coded	Not a risk factor study

Table 5: A list of studies that have not been coded due to lack of time

Authors	Title	Year
Alcaniz, M., Guillen, M., Santolino, M., Sanchez-Moscina, D., Llatje, O., Ramon, L.	Prevalence of alcohol-impaired drivers based on random breath tests in a roadside survey in Catalonia (Spain)	2014
Bogstrand, S. T., Larsson, M., Holtan, A., Staff, T., Vindenes, V., & Gjerde, H.	Associations between driving under the influence of alcohol or drugs, speeding and seatbelt use among fatally injured car drivers in Norway.	2015
Constant, A., Encrenaz, G., Zins, M., Lafont, S., Chiron, M., Lagarde, E., Messiah, A.	DRINK-DRIVING Why Drivers Start Drinking and Driving—A Prospective Study Over a 6-Year Period in the GAZEL Cohort	2011
Constant, A., Salmi, L.R., Lafont, S., Chiron, M., Lagarde, E.	The recent dramatic decline in road mortality in France: how drivers' attitudes towards road traffic safety changed between 2001 and 2004 in the GAZEL cohort	2008
Downey, L.A., King, R., Papafotiou, K., Swann, P., Ogden, E., Boorman, M., Stough, C.	The effects of cannabis and alcohol on simulated driving: Influences of dose and experience	2013
Eensoo, D., Paaver, M., Haao, M., Harro, J.	Predicting drunk driving: contribution of alcohol use and related problems, traffic behaviour, personality and platelet monoamine oxidase (MAO) activity	2005
Gjerde, H., Christophersen, A.S., Normann, P.T., Morland, J.	Associations between substance use among car and van drivers in Norway and fatal injury in road traffic accidents: A case-control study	2013
Horrey, W.J., Lesch, M.F., Mitsopoulos-Rubens, E., Lee, J.D.	Calibration of skill and judgment in driving: Development of a conceptual framework and the implications for road safety	2004
Horwood, L.J., Fergusson, D.M.	Drink driving and traffic accidents in young people	2000
Houwing, S., Twisk, D.	Nothing good ever happens after midnight: Observed exposure and alcohol use during weekend nights among young male drivers carrying passengers in a late licensing country	2015
Keall, M.D., Frith, W.J., Patterson, T.L.	The influence of alcohol, age and number of passengers on the night-time risk of driver fatal injury in New Zealand	2004
Mann, R.E., Stoduto, G., Vingilis, E., Asbridge, M., Wickens, C.M., Ialomiteanu, A., Sharoley, J., Smart, R.G.	Alcohol and driving factors in collision risk	2010
Rudin-Brown, C.M., Filtness, A.J., Allen, A.R., Mulvihill, C.M.	Performance of a cognitive, but not visual, secondary task interacts with alcohol-induced balance impairment in novice and experienced motorcycle riders	2012
Scott-Parker, B., Watson, B., King, M.J., Hyde, M.K.	"I drove after drinking alcohol" and other risky driving behaviours reported by young novice drivers	2014
Zhang, X., Zhao, X., Du, H., Ma, J., Rong, J.	Effect of different breath alcohol concentrations on driving performance in horizontal curves	2014

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Ahlner, J., Holmgren, A., Jones, A.W. (2014). Prevalence of alcohol and other drugs and the concentrations in blood of drivers killed in road traffic crashes in Sweden. Scandinavian Journal of Public Health, 42, 177-183.

Banks, S., Catcheside, P., Lack, L., Grunstein, R.R., McEvory, R.D. (2004). Low Levels of Alcohol Impair Driving Simulator Performance and Reduce Perception of Crash Risk in Partially Sleep Deprived Subjects. SLEEP, 27(6), 1063-7.

Dubois, S., Mullen, N., Weaver, B., Bedard, M. (2015). The combined effects of alcohol and cannabis on driving: Impact on crash risks. Forensic Science International, 248, 94–100.

Gjerde, H., Sousa, T.R., De Boni, R., Christophersen, A.S., Limberger, R.P., Zancanaro, I., Øiestad, E.L., Normann, P.T., Mørland, J., Pechansky, F. (2014). A comparison of alcohol and drug use by random motor vehicle drivers in Brazil and Norway. International Journal of Drug Policy, 25, 393–400.

Jongen, S., Vuurman, E., Ranaekers, J., Vermeeren, A. (2014). Alcohol calibration of tests measuring skills related to car driving. Psychopharmacology, 231(12), 2435–2447.

Krüger, N.C. (2013). Fatal connections–socioeconomic determinants of road accident risk and drunk driving in Sweden. Journal of Safety Research, 46, 59-65.

Moller, M., Haustein, S., Prato, C.G. (2015). Profiling drunk driving recidivists in Denmark. Accident Analysis and Prevention, 83, 125-131.

Veldstra, J.L., Brookhuis, K.A., de Waard, D., Molmans, B.H.W., Verstraete, A.G., Skopp, G., Jantos, R. (2012). Effects of alcohol (BAC 0.5‰) and ecstasy (MDMA 100 mg) on simulated driving performance and traffic safety. Psychopharmacology, 222, 377-390.

Verster, J. C., Bervoets, A. C., de Klerk, S., Vreman, R. A., Berend O., Roth, T., Brookhuis, K. A. (2014). Effects of alcohol hangover on simulated highway driving performance. Psychopharmacology, 231(15), 2999-3008.

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Anum, E.A., Silberg, J., Retchin, S.M. (2014). Heritability of DUI convictions: a twin study of driving under the influence of alcohol. Twin research and human genetic, 17(1), 10-5.

Assum, T., Sørensen, M. (2010). Safety Performance Indicator for alcohol in road accidents - International comparison, validity and quality. Accident Analysis and Prevention, 42, 595-603.

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De Winter, J.C.F, Dodou, D. (2010). The Driver Behaviour Questionnaire as a predictor of accidents: A meta-analysis. Journal of Safety Research, 41, 463-470.

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Klipp, S. (2009). EU DRUID project: results of a questionnaire survey amongst participants of driver rehabilitation programmes in Europe. European Conference of Transport Research Institutes (ECTRI), 1, 185-198.

Mattsson, M., O'Brien F., Lajunen, T., Gormley, M. (2015). Measurment invariance of the Driver Behavior Questionnaire across samples of young drivers from Finland and Irland. Accident Analysis and Prevention, 78, 185-200.

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Widmark, E.M.P. (1932). Die theoretischen Grundlagen und die praktische Verwendbarkeit der gerichtlich-medizinischen Alkoholbestimmung. Urban und Schwarzenberg, Berlin.

Driving Under the Influence: Legal and Illegal Drugs

Driving/riding a vehicle after taking medication or illegal drugs

Insert photograph in this frame and adjust to 16 x 16

SafetyCube

1 Summary

Leblud, J., August 2016

1.1 COLOUR CODE: RED

Legal and illegal drugs generally have a significant negative effect on crashes and driving performance. The crash risk is increased with most drug types. When combined with other drugs or alcohol, the effect on road safety is even worse than when taken alone.

1.2 KEYWORDS

Driving under influence, DUI, drugs, medicines, cannabis, cocaine, opioids, benzodiazepines, Z-drugs, medicinal opiate, tetrahydrocannabinol, cocaine, amphetamines

1.3 ABSTRACT

'Drugs' is a very common term which refers to countless numbers of substances. It can have positive or negative effects on efficiency, reflexes, concentration, sleeping etc. More specifically, substances having physiological effects on the human body and behaviour are defined as psychoactive drugs. In the context of road safety, they could be a major danger when driving a vehicle. In this synopsis the main types of drugs were assessed to determine their impact on road safety. Legal drugs studied were divided into benzodiazepine and medicinal opioids. Illegal drugs were divided into amphetamines, cocaine, opioids, and cannabinoids. The literature study firstly highlighted that driving under the influence of drugs is a well-studied subject, with hundreds of papers found. It also showed that the main legal and illegal drugs have a negative impact on road safety. They increase the crash risk, injury severity, fatal crash rate, but also the general ability to drive. When combined with alcohol or other drugs, their effects are even worse. Considering that more than 10% of fatal accidents could be linked to drug use, it is important to systematically monitor their use and increase the enforcement.

1.4 BACKGROUND

Definition of drugs and psychoactive drugs

A drug is defined as any substance other than food that causes a physiological change in the body (*Stedman's Medical Dictionary).* In pharmacology, some of these substances are referred to as medicinal drugs or medicines, and can be used to cure and/or to prevent disease but also to promote well-being. Historically, all drugs were extracted from medicinal plants. Nevertheless drugs can nowadays be synthesised chemically.

Psychoactive drugs are a type of drugs that can affect mood, perception or consciousness as a result of modification in the functioning of the nervous system (Northern Territory Government information and services, 2016).

Please also note that many drugs are legal and widely used. Nicotine for instance is a very addictive substance and caffeine is a stimulant used by 90% of North Americans on a daily basis: they are both drugs.

Division of psychoactive drugs that can affect road safety

Psychoactive substances, referred to as drugs in this document, can be divided into two classes: medicinal drugs that are allowed under specific circumstances, and that are sometimes associated with secondary effects; and illegal drugs that are substances (naturally extracted or synthesised) which are not allowed to be possessed, used or sold.
The reader is invited to see the box from Wolff (2013) to get a more systematic definition of the different types of drugs (see section 3).

Physiological effects of drugs

As previously said, the effects of psychoactive drugs are a change of emotional status, consciousness or awareness. These effects can be very dangerous on the road, when all the attention has to be focused on driving.

How are drugs measured?

In order to quantify the presence of all these drugs among (fatally injured) drivers, biological material is sampled from human bodies, which can be blood samples or urine. Different experimental devices are used to detect the presence of drugs, depending on the nature of the substance.

Primary screening can be done using immunological analyses, gas chromatography, liquid chromatography, or mass spectrometry (Mørland *et al.*, 2011). It can be then confirmed by more accurate and specific gas chromatography or liquid chromatography methods.

Which factors influence the effect of drugs on road safety?

Studies have demonstrated a relation between the effects of drugs on road safety and the age, gender and ethnicity. The combination of more than one drug acts often as a synergistic factor and increases the crash risk in most of the studies. Finally, when combined with alcohol, the crash risk is dramatically increased.

Unfortunately, there are very few studies that have compared road user types. To our best knowledge, very little is known on the effect of drug use on different types of vulnerable road user's crash risk.

Prevalence of drugs in accidents

According to a study by Mørland *et al.* (2011), 12% of drivers aged under 30 that were fatally injured in single vehicle accidents had drugs in their system (plus 14% that had both drugs and alcohol). The prevalence is of course highly dependent on the country and on the substance.

Main conclusion

Psychoactive drugs are known to have an important impact on human body and behaviour. In the case of road safety, they could play a major role by modifying the ability to drive for people that use them. It is important to keep in mind that these drugs are not all illegal, and that a substantial part of them are not perceived as a problem to use it and then drive. Nevertheless, it has been shown in this literature research that both legal and illegal drugs can have a dramatic impact on road safety.

The effects of driving under the influence of drugs seem well known in the literature. It is indeed a well investigated field, with hundreds of scientific articles that could suit to this synopsis. Across all the coded studies, results have highlighted that driving under the influence of drugs (both licit and illicit) are linked with a higher chance of a fatal crash. The effects vary between the types of drugs, but the increase is in general less than 100% increase. For illegal drugs, amphetamines and cannabinoids seem to be the most dangerous substance, while surprisingly cocaine did not significantly increase the risk of accident in most of the studies. For legal drugs, both benzodiazepines and medicinal opioids use can be linked to negative effects on road safety.

Nevertheless, the increased risk of having a crash when using drugs is not as important as using alcohol for instance. Moreover, some studies investigated the impact of the use of more than one drug at a time, and the use of drugs in combination with alcohol. The results are pretty straightforward: combination of drugs or drugs and alcohol gave even worse effects on road safety. Driving under the influence of legal and illegal drugs is thus unambiguously linked to negative effects on road safety, and should be targeted into more regular controls all over Europe.

2 Scientific Details

2.1 DEFINING THE RISK FACTORS ASSOCIATED TO DRUGS

Psychoactive drugs are a type of drugs that can affect mood, perception or consciousness as a result of modification in the functioning of the nervous system (Northern Territory Government information and services, 2016). These substances may thus have important effects on driving capacity/ behaviour, and thus on road safety.

These substances can be divided into (1) legal drugs, so called medicines and (2) illicit drugs. **Table 1** presents the main groups of drugs generally related to road safety.

Table 1: Main types of drugs usually analysed when dealing with roads safety and driving performance.

Type of drug	**Specific substance**
Drugged driving/riding, legal (medicine)	Benzodiazepines
	Z-drugs
	Medicinal opiate
	Others (antidepressants etc.)
Drugged driving/riding, illegal	Tetrahydrocannabinol (active substance of cannabis)
	Cocaine
	Amphetamines
	Illegal opiate
	Synthetic drugs

2.2 ANALYSIS

A recent meta-analysis has been performed on this topic (Elvik, 2013). It has been further developed in the working document written by Elvik (2015). This meta-analysis reviewed an important amount of papers (see Table 7). The results of this meta-analysis are used as part of the present results (see Results section below).

The original results of this meta-analysis are presented in **Table 2**.

Table 2: Summary estimates of relative risk of accident involvement associated with the use of various drugs. Based on meta-analysis from Elvik (2013).

Drug	Accident severity	Number of estimates	Best estimate of odds ratio	95% confidence interval	Best estimate adjusted for publication bias	95% confidence interval
Amphetamine	Fatal	8	5.61	(2.74,11.49)	5.17	(2.56,10.42)
	Injury	2	6.19	(3.46,11.06)	6.19	(3.46, 11.06)
	Property damage	1	8.67	(3.23,23.32)	8.67	(3.23, 23.32)
Analgesics	Injury	8	1.06	(0.92, 1.21)	1.02	(0.89, 1.16)
Anti-asthmatics	Injury	6	1.33	(1.09, 1.62)	1.31	(1.07, 1.59)
Anti-depressive	Injury	20	1.39	(1.17, 1.70)	1.35	(1.11, 1.65)
	Property damage	5	1.28	(0.90, 1.80)	1.28	(0.90, 1.80)
Anti-histamines	Injury	7	1;12	(1.02, 1.22)	1.12	(1.02, 1.22)
Benzodiazepines	Fatal	10	2.30	(1.59, 3.32)	2.30	(1.59, 3.32)
	Injury	51	1.65	(1.49, 1.82)	1.17	(1.08, 1.28)
	Property damage	4	1.35	(1.04, 1.76)	1.35	(1.04, 1.76)
Cannabis	Fatal	10	1.31	(0.91, 1.88)	1.26	(0.88, 1.81)
	Injury	15	1.26	(0.99, 1.60)	1.10	(0.88, 1.39)
	Property damage	17	1.48	(1.28, 1.72)	1.26	(1.10, 1.44)
Cocaine	Fatal	4	2.96	(1.18, 7.38)	2.96	(1.18, 7.38)
	Injury	3	1.66	(0.91, 3.02)	1.66	(0.91, 3.02)
	Property damage	4	1.44	(0.93, 2.23)	1.44	(0.93, 2.23)
Opiates	Fatal	7	2.13	(1.23, 3.72)	1.68	(1.01, 2.81)
	Injury	18	1.94	(1.51, 2.50)	1.91	(1.48, 2.45)
	Property damage	1	4.76	(2.10, 10.80)	4.76	(2.10, 10.80)
Penicillin	Injury	5	1.12	(0.91, 1.39)	1.12	(0.91, 1.39)
Zopiclone	Fatal	1	2.60	(0.89, 7.56)	2.60	(0.89, 7.56)
	Injury	4	1.42	(0.87, 2.31)	1.42	(0.87, 2.31)
	Property damage	1	4.00	(1.31, 12.21)	4.00	(1.31, 12.21)

2.3 RESULTS

Table 3: Published data on the incidence of drugs in injured drivers during in 2000-2012 (adapted from Drummer & al, 2012)

Locality	Sample size	Incidence of key drugs detected	Reference
Melbourne, Australia	436	Blood analysed. Benzodiazepines 15.6%, opioids 11%, THC 7.6%, cannabis metabolites 46.7%, amphetamines 4.1%, methadone 3%	Ch'ng *et al.* (2007)
Maryland, USA	108	Blood analysed. 65.7% positive to drugs; THC 26.9%, cocaine 10.2%, MA 5.6%, opioids 10.2%	Walsh *et al.* (2005)
France	900	Blood analysed. THC 10%, benzodiazepines 14%, morphine 2.7%, antidepressants 1.8%	Mura *et al.* (2003)
Sweden	144	Blood analysed. Illicit drugs 4.2% of which THC was 4.0%, impairing pharmaceuticals 12.5%	Ahlm *et al.* (2009)
Denmark	330	Used a combination of blood and/or saliva. THC 3.3%, benzodiazepines 3.0%, opioids 1.8%, amphetamines 1.5%	Bernhoft *et al.* (2005)
Tilburg region, The Netherlands	110	Urine and/or blood were analysed. Cannabis metabolites 12%, cocaine 9%, opioids 7%	Movig *et al.* (2004)
Modena, Italy	115	Urine was measured in crash-responsible drivers. Cannabis metabolite (19%), Benzodiazepines (9.6%), amphetamines (7.0%), cocaine metabolites (6.1%), opiates 3.5%, antidepressants 1.7%	Giovanardi *et al.* (2005)
Catalonia, Spain	360	Oral fluid analysed. Alcohol (11%), THC and/or metabolites (8.5%),cocaine (4.3%), ecstasy 90.5%), benzodiazepines (1.1%). 75% compliance rate and samples obtained up to 6 h post-crash	Santamarina-Rubio *et al.* (2009)
Verona, Italy	100	Urine analysed. Benzodiazepines (42%), cannabis metabolite (21%) and cocaine metabolite (14%).	Ricci (2008)
Tilburg, The Netherlands	106	Blood and urine analysed. Alcohol (0.05%) (23%), cannabis (12%), benzodiazepines (10%), cocaine (9%), amphetamines (7%), opiates (8%), anti-depressants (1%)	Smink *et al.* (2008)

Thirteen scientific articles were coded for this literature analysis. **Table 4** presents the main outcomes from the coded studies.

Table 4: Studies on drug driving analysed for this study.

Author, Year, Country	Risk factor	Study type	Outcome variable	Effects for Road Safety
Asbridge *et al.*, 2012, Canada	Influenced driving – Drugs - Cannabis	Systematic review	Collision risk	Negative effects on road safety
Bédard *et al.*, 2007, United States	Influenced driving – Drugs - Cannabis	Case-control study	Probability for the killed driver of having made an action that may have contributed to the crash	Significant negative effect on road safety
Bernhoft *et al.*, 2012, 9 European countries	Influenced driving – Drugs- Various drugs + combined usage	Meta-analysis	Risk of being killed Risk of getting seriously injured	The risk associated with benzoylecgonine that is not an active agent might be caused by sleep deprivation after cocaine consumption. The risk associated with THC seems to be similar to the risk when driving with a low alcohol concentration.
Elvik, 2013, Many countries	Influenced driving – Drugs – various drugs	Meta-analysis	Fatal crash, injuries, only property damage	See Table 2.
Gjerde *et al.*, 2011, Norway	Influenced driving – Drugs – Various drugs – Combined usage	Case-control study	Fatal crash	Combination of drugs significantly increase the fatal crash Amphetamine significantly increase the fatal crash
Gjerde *et al.*, 2013, Norway	Influenced driving - Drugs– Various drugs – Combined usage	Case-control study	Crash	Non-significant for Marijuana and zopiclone, but significant negative effect for benzodiazepine, amphetamine or combination of drugs
Gjerde *et al.*, *2015*, International	Influenced driving - Drugs– Various drugs – Combined usage	Case-control study	Crash risk	Negative effects on road safety
Kuypers *et al.*, 2012, Belgium	Influenced driving - Drugs– Various drugs – Combined usage	Case-control study	Crash risk	Significant negative effect except for : benzoylecgonine, cocaine and benzodiazepine
Laumon *et al.*, 2013, France	Influenced driving – Drugs – Cocaine and amphetamines	Case-control study	Driver responsibility in crash	Non-significant effect of cocaine and amphetamines on road safety
Romano *et al.*, *2011* United States	Influenced driving – Drugs- various drugs	Case-control study	Probability to be killed in accident	Significant negative effects of combination of drugs and amphetamines on road safety

Romano *et al.*, 2014, United States	Influenced driving – Drugs	Observational study	Fatal crash	Non-significant effect for Marijuana but significant negative effect for other drugs
Sewell *et al.*, 2009, United States	Influenced driving – Drugs - cannabis	Experimental study	Automatic action, action with conscious control, accident risk	Non-significant effect on task with conscious control, but significant effects on highly automatic driving functions Significant negative effects on accident risk
Veisten *et al.*, 2011	Influenced driving – Drugs	Systematic review	Cost benefit analyses: Net benefits, BC ratio	Most of the analyses show a significant positive effect on road safety

Crash risk

Most of the studies had an outcome related to **crash risk**. All the presented studies used "motor vehicles" as samples without further divisions. So very little is known about modification of the effects between different road users, professional drivers for instance, motorbike users, or vulnerable road users. Other grouping variables are used sometimes such as age, gender and even ethnicity. Interaction between drugs and these variables happened very often.

In order to get a clearer overview of the effects of each drug on road safety, each study was described in **Table 5**.

Table 5: Effects of each drug on road safety.

Reference	**Illegal Drugs**					**Legal**		**Combination**	
	Amphetamines	Benzoylegonin	Cocaine	Cannabinoids	Opiates (illicit	Benzodiazepines	Medicinal opioids - analgesics	Alcohol + drugs	Drugs + drugs
Asbridge *et al.* 2012				↗					
Bédard et al. 2007				↗					
Bernhoft et al. 2012	↗	↗	-	↗	-	↗	↗	↗	↗
Elvik 2013	↗		↗	-		↗	-		
Gjerde *et al.* 2013	↗			-		↗			↗
Gjerde *et al.* 2011	↗			-		-			↗
Gjerde et al 2015	↗			-		-			↗

Kuypers ***et al.*** **2012**	↗	-	-	↗	-	-	↗		↗
Laumon ***et al.*** **2005**	-		-						
Romano ***et al.*** **2014**				-					
Romano ***et al.*** **2011**	↗		-	-					↗
Sewell ***et al.*** **2009**				↗				↗	

Key: ↗ means increase in crash risk; - means no significant effect

Many types of drug seem to have a significant negative effect on road safety. We indeed saw that both legal and illegal drugs increased the crash risk and the crash severity.

- **Amphetamines** had a significant negative effect on road safety in almost all studies (Bernhoft et al, 2012; Elvik, 2013; Gjerde *et al.*, 2013; Kuypers *et al.*, 2012; Romano *et al.*, 2011)**.**
- **Cocaine and benzoylegonine** (its metabolite) also play a negative role in traffic accidents (Bernhoft et al., 2012; Elvik 2013).
- **Cannabinoids** gave quite inconsistent results. In all coded studies, half showed negative significant effects while the other half showed no significant effect (Table 5: Effects of each drug on road **safety.**).
- **Illicit Opiates** showed a not significant negative effect on road safety (Bernhoft *et al.,* 2012 and Kuypers *et al.,* 2012), but these drugs seem less studied than the others.
- Medicinal drugs, represented by **Benzodiazepines and Medicinal opioids,** both showed significant negative effects on road safety.
- When combined, the negative effects on road safety are even worse: it is indeed the case for **drugs combined with alcohol and a combination of drugs.**

The meta-analysis made by Elvik (2013) is in agreement with the present results. Zopiclone, studied in this meta-analysis (**Table 7**), which is part of the Z-drugs, has only showed significant negative effects on property damage, but not on fatal crashes.

Elvik (2013), estimated to a less than 100% increase of crash risk with the use of drugs. Nevertheless he warns about the fact that publication bias exist in this field.

Driving performance

A few studies investigated the effects of drugs on driving performance. It would be indeed difficult to drug people with illicit substances in order to perform simulator studies. Nevertheless some studies were found for cannabis. Bédard *et al.* (2007) showed that **cannabinoids** increased the risk for road users to make an error that lead to an accident. Another study performed by Sewel et al (2009) interestingly highlighted that cannabinoids were more affecting automated tasks rather than tasks with conscious control: cannabinoids act in the opposite way of alcohol.

Conclusion

This literature research analysis on driving under the influence of drugs highlighted that this is a well-documented topic. More than 80 studies in relation with this subject were found.

Many studies highlighted that the use of drugs can be associated with an increased crash risk and crash severity. Some drugs should be more investigated, for instance THC, because results are different between studies. Moreover cannabis is the most used drug substance, almost equalling the alcohol prevalence in some studies (Mørland *et al.*, 2011).

Most of the studies are linked to the crash risk or severity, but only a few ones investigated the driving performance. This can of course be explained by the difficulty to plan these kinds of experiments.

Nevertheless, very little is found about varying effects of drugs as a function of road users. Most of the studies investigate motor vehicle accidents, without further division. The effects of drugs on specific road users it thus, to our best knowledge, under investigated. It should be taken into account for further studies, specifically for vulnerable road users.

3 Supporting Documents

3.1 DEFINITION OF VARIOUS DRUGS

Controlled Drugs -This is a legal definition and refers to those drugs that are controlled under the 1971 Act. This regulates the import, export, possession, supply, and other aspects of activities relating to those drugs specified in the 1971 Act. The **Advisory Council on the Misuse of Drugs (ACMD)** was established under the 1971 Act and its role includes advising ministers on substances "*which appear to them likely to be misused and of which the misuse is having or appears to them capable of having effects sufficient to constitute a social problem*" and on measures which ought to be taken, for example to restrict the availability of such drugs or supervise the arrangements for their supply. **Psychoactive drugs** -This is the medical term for all those drugs which have an effect on the brain and central nervous system and alter behavior or cognition. This group includes freely available drugs (alcohol and tobacco) as well as illicit drugs (e.g. cannabis) and medicinal drugs (e.g. benzodiazepines). **Prescription only medicines** -This refers to those substances which, by virtue of an entry in the Prescription Only Medicines (Human Use) Order 1997, as amended, may be sold or supplied to the public only on a practitioner's prescription. The vast majority of controlled drugs are prescription only medicines (with the exception of those in Schedule 1 and, for the most part, 5 of the 2001 Regulations, the latter covering preparations containing small quantities of controlled drugs available as Pharmacy medicines) **Over-the-Counter (OTC) medicines** -This term refers to medicines that can be sold by a pharmacist but do not require a prescription by a medical practitioner. For the purposes of the Panel's work, this group of drugs is relevant as there are some medicines in this group which can contain small quantities of controlled medicines. **Illegal drugs -**This term refers to the circumstances under which a drug is possessed, so any controlled drug can be an illegal drug, including medicines such as benzodiazepines, f they have not been acquired via a valid prescription.

Box 1: From Wolff *et al.*, 2013

Molecules generally analysed to screen the use of drugs

Table 6: Main molecules usually quantified when looking for drugs in drivers (From Mørland *et al.*, 2011)

Group	**Specific substance**
Alcohol	Ethanol
Illicit drugs	Amphetamine Methamphetamine MDMA MDA THC Cocaine Benzoylecgonin

	6-Monoacetylmorphine Morphine GHB
Psychoactive medicinal drugs with warning label	*Benzodiazepines and related drugs* Diazepam N-Desmetyldiazepam Oxazepam Alprazolam Midazolam Flurazepam Nitrazepam 7-Aminonitrazepam Flunitrazepam 7-Aminoflunitrazepam Clonazepam 7-Aminoclonazepam Other benzodiazepines (bromazepam, estazolam) Zopiclone Zolpidem *Opiates/opioids* Codein Oxycodone Ethylmorphine Methadone Buprenorphine Tramadol Other opioids (dextropropoxyphen, ketobemidon) *Antiepileptics* Phenobarbital Other antiepileptics (carbamazepin, topiramate, phenytoin) Carisoprodol Meprobamate First generation anti-histamines (dexchlorpheneramineb, alimemazine, prometazine) Other (orphenadrine)
Psychoactive medicinal drugs without warning label	Antidepressants, tricyclic (chlomipramine, trimipramine, amitriptyline, nortriptyline, doxepine) Antidepressants, other (fluoxetine, citalopram, paroxetine, sertralineb, fluvoxamine, moclobemide, mianserine, mirtazapine, venlafaxine) Antipsychotics, (levomepromazine, per-phenazine, prochlorperazine, haloperidol, sertindole, ziprasidone, flupentixol, chlorprotixene, zuchlopen-tixole, clozapine, olanzapine, quetiapine, lithium, risperidone) Other (phentylpropanine, metoclopramide, ephedrine)
Non-psychoactive medicinal drugs	Paracetamol NSAIDS (ibuprophene, indomethacine) Anticoagulant drugs (warfarin) Antihypertensives (diltiazem) Other heart medicines Other (theophylline metronidazole, phenazone)

3.2 LITERATURE REVIEWED BY THE ELVIK 2013 META-ANALYSIS

Table 7: List of Articles used in Elvik (2013) meta-analysis.

Authors	Title	Year	Source
Smart au, R. G., & Fejér, D.	Drug use and driving risk among high school students.	1976	Accident Analysis & Prevention, 8(1), 33-38.
Skegg, D. C., Richards, S. M., & Doll, R.	Minor tranquillisers and road accidents.	1979	Br Med J, 1(6168), 917-919.
Honkanen, R., Ertama, L., Linnoila, M., Alha, A., Lukkari, I., Karlsson, M., ... & Puro, M.	Role of drugs in traffic accidents.	1980	BMJ, 281(6251), 1309-1312.
Jick, H., Hunter, J. R., Dinan, B. J., Madsen, S., & Stergachis, A.	Sedating drugs and automobile accidents leading to hospitalization.	1981	American journal of public health, 71(12), 1399-1400.
Terhune, K. W.	An evaluation of responsibility analysis for assessing alcohol and drug crash effects.	1983	Accident Analysis & Prevention, 15(3), 237-246.
Williams, A. F., Peat, M. A., Crouch, D. J., Wells, J. K., & Finkle, B. S.	Drugs in fatally injured young male drivers.	1985	Public Health Reports, 100(1), 19.
Oster, G., Russell, M. W., Huse, D. M., Adams, S. F., & Imbimbo, J.	Accident-and injury-related health-care utilization among benzodiazepine users and nonusers	1987	Journal of clinical psychiatry.
Oster, G., Huse, D. M., Adams, S. F., Imbimbo, J., & Russell, M. W.	Benzodiazepine tranquilizers and the risk of accidental injury.	1990	American journal of public health, 80(12), 1467-1470.
Ray, W. A., Fought, R. L., & Decker, M. D.	Psychoactive drugs and the risk of injurious motor vehicle crashes in elderly drivers.	1992	American journal of epidemiology, 136(7), 873-883.
Terhune, K. W., Ippolito, C. A., Hendricks, D. L., Michalovic, J. G., Bogema, S. C., Santinga, P., ... & Preusser, D. F.	The incidence and role of drugs in fatally injured drivers.	1992	Report DOT HS 808 065. U.S. Department of Transportation, National Highway Traffic Safety Administration, Washington, DC.
'Benzodiazepine/Driving', C. G.	Are benzodiazepines a risk factor for road accidents?	1993	Alcohol Dependence, 33(1), 19-22.
Leveille, S. G., Büchner, D. M., Koepsell, T. D., McCloskey, L. W., Wolf, M. E., & Wagner, E. H.	Psychoactive medications and injurious motor vehicle collisions involving older drivers.	1994	Epidemiology, 5(6), 591-598.
Currie, D., Hashemi, K., Fothergill, J., Findlay, A., Harris, A., & Hindmarch, I.	The use of anti-depressants and benzodiazepines in the perpetrators and victims of accidents.	1995	Occupational medicine, 45(6), 323-325.
Neutel, C. I.	Risk of traffic accident injury after a prescription for a benzodiazepine.	1995	Annals of epidemiology, 5(3), 239-244.

Hemmelgarn, B., Suissa, S., Huang, A., Jean-Francois, B., & Pinard, G.	Benzodiazepine use and the risk of motor vehicle crash in the elderly	1997	Jama, 278(1), 27-31.
Barbone, F., McMahon, A. D., Davey, P. G., Morris, A. D., Reid, I. C., McDevitt, D. G., & MacDonald, T. M.	Association of road-traffic accidents with benzodiazepine use.	1998	. The Lancet, 352(9137), 1331-1336.
Neutel, I.	Benzodiazepine-related traffic accidents in young and elderly drivers.	1998	Psychopharmacology: Clinical and Experimental, 13(S2), S115-S123.
Longo, M. C., Hunter, C. E., Lokan, R. J., White, J. M., & White, M. A.	The prevalence of alcohol, cannabinoids, benzodiazepines and stimulants amongst injured drivers and their role in driver culpability: Part I: the prevalence of drug use in drivers, and characteristics of the drug-positive group.	2000	Accident Analysis & Prevention, 32(5), 613-622.
McGwin, G., Sims, R. V., Pulley, L., & Roseman, J. M.	Relations among chronic medical conditions, medications, and automobile crashes in the elderly: a population-based case-control study.	2000	American Journal of Epidemiology, 152(5), 424-431.
Swann, P.	The real risk of being killed when driving whilst impaired by cannabis.	2000	International conference of alcohol, drugs and traffic safety.
Fergusson, D. M., & Horwood, L. J.	Cannabis use and traffic accidents in a birth cohort of young adults.	2001	Accident Analysis & Prevention, 33(6), 703-711.
Lowenstein, S. R., & Koziol-McLain, J.	Drugs and traffic crash responsibility: a study of injured motorists in Colorado.	2001	Journal of Trauma and Acute Care Surgery, 50(2), 313-320.
Chipman, M., Macdonald, S., & Mann, R. E.	Interactions between alcohol, cannabis and cocaine in risks of traffic violations and traffic crashes.	2002	In Proceedings International Council on Alcohol, Drugs and Traffic Safety Conference (Vol. 2002, pp. 59-64). International Council on Alcohol, Drugs and Traffic Safety.
Dussault, C., Brault, M., Bouchard, J., & Lemire, A. M.	The contribution of alcohol and other drugs among fatally injured drivers in Quebec: some preliminary results.	2002	Proceedings of 16th International Conference on Alcohol, Drugs and Traffic Safety, Montreal, pp. 423–430.
Gerberich, S. G., Sidney, S., Braun, B. L., Tekawa, I. S., Tolan, K. K., & Quesenberry, C. P.	Marijuana use and injury events resulting in hospitalization.	2003	Annals of epidemiology, 13(4), 230-237.
Mura, P., Kintz, P., Ludes, B., Gaulier, J. M., Marquet, P., Martin-Dupont, S., ... & Moulsma, M.	Comparison of the prevalence of alcohol, cannabis and other drugs between 900 injured drivers and 900 control subjects: results of a French collaborative study.	2003	Forensic science international, 133(1), 79-85.
Wadsworth, E. J., Moss, S. C., Simpson, S. A., & Smith, A. P.	Preliminary investigation of the association between psychotropic medication use and accidents, minor injuries and cognitive failures.	2003	Human Psychopharmacology: Clinical and Experimental, 18(7), 535-540.

Brault, M., Dussault, C., Bouchard, J., & Lemire, A. M.	The contribution of alcohol and other drugs among fatally injured drivers in Quebec: final results.	2004	In Proceedings of the 17th International Conference on Alcohol, Drugs and Traffic Safety.
Drummer, O. H., Gerostamoulos, J., Batziris, H., Chu, M., Caplehorn, J., Robertson, M. D., & Swann, P.	The involvement of drugs in drivers of motor vehicles killed in Australian road traffic crashes.	2004	Accident Analysis & Prevention, 36(2), 239-248.
Etminam, M., Hemmelgarn, B., Delaney, J.A.C., Suissa, S.	Use of lithium and the risk of injurious motor vehicle crash in elderly adults: case–control study nested within a cohort	2004	British Medical Journal 328, 558–559.
Movig, K.L.L., Mathijssen, M.P.M., Nagel, P.H.A., van Egmond, T., de Gier, J.J., Leufkens,H.G.M., Egberts, A.C.G.	Psychoactive substance use and the risk of motor vehicle accidents	2004	. Accident Analysis and Prevention 36, 631–636.
Macdonald, S., Mann, R.E., Chipman, M., Anglin-Bodrug, K	Collisions and traffic violations of alcohol, cannabis and cocaine abuse clients before and after treatment.	2004	Accident Analysis and Prevention 36, 795–800.
Assum, T.	The prevalence and relative risk of drink and drug driving in Norway	2005	Report 805. Institute of Transport Economics, Oslo.
Blows, S., Ivers, R.Q., Connor, J., Ameratunga, S., Woodward, M., Norton, R.	Marijuana use and car crash injury	2005	Addiction 100, 605–611.
Delaney, J.A.C., Opatrny, L., Suissa, S.	Warfarin use and the risk of motor vehicle crash in older drivers.	2005	British Journal of Clinical Pharmacology 61, 229–232.
French, D.D., Chirikos, T.N., Spehar, A., Campbell, R., Means, H., Bulat, T.	Effect of concomitant use of benzodiazepines and other drugs on the risk of injury in veteran's population.	2005	Drug Safety 28, 1141–1150.
Lam, L.T., Norton, R., Connor, J., Ameratunga, S.	Suicidal ideation, ant depressive medication and car crash injury	2005	Accident Analysis and Prevention 37,335–339.
Laumon, B., Gadegbeku, B., Martin, J.-L., Biecheler, M.-B.	Cannabis intoxication and fatal road crashes in France: population based case–control study	2005	British Medical Journal 331, 1371–1376.
Mathijssen, M.P.M., Houwing, S.	The risk of drink and drug driving – results of a case–control study conducted in the Netherlands.	2005	Proceedings of Drugs and Traffic: A Symposium, 22–35. Transportation Research Circular, E-circularE-C096, Transportation Research Board, Washington, DC.
Tamblyn, R., Abrahamowicz, M., du Berger, R., McLeod, P., Bartlett, G.,	A 5-year prospective assessment of the risk associated with individual benzodiazepines and doses in elderly users	2005	Journal of the American Geriatrics Society 53, 233–241.

Wadsworth, E.J.K., Moss, S.C., Simpson, S.A., Smith, A.P.	Psychotropic medication use and accidents, injuries and cognitive failures	2005	Human Psychopharmacology Clinical Experiments 20, 391–400.
Hemmelgarn, B., Lévesque, L.E., Suissa, S.	Anti-diabetic drug use and the risk of motor vehicle crash in the elderly	2006	Canadian Journal of Clinical Pharmacology13, 112–120.
Sagberg, F.	Driver health and crash involvement: a case–control study	2006	Accident Analysis and Prevention 38, 28–34.
Bramness, J.G., Skurtveit, S., Mørland, J., Engeland, A.	The risk of traffic accidents after prescriptions of car isoprodol.	2007	Accident Analysis and Prevention 39, 1050–1055.
Fergusson, D.M., Horwood, L.J., Boden, J.M.,	Is driving under the influence of cannabis becoming a greater risk to driver safety than drink driving? Findings from a longitudinal study	2008	Accident Analysis and Prevention 40, 1345–1350.
Gustavsen, I., Bramness, J.G., Skurtveit, S., Engeland, A., Neutel, I., Mørland, J.	Road traffic accident risk related to prescriptions of the hypnotics zopiclone, zolpidem, flunitrazepam and nitrazepam.	2008	Sleep Medicine 9, 818–822.
Hours, M., Fort, E., Charnay, P., Bernard, M., Martin, J.-L., Boisson, D., Sancho, P.-O., Laumon, B.	Diseases, consumption of medicines and responsibility for a road crash: a case–control study	2008	Accident Analysis and Prevention 40, 1789–1796.
Rapoport, M.J., Molnar, F., Rochon, P.A., Juurlink, D.N., Zagorski, B., Seitz, D., Morris,J.C., Redelmeier, D.A.	Psychotropic medications and motor vehicle collisions in patients with dementia	2008	Journal of the American Geriatrics Society 56, 1968–1970.
Vingilis, E., Wilk, P.	The effects of health status, distress, alcohol and medicinal drug use on subsequent motor vehicle injuries	2008	Accident Analysis and Prevention40, 1901–1907.Bachs, L.C.
Engeland, A., Mørland, J.G., Skurtveit, S.	The risk of motor vehicle accidents involving drivers with prescriptions for codeine or tramadol.	2009	Clinical Pharmacology and Therapeutics 85, 596–599.
Gibson, J.E., Hubbard, R.B., Smith, C.J.P., Tata, O.J., Britton, J.R., Fogarty, A.W.	Use of self-controlled analytical techniques to assess the association between use of prescription medications and the risk of motor vehicle crashes	2009	American Journal of Epidemiology 169, 761–768.
Majdzadeh, R., Feiz-Zadeh, A., Rajabpour, Z., Motevalian, A., Hosseini, M., Abdollah,M., Ghadirian, P.	Opium consumption and the risk of traffic injuries in regular users: a case-crossover study in an emergency department	2009	Traffic Injury Prevention 10, 325–329.
Richer, I., Bergeron, J.	Driving under the influence of cannabis: links with dangerous driving, psychological predictors, and accident involvement	2009	Accident Analysis and Prevention 41, 299–307.
Orriols, L., Philip, P., Moore, N., Gadegbeku, B.,	Benzodiazepine-like hypnotics and the associated risk of road traffic accidents	2011	Clinical Pharmacology and Therapeutics (advanced

Delorme, B., Mallaret, M., Lagarde, E.			online publication).
Pulido, J., Barrio, G., Lardelli, P., Bravo, M.J., Regidor, E., de la Fuente, L.	Association between cannabis and cocaine use, traffic injuries and use of protective devices	2010	European Journal of Public Health (e-publication November 10).
Yang, Y.-H., Lai, J.-N., Lee, C.-H., Wang, J.-D., Chen, P.-C.	Increased risk of hospitalization related to motor vehicle accidents among people taking Zolpidem: a case-crossover study	2011	. Journal of Epidemiology, 2010 (on-line publication October 23).
Orriols, L., Salmi, L.-R., Philip, P., Moore, N., Delorme, B., Castot, A., Lagarde, E.	The impact of medicinal drugs on traffic safety: a systematic review of epidemiological studies.	2009	Pharmacoepidemiology and Drug Safety 18, 647–658.

3.3 METHODOLOGY

Two scientific literature databases were investigated for this literature study: Science Direct and Google Scholar. Both were analysed between 12 and 14 April 2016. Some limitations/ exclusions have to be applied: only papers after the year 2000, only relevant countries, meta-analyses were preferred, simple experimental design were preferred, and we tried to have a mix of legal and illegal drugs. Table 8 and Table 9 present the results of the database research using different keywords.

Table 8: Results from the Science Direct database research

search no.	search terms / operators / combined queries	hits
#1	Drugs AND road safety	21.688
#2	Drugs AND crashes	8.014
#3	Drugs AND accident	43.602
#4	effects AND drugs AND Driving	212.912
#5	drug AND accident AND review	49.514
#6	Drug AND effect AND Road AND safety AND meta-analyses	2.579
#7	ABS-TITLE-KEY + #1	72

Table 9: Results from the Google Scholar database research

search no.	search terms / operators / combined queries	hits
#1	Drugs "road safety"	16300 first 5 results pages only
#2	drugs AND road AND accidents	21100 first 5 results pages only
#3	drugs AND risk AND "road safety"	15000 first 5 results pages only
#4	Drugs AND "road safety" AND meta-analysis	2860 10 pages screened
#5	Drugs AND "road safety" AND meta-analysis AND accident	2470 10 pages screened

From this first research, only relevant titles were selected, and the number of relevant studies is presented in Table 10.

Table 10: Results Literature Search: Papers which have relevant titles

Database	Hits
Science Direct (remaining papers after limitations/exclusions)	>100
Google Scholar (remaining papers after limitations/exclusions)	>200
Total number of studies to screen title/abstract	**>300**

Screening

Once the papers were selected, abstracts were read in order to see if the article was relevant. Papers duplicated were excluded, papers included in other meta-analyses were also excluded, and non-risk factors and non-relevant countries as well. The next table illustrates this process:

Total number of studies to abstract	314
-De-duplication	-115
-exclusion part of meta analyses	-30
-exclusion focus on other than risk factor	-43
-exclusion only relevant countries	-42
Remaining studies	80
Not clear (full-text is needed)	4
Studies to obtain full-texts	84

Eligibility

Finally, full texts of the remaining articles had to be obtained, and 50 of the 84 papers were ready for analyses.

Total number of studies to screen full-text	84
Full-text could be obtained	50
Reference list examined Y/N	N
Eligible papers	50

Prioritising Coding

The coding order was prioritised following the order below:

1. Meta-analysis.
2. Recent studies.
3. Clear experimental design.
4. Tried to mix legal and not legal drugs.
5. Tried to cover most types of drugs.

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Non-coded studies after analyses

Author, Year, Country	Risk factor	Reason not coded
Mura *et al.* 2006	Influenced driving - Drugs	Only speaking about Prevalence
Ahlm *et al.* 2008	Influenced driving - Drugs	Very descriptive, very small sample
Azofeifa *et al.* 2015	Influenced driving - Drugs	Only prevalence
Morlan *et al.* 2011	Influenced driving - Drugs	Prevalence study
Neavyn *et al.* 2014	Influenced driving - Drugs	Narrative review, no quantification
Kelly *et al.* 2004	Influenced driving - Drugs	Narrative review, no quantification
Orriolls *et al.* 2009	Influenced driving - Drugs	Narrative review, no quantification
Wolff *et al.* 2013	Influenced driving - Drugs	Huge report, very interesting but impossible to code

Speeding and Inappropriate Speed

Travelling above the speed limit or too fast for the conditions

1 Summary

Braun, E., Eichhorn, A., July 2016

1.1 COLOUR CODE: RED

Research shows that there is a very strong statistical relationship between speed and road safety. When speed increases, the number of accidents and the number of injured road users rises. When speed goes down, the number of accidents and the number of injured road users decreases.

1.2 KEY WORDS

Speeding, built-up areas, rural roads, motorways, inappropriate speed, driving too slowly, Power Model

1.3 ABSTRACT

Speed is a well-known risk factor. Studies documented a strong statistical relationship between speed and road safety. If the (mean) speed of traffic is reduced, the number of accidents and the severity of injuries decrease. The relationship between changes in speed and changes in road safety can be described by the Power Model – developed by Nilsson in 1981. Mainly case-control, cross-sectional and observational study designs are used for investigating the effect of speeding. Studies mainly compare speeders and non-speeders, drivers with and without crashes, or analyse accident outcomes regarding the proportion of speeders. However, studies on speeding often reveal several limitations like availability of a control group or completeness of data.

1.4 BACKGROUND

How are "speeding" and "inappropriate speed" defined?

In the case of speeding, two definitions are of importance. (1) Speeding is defined as exceeding the posted speed limit; (2) inappropriate speed means that the speed chosen does not fit to the surrounding conditions, e.g. it is raining and therefore, the road is slippery (ERSO[1]).

Both (1) and (2) are used in accident reports to describe the causality factor of an accident. Exceeding the speed limit can be defined easily, but it is often difficult to measure "inappropriate speed" as this would need analysis of surrounding conditions (e.g. slippery road and to small distance to car in front etc.).

What is the effect of speeding on road safety?

Speeding very often not only means endangering oneself, but also endangering passengers and other road users.
If travelling speed is higher, the collision speed also increases and this results in more severe injuries. If drivers drive at higher speeds, there is less time to process information and to react, the breaking

[1]http://ec.europa.eu/transport/wcm/road_safety/erso/knowledge/Content/20_speed/speed_choice_why_do_drivers_exceed_the_speed_limit_.htm

distance increases and it becomes more difficult for drivers to avoid a collision (Aarts, 2004; Aarts & Van Schagen, 2006; cited in SWOV Factsheet "Speed", 2012).

How frequent does speeding occur?

The better the coverage of speed enforcement, the more reliable the statements on the prevalence of speeding. Data on prevalence is influenced by density of enforcement, measuring methods and measure tolerances (regarding devices, enforcement).

"It is generally assumed that about one third of fatal crashes are (partly) caused by excessive or by inappropriate speed" (OECD/ECMT, 2006; cited in SWOV Factsheet "Speed", 2012, p. 1). It is difficult to obtain prevalence data to inappropriate speed, because not enough is known about the appropriate speed for specific conditions (ERSO).

Dingus et al. (2016) analysed crash risk factors by using naturalistic driving data. Results show that driving well above the speed limit or driving too fast for the conditions has a baseline prevalence of 2.77%[2]. The risk to be involved in a crash when speeding is 12.8 times higher than for non-speeders.

Which factors influence the effect of speeding on road safety?

In the case of speeding, several situational factors and driver characteristics play a decisive role. Relevant situational factors are road type, time of day, weather, number of lanes, road width, etc. but also enforcement, driving comfort, engine power, and presence of car passengers. Important driver characteristics are sex and age, but also sensation seeking, attitudes and intention to (traffic) violations (e.g. SWOV Factsheet, 2012; ERSO; Goldenbeld and Mesken, 2012; Stradling and Parker, 1996; Haglund and Aberg, 2000, Evers and Ewert, 2004, Yannis et al. 2004, Praschl, 2000; see table in supporting document). Additionally, weather conditions, road surface and failures in perception and estimation are especially important regarding inappropriate speed (e.g. SWOV Factsheet speed choice, 2012; ERSO).

"The injury severity of the vehicle occupants in a crash, for example, is not only determined by the collision speed, but also by the mass difference between the vehicles and by the vulnerability of the vehicles/road users who are involved. In a crash between a light vehicle and a heavier one, the occupants of the lighter vehicle generally are considerably worse off than the occupants of the heavier vehicle. Even more so this is the case for pedestrians, cyclists, and moped riders in crashes with (much) heavier motor vehicles." (SWOV Factsheet "Speed", 2012, p.1).

How is the effect of speeding on road safety measured?

Generally, the following safety performance indicators are used for research on speeding:

- Mean speed on a defined road section.
- Speed of 85% of all drivers on a defined section (v85).
- Percent speed limit offenders by road type, by vehicle type, by period of time.
- Self-reported speeding (driving above the speed limit).

The main approaches to study the relationship between speeding and crash risk are case control studies, cross sectional studies and observational studies. Research on speeding was mostly conducted in Europe, Australia and in the USA. Most of the research is on private drivers, few studies are on commercial drivers. The studies show a significant relationship between speeding and crash risk.

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[2] „The baseline prevalence of a factor represents the percentage of time the factor was present during normal driving condition" (Dingus et al., 2016, p. 4).

1.5 OVERVIEW OF RESULTS

Speed is a key risk factor when dealing with traffic safety. Research shows that accident risk increases when speed increases.

Studies on the risk factor “speed” go back to the late sixties. Case control studies, cross sectional studies and observational studies were used to investigate the effect of speeding on road safety. Mostly driving above the speed limit is covered, just a few studies additionally investigated inappropriate speed.

Frequent biases relating to study designs and study implementations are 1) missing availability of a control group of non-speeders, 2) restrictions of data sources, 3) further missing information on data and data exploitation, 4) exclusion of datasets and 5) no detailed information on speeding resp. inappropriate speed.

2 Scientific Details

2.1 THEORETICAL BACKGROUND

For the relationship between speed and crash risk, a theoretical model is available. In order to define the relationship between speed and crash risk, Nilsson (1982, validated in 2004) developed the Power Model. This function shows that the crash rate increases more rapidly when the speed increases.

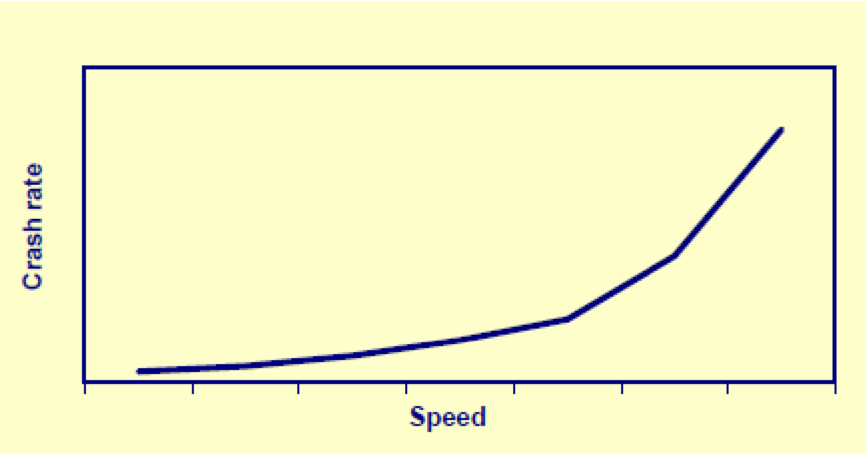


Figure 1: Relation between speed and crash rate (SWOV Fact sheet speed, 2012, p. 3)

"The Power Model suggests that the number of fatal accidents, serious injury accidents (including fatal accidents), and all police reported injury accidents (including fatal and serious injury accidents) change in proportion to, respectively, the fourth, third and second power of the relative change in the mean speed of traffic" (Elvik, Christensen & Amundsen 2004, p.5). However, the relationship between speed and crash risk can be described in other theoretical functions as well. Elvik's analysis found exponential functions that fitted "the data extremely well and imply that the effect on accidents of a given relative change in speed is largest when initial speed is highest" (Elvik 2013, p. 854). Nevertheless, the Power Model is especially simple, easily applicable and widely recognized.

2.2 METHODOLOGY

Literature search was carried out in two databases (Scopus and a KFV-internal literature database) with separate search strategies (for a detailed description see "Supporting documents").

Description of studies

The following table gives an overview on study samples and design of the coded studies on speeding and inappropriate speed.

Table 1: Information on sample and design of coded studies (sorted by year of publication, meta-analysis first)

Author(s), year, country	Sample, method/design and analysis	Risk group/ cases	Control group/ controls	Research conditions
Elvik, 2004, Norway	Studies from 20 countries; 1966-2004, case-control studies, vote and count analysis regarding the effect of speed, meta-analysis of Power Model	Drivers with crash events	Drivers without crash events	Vote and count regarding effect of speed; evaluation of the Power Model (Nilsson)
Dingus et al., 2016, USA	Naturalistic driving data, case-control study (3 year period) Odds ratios	N= 905 Drivers with crash events	N= 3,500 Drivers (alert attentive sober driving episodes in same length as crash exposure)	SHRP 2 NDS database
Watson et al., 2015 Australia	Crash and offence data, observational study Chi-square and Logistic regression analysis	Profiling speeders N=84,456	-	Traffic offence data from 1996 to 2007, Queensland road crash data base & police service data
Elvik, 2013 Norway	Relative change in speed; initial speed, cross sectional study Accident modification factor	Initial speed	Final speed	526 estimates of relation-ship between changes in speed and changes in road safety. Re-analysis of the Power Model
Viallon et al., 2013 France	Speed data, crash data Time series study Group comparisons	Speeders	Non-speeders	Data for speed distributions and numbers of fatal crashes over the 2001-2010 period
Peng et al., 2012, USA	Crash data, case-control study Logistic Modelling; Chi Square	Speeders	Non-speeders	1,528 single vehicle ROR Crashes of trucks; PDO, injury and fatal accidents Period 2006-2009
Siskind et al., 2011, Australia	Crash data, case-control study Contingency table methods and multiple logistic regression analysis; calculation of risk ratios	Fatal crash victims	Non-fatal crash victims	Period 2004-2007; Exceeding the speed limit or not
Elvik, 2008, Norway	Speeding data, crash data, case-control study Risk estimation	Speeders	Non-speeders	Fatal, severe and minor injuries
Vorko-Jović et al., 2005, Croatia	Accident data linked to hospital and police data, local observational study, simple and bivariate analysis, odds ratio	Speeders	-	Fatal, severe and mild injuries
Kloeden et al., 2002, Australia	speed and crash data, case-control study Logistic regression modelling	At free speed travelling verhicles involved in a crash	At free speed travelling vehicles not involved in a crash	Re-analysis of 1997 data
Rajalin, 1994 a/b, Finland	Number of speeding offences, fatal crashes and roadside stops Case-Control study, odds ratio	Speeders	Non speeders	Connection between risky driving and fatal crashes

Author(s), year, country	Sample, method/design and analysis	Risk group/ cases	Control group/ controls	Research conditions
West et al., 1993, UK	Observational data, observational study Correlation; Multiple logistic regression; Slope development	Speeders		Study on a standardized 70 miles trip – motorway, rural and urban roads Accident involvement
Nilsson, 1982, Sweden	Crash data from road sections Cross sectional study No remark on statistical analysis	Speed limit reduced	Speed limit not reduced	Fatal and severe accidents 1978-1979

Description of the main research methods

There are three main approaches for investigating crash risk regarding the risk factor speeding. Mostly, case control studies, cross sectional studies and observational studies are used to investigate the effects of speeding. Most coded studies have a focus on speeding over the limit, only three studies covered inappropriate speed as well (Dingus et al., 2016; Siskind et al., 2011, Peng and Boyle, 2012). Elvik (2013) included relative change in speed and e.g. Kloeden et al. (2002) driving at or below the posted speed limit. Mainly police crash data, but also self-reported crashes have been used to investigate speeding and inappropriate speed. One study used observed crashes from naturalistic driving data (Dingus et al., 2016).

Most research is on private car drivers, only two coded studies included crashes of trucks (Peng and Boyle, 2012; Watson, 2015). Effects on road safety, especially for PTW, were reported by Watson et al. (2015). In several studies a distinction on vehicle types regarding speeding was not made. Generally, speeding on rural roads is more often covered by analysis than on other road types.

Overview results

The following tables present information on the main outcomes of all coded studies. By carrying out a meta-analysis in order to verify the Power Model, Elvik et al. (2004) investigated 98 studies from 20 countries with a time-frame from 1966 to 2004, with studies after 1990 standing for 50% of the evidence (list of studies in supporting document).

Table 2: Summary of vote and count analysis' results (Elvik, 2004)

Author(s), Year, Country	Exposure variable	Dependant / outcome type	Effects on Road Safety		Main outcome - Description
Elvik, 2004, Norway	Speed decreased	Relative proportion of fatal, severe and minor injuries	↘	RP=0,95	95% of all studies, that had a downwards change in speed, had a reduction in accidents or accident victims number.
	Speed increased	Relative proportion of fatal, severe and minor injuries	–	RP=0,295	29.5% of all studies, that had an upwards change in speed, had a reduction in accidents or accident victims number.
	Speed decreased	Relative proportion of fatal, severe and minor injuries	–	RP=0,05	5% of all studies, that had a downwards change in speed, had an increase in accidents or accident victims number.
	Speed increased	Relative proportion of fatal, severe and minor injuries	↗	RP=0,705	70.5% of all studies, that had an upwards change in speed, had an increase in accidents or accident victims number.

A vote and count analysis shows that 95% of all included studies, that had a downwards change in speed, had a reduction in accidents or accident victims number as well. 70.5% of all studies that had an upwards change in speed showed an increase in accidents or accident victims number (Table 2). Additionally, Elvik et al. (2004) confirmed that the Power Model is appropriate to show the strong statistical relationship between speed and road safety.

More recent studies showed that it makes a difference if speeding takes place on rural roads or urban roads. The effect of a relative increase or decrease of speed on rural roads is larger than the effect on urban roads (Elvik, 2009). A re-analysis of the Power Model (Elvik, 2013) indicated that the relationship between speed and road safety does not only depend on relative change in speed, but also on initial speed. That is, a 25% speed change from 20 km/h to 15 km/h will have lower effects than the same reduction from 100 km/h to 75 kmh.

Additionally, Elvik's analysis found exponential functions that fitted "the data extremely well and imply that the effect on accidents of a given relative change in speed is largest when initial speed is highest" (Elvik 2013, p. 854).

Additional studies on speeding and inappropriate speed

Additionally considered studies were quite different in design and methods, and many studies had at least minor limitations, so it was not feasible to give a summarized analysis in terms of vote and count results. However, most of the studies not included in Elvik (2004) showed a significant relationship between speeding and crash risk, as well (Table 3).

Table 3: Summary of coded study results regarding speeding (driving over limit; sorted by date of publication)

Author(s), Year, Country	Exposure variable	Dependant / outcome type	Effects on Road Safety		Main outcome - Description
Dingus et al., 2016, USA	Speeding over limit and too fast for conditions	Observed crashes	↗	OR=12.8, CI=95%: 10.1-16.2	Risk to be involved in a crash when speeding is 12.8 times higher
	Speeding unsafe in work zone	Observed crashes	↗	OR=14.2, CI=95%: 3.9-52.0	Risk to be involved in a crash when speeding in work zones is 14.2 times higher
Watson et al., 2015, Australia	Repeat high range speeding offenders	Previous crash involvement	↗	OR=3.85; p=0.0010; CL 99%; CI 2.52-5.88	Repeat high range speeding offenders have a 3.85 higher probability to have a previous crash involvement than low range offenders.
			↗	OR=1.83; p=0.0010; CL 99%; CI 1.54-1,93	Repeat high range speeding offenders have a 1.83 higher probability to have a previous crash involvement than other offenders.
Elvik, 2013, Norway	Initial speed lowered from 95 km/h to 85 km/h	Number of accidents	↘	AMF=0,697	30% less accidents if initial driving speed is reduced from 95km/h to 85km/h
	Initial speed lowered from 45 km/h to 35 km/h	Number of accidents	↘	AMF=0,578	42% less accidents if initial driving speed is reduced from 45km/h to 35km/h
Viallon et al., 2013, France	Speeding <10 km/h over limit	Fatal crashes in 2001 and 2010	↗	Relative proportion 2001= 0,07 Relative proportion 2010= 0,13	Fatal crashes due to low level speeding increased from 7% in 2001 to 13% in 2010 (in the same time number of low level speeding offences decreased from 23% to 18%).

Author(s), Year, Country	Exposure variable	Dependant / outcome type	Effects on Road Safety		Main outcome - Description
	Speeding 10-20 km/h over limit	Fatal crashes in 2001 and 2010	↘	Relative proportion in 2001 = 0.13 Relative proportion in 2010 = 0.09	Fatal crashes due to speeding with 10 to 20 km/h decreased from 13% in 2001 to 9% in 2010 (in same time medium level speeding offences decreased from 18% to 5%).
	Speeding >20 km/h over limit	Fatal crashes in 2001 and 2010	↘	Relative proportion in 2001 = 0.25 Relative proportion in 2010 = 0.06	Fatal crashes due to speeding over 20 km/h decreased from 25% in 2001 to 6% in 2010 (in same time high-range level speeding offences decreased from 14% to 2%).
Peng et al., 2012, USA	Speeding of trucks	Single vehicle ROR crashes; injury and fatal accidents	↗	OR =3.89; p<0.0001; CI 95%, CI 2.67-5.66	Trucks speeding have a 3.89 times higher risk to have an injury or fatal ROR crash
	Trucks driving with a speed over posted speed of 50 mph	Single vehicle ROR crashes; PDO accidents	↗	Relative proportion= 0.3626	36% of ROR drivers had a PDO due to own speeding (posted speed ≥50 mph).
		Single vehicle ROR crashes; injury and fatal accidents	↗	Relative proportion= 0.7256	72.56% of ROR drivers had an injury/fatal accident due to own speeding (posted speed ≥50 mph).
Siskind et al., 2011, Australia	Speeding at having a limit 70-90 km/h	Fatal crashes	–	OR=2.0; p=0.09; CI 95%, CI 0.9-4,44	Drivers speeding over a limit of 70-90 km/h have a 2 times higher risk to be involved in a fatal crash.
	Speeding at having a limit 100-110 km/h	Fatal crashes	↗	OR=3.53; p=0.001; CI 95%, CI 1.73-7.22	Drivers speeding over a limit of 100-110 km/h have a 3.53 times higher risk to be involved in a fatal crash.
Elvik, 2008, Norway	Speeding over limit 80 km/h vs. no speeding	Number of fatal injuries	↘	AMF=0.781, CI=95%:	The elimination of speeding results in a reduction of mean speed of travel from 78.5 to 74.3 km/h; fatalities could be reduced by about 22% (estimated by applying the Power model; exponent 4.5)
	Speeding over limit 80 km/h vs. no speeding	Number of severe injuries	↘	AMF=0.848, CI=95%:	The elimination of speeding results in a reduction of mean speed of travel from 78.5 to 74.3 km/h; severe injuries could be reduced by about 15% (estimated by applying the Power model; exponent 3.0)
	Speeding over limit 80 km/h vs. no speeding	Number of minor injuries	↘	AMF=0,921, CI=95%:	The elimination of speeding results in a reduction of mean speed of travel from 78.5 to 74.3 km/h; minor injuries could be reduced by about 8% (estimated by applying the Power model; exponent 1.5)
Vorko-Jović et al., 2005, Croatia	speeders	Fatal injury	↗	OR=2.56, p=0.0012, CI95%, CI 1.43-4.61	Fatal outcomes are 2.56 times more frequent than non-fatal (reference group is a speeders group as well)
Kloeden et al., 2002, Australia	Free travelling speed at 50 km/h (compared to 60 km/h set as 1)	Relative risk	↘	RR=0.39, CI=95%; CI=0,26-0,54	Relative risk at a travelling speed of 50 km/h is 0.39 lower than at 60 km/h
	Free travelling speed at 70 km/h (compared to 60 km/h set as 1)	Relative crash risk	↗	RR=3.57 CI=95%; CI=2.7-5.28	Relative risk at a travelling speed of 70 km/h is 3.57 higher than at 60 km/h

Author(s), Year, Country	Exposure variable	Dependant / outcome type	Effects on Road Safety		Main outcome - Description
Rajalin, 1994 a, Finnland	Number of speeding offences	Fatal accidents	↗	OR=1.84; p<0.0001; CI 95%, CI 1.48-2.29	Drivers with speeding offences have a 1.84 times higher risk to be involved in a fatal accident compared to randomly selected control group.
Rajalin, 1994 b, Finnland	High risk driver stopped by police for risky driving	Number of speeding offences	↗	OR=3,53; CI 95%, CI 2,67-4,74	High risk drivers have significantly (3.53 times) more speeding offences than the control group.
West et al., 1993, UK	Reported prior accident involvement	Observed preferred speed of motorway	↗	Slope, B (logistic regression)=0.44; p=0.018	Observed preferred speed is a significant and independent predictor for accident involvement.
		Observed maximum speed	–	Slope, B (logistic regression)=-0.19; p>0.05	Observed maximum speed is no significant predictor for accident involvement.
Nilsson, 1982, Sweden	Decrease of speed limit from 110 to 90 km/h	Fatal accidents	↘	Percent accident reduction = 0.52	Reducing the speed limit from 110 to 90 km/h showed a 52% reduction of fatal accidents.
	Decrease of speed limit from 110 to 90 km/h	Single accidents	–	Percent accident reduction = 0.2	Reducing the speed limit from 110 to 90 km/h showed a 20% reduction of single accidents

*Significant effects on road safety are coded as: positive (↘), negative (↗) or non-significant (–)

Table 4 deals with research results regarding inappropriate speed. There aren't any coded studies focusing on inappropriate speed exclusively, but three studies covered inappropriate speed besides driving over the speed limit.

Table 4: Study results regarding inappropriate speed

Author(s), Year, Country	Exposure variable	Dependant / outcome type	Effects on Road Safety		Main outcome - Description
Dingus et al., 2016, USA	Speeding over limit and too fast for conditions	Observed crashes	↗	OR=12.8, CI=95%: 10.1-16.2	Risk to be involved in a crash when speeding is 12.8 times higher
	Driving too slowly	Observed crashes	↗	OR=2.3, CI=95%: 1.1-4.8	Risk to be involved in a crash when driving too slowly is 2.3 times higher
Peng et al., 2012, USA	Speeding of trucks (exceeding posted speed or exceeding safe speed for the condition)	Single vehicle ROR crashes; PDO accidents	↗	Relative proportion 0.194	19.4% of ROR drivers had a PDO due to own speeding
		Single vehicle ROR crashes, injury and fatal accidents	↗	Relative proportion 0.36	36% of ROR drivers had a injury/fatal accident due to own speeding
Siskind et al., 2011, Australia	Speeding (too fast for prevailing conditions)	Fatal crashes	↗	Relative proportion 0.187	18.7% of all fatal units were related to speeding
			↗	RR=2,39; p=0,001; CI 95%, CI 1,61-3,55	Relative risk of speeding to have a fatal crash is 2.39

Author(s), Year, Country	Exposure variable	Dependant / outcome type	Effects on Road Safety		Main outcome - Description
	Speeding (too fast for prevailing condition)	Non fatal crashes	–	Relative proportion 0.066; not sign.	6.6% of all non-fatal units were related to speeding

*Significant effects on road safety are coded as: reduced risk (↘), increased risk (↗) or non-significant (–)

In order to provide a better overview, summarized results are presented by road type, subsequently.

Built-up areas

Three coded studies (Elvik, 2013, Kloeden et al., 2002 and Vorko-Jovic et al., 2005) covered speeding on urban roads. Elvik concentrated on speed change and indicated that there are 42% less accidents if initial speed is reduced from 45km/h to 35km/h. Kloeden et al.'s analysis compared the crash risk of different levels of free travelling speed in a built up area with those of 60 km/h limits. Results show that the relative crash risk at a travelling speed of 50 km/h is 0.39 times lower than at 60 km/h and at a free travelling speed of 70 km/h it is 3.57 times higher than at 60 km/h. Vorko-Jovic at al. carried out an observational study on speeders in Zagreb (Croatia). Findings indicate that fatal outcomes were 2.56 times more frequent for speeders than non-fatal outcomes.

Rural roads

Siskind et al. (2011) show for rural roads in Australia that drivers speeding over a limit of 70-90 km/h had a 2 times higher risk to be involved in a fatal crash. Elvik (2013) reports on changes due to the reduction of travel speed in Norway e.g. the reduction from 95 to 85 km/h led to a 30% reduction in number of accidents.

Viallon and Laumon (2013) explored the prevalence of different over the limit speeding levels and crashes in France during 2001 to 2010. It could be observed that the prevalence of non-speeders increased from 2001 to 2010 (44.6% in 2001 to 75% in 2010). Regarding the number of crashes, they indicated that e.g. fatal crashes due to speeding with 10 to 20 km/h over the limit decreased from 13% to 9%; fatal crashes due to speeding more than 20 km/h over limit decreased from 25% to 6%. Looking at high risk driving on rural roads and speeding offences, Rajalin et al. (1994b) found that high risk drivers (stopped by the police because of speeding) had significantly (3.53 times) more speeding offences than the control group.

Motorways

Four studies included motorways, besides rural roads. Nilsson (1982) found that a downwards change in speed reducing the speed limit from 110 to 90 km/h showed a 52% reduction of fatal accidents. Drivers speeding over a limit of 100-110 km/h had a 3.53 times higher risk to be involved in a fatal crash, as Siskind et al. (2011) could figure out.

West et al. (1993) explored speeding in the frame of an observational driving study. Results indicated that observed preferred speed on the motorway was a significant and independent predictor for accident involvement, whereas observed maximum speed on this road section was not.

Peng and Boyle (2012) focussed on run off road (ROR) crashes of trucks. Speeding trucks had a 3.89 times higher risk of an injury or fatal ROR crash.

All Road Types or “not specified”

A naturalistic driving study showed that the risk to be involved in a crash when speeding is 12.8 times higher than when not speeding. No further distinction for road type was made (Dingus et al. 2016).

Watson et al. (2015) analysed the group of repeat high range offenders and their previous crash involvement in Australia (all road-types included). Results show that repeat high range speeding offenders can be distinguished from other offending drivers. Further it was found that high range speeding offenders have a 3.85 higher probability of a previous crash involvement than low range offenders, and a 1.83 higher probability of a previous crash involvement compared to drivers with other offences. Rajalin et al. (1994 a) came to a similar conclusion for Finland: Drivers with speeding offences have a 1.84 times higher risk to be involved in a fatal accident compared to a randomly selected control group.

In addition to speeding over the limit, three studies included inappropriate speed as well (Dingus et al., 2016, Peng and Boyle, 2012 and Siskind et al., 2011). However, “driving too slowly” was only mentioned once. According to this study, the risk to be involved in a crash when driving too slowly is 2.3 times higher (Dingus, 2016).

Modifying conditions

Conditions that might modify the speed-risk relationship could be personal factors (like gender and age) or situational factors (like car, road surface, surrounding conditions, and weather conditions). Some of the coded studies investigated the influence of numbers of speeding offences (high risk drivers or repeat high range speeding offenders), further the influence of sex and age. As the studies found out, speeding offences most of all are committed by male drivers. Younger but also middle aged drivers are more often involved than other age groups. (e.g. Watson et al., 2015; Vorko-Jović et al., 2005).

One coded study investigated the ROR crashes of commercial drivers: 36% of ROR drivers had a crash with property damage only (PDO) due to own posted speed (≥50 mph), but 72.56% of ROR drivers had an injury/fatal accident due to own posted speed (≥50 mph) (Peng and Boyle, 2012). The enhanced risk of PTW and speeding was documented by Watson et al. (2015).

Accident characteristics

An analysis was conducted of the German In-Depth Accident Study (GIDAS) database. The GIDAS database details those accidents which occurred on a public road where at least one person was injured. The accidents are collected according to a statistical sampling process to ensure a high level of representativeness of the actual accident situation in the sample regions (Hannover and Dresden). The data collection is conducted using the “on the scene” approach where all factors which were present at a crash are recorded. The analysis of speeding used the data from the Hannover accidents of the GIDAS data was done using the ACAS codes which describe (mostly human) causation factors which led to the accident occurrence.

Analysis of the GIDAS database (GIDAS Hannover accidents; years 2008-2014 with ACAS-codes; data basis: 2599 accidents) showed that speeding is significantly different from not speeding in regard to the following accident characteristics (main outcomes):

- time of day (more speeding than non speeding accidents occur at night-time),
- crash type (more speeding than non speeding accidents occur when turning in at crossing),
- type of road (more speeding than non speeding accidents occur on regional and county roads),

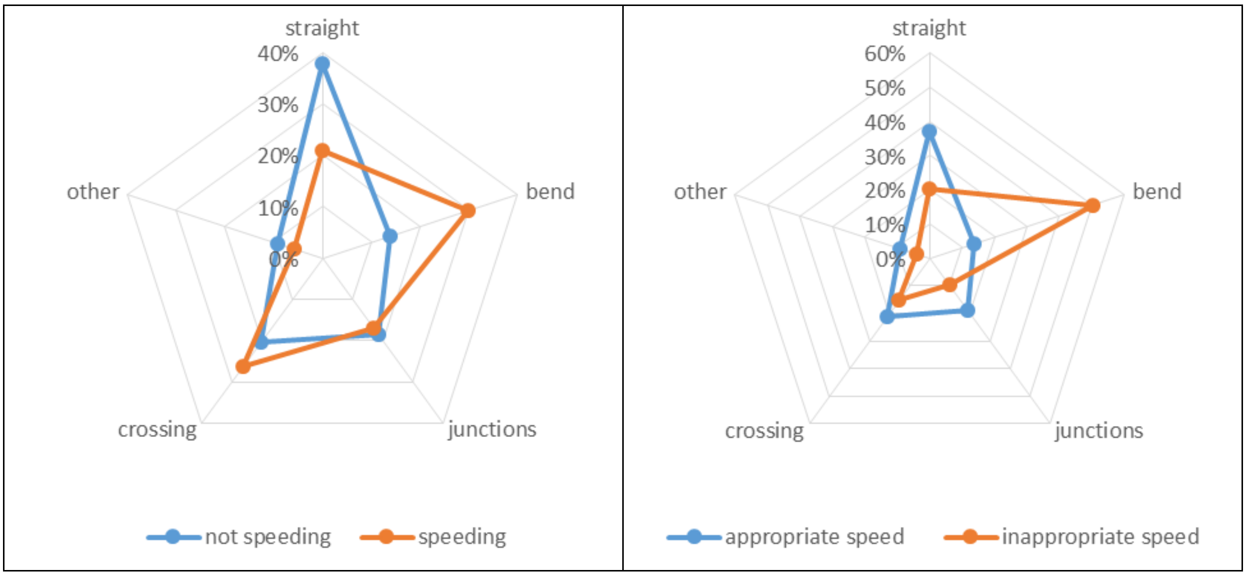
- accident location (more speeding than non speeding accidents occur at bends and crossings)
- sex (more speeding than non speeding accidents are caused by men)

Inappropriate speed is significantly different from appropriate speed in regard to following accident characteristics (main outcomes):

- time of day (more inappropriate speeding than appropriate speeding accidents occur at night-time),
- type of road (more inappropriate speeding accidents occur on county and regional roads and motorways),
- road surface (more inappropriate speeding accidents occur on moist and wet roads),
- accident location (more inappropriate speeding accidents occur at bends).

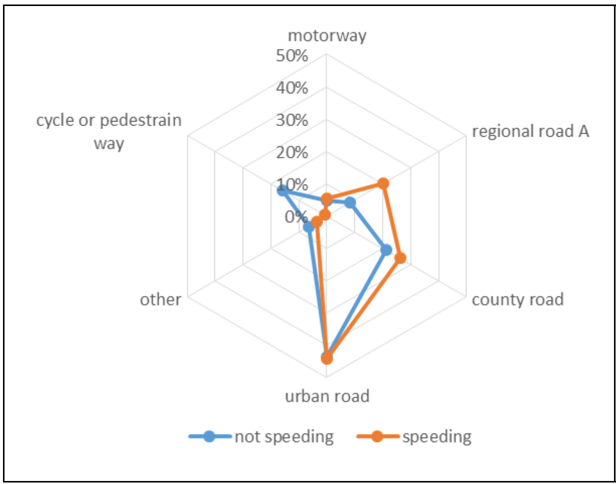
Several accident characteristics of both – speeding and inappropriate speed – are significantly different from not speeding, but also there are some differences compared to each other. By way of example,
Figure **2** – a comparison of speeding and inappropriate speed in regard to the accident location – reveals that a lot more accidents in bends occur when choosing an inappropriate speed, whereas more accidents occur at crossings when driving over the speed limit.

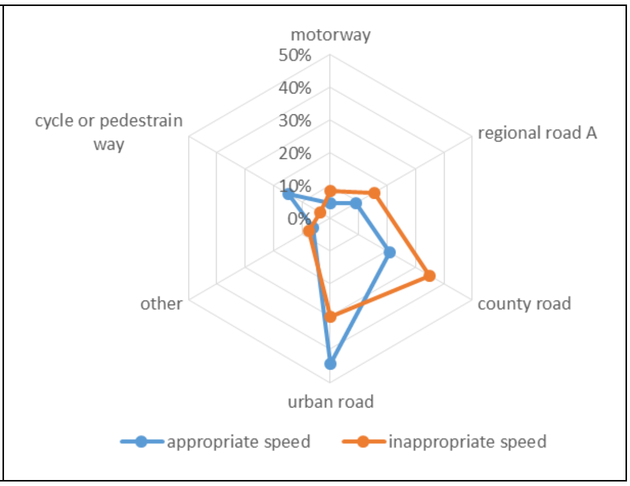
Figure 2: Differences of speeding/not speeding and appropriate/inappropriate speed in regard to accident location



A comparison of speeding and inappropriate speed in regard to type of road as well shows that more accidents occur on rural and regional roads when speeding over the limit, whereas more accidents occur on county roads when choosing an inappropriate speed (Figure 3).

Figure 3: Differences of speeding/not speeding and appropriate/inappropriate speed in regard to type of road





Conclusion

General – Literature search turned out to be challenging as measures in relation to speed were not considered for analysis. In fact, it proved to be difficult to capture studies that merely describe the effect of speed on crash risk without any relation to a specific measure. Furthermore, inappropriate speed – contrary to speeding over the limit – is not at the focal point in research. According to this, the effects of speed or rather speeding on vulnerable road users will be covered by research on speeding measures.

Main results – Studies documented a strong statistical relationship between speed and road safety. If the (mean) driving speed is reduced, the number of accidents and the severity of injuries decrease. This was shown in a vote and count analysis (Elvik, 2004), but also in additional studies later on. The relationship between speed and crash risk can be described by the Power Model, which is easily applicable and widely used in research (Nilsson, 1982, validated in 2004).

Most research focused on rural roads and motorways. This appears reasonable, as it seems generally accepted that the effect on accidents of a given relative change in speed is largest when initial speed is highest (e.g. Elvik, 2013).

Beyond that, research showed that speeding drivers are predominantly male.

Biases and transferability – Used databases often did not fit research conditions (e.g. administrative data; sometimes inaccurate or incomplete data were matched). On the other hand, the exclusion of incomplete datasets might have led to biases with regard to interpretation of results. For some speeding ranges comprehensive data was not available. Regional circumstances might have had an effect on data collection and analysis, as well.

Some studies lacked in documentation of details regarding numbers of accidents, statistical analysis, and number of speed measurements.

Several studies used observational designs. However, before and after studies and/or case control studies would allow direct comparisons and therefore, odds ratio calculations (e.g. control groups of non-speeders).

3 Supporting Documents

3.1 FACTORS INFLUENCING SPEEDING

The following tables gives a summary on factors which influence speeding, extracted from different studies (e.g. SWOV Factsheet, 2012; ERSO; Goldenbeld and Mesken 2012; , Stradling and Parker 1996; Haglund und Aberg 2000, Evers and Ewert 2004, Yannis et al. 2004, Praschl 2000).

Table 5: Situational factors and driver characteristics influencing speeding

Situation	Driver characteristics
• Road type (urban road, rural road, motorway) • Time of the day (daytime /night time) • Good weather conditions • Number of lanes • Road width • Width of the obstacle free zone • Presence/absence of emergency lane • Presence/absence of cycle track or service road present • Presence/absence of road marking • Level road surface • Enforcement • Adapting to other traffic • Driving comfort (noise, vibration) • Engine power of car • Presence/absence of car passengers • Driver's position in relation to road surface (e.g. sitting in a SUV): the higher, the faster	• Sex • Age • Driving experience, annual mileage • Sensation seeking • Haste • Pleasure • Unintended speeding • Boredom • Overestimation of one's skills • Peer pressure • Attitude • Intention to violate • Assumption on speed behaviour of others • Socially deviant (Subgroup extreme speeders)

Table 6: Situational factors and driver characteristics influencing the choice for inappropriate speed

Situation	Driver characteristics
• Weather conditions (e.g. fog, rain, snow fall) • Road surface	• Sex • Age • Overestimation of one's skills • Failure in perception • Failure in estimation • Haste

3.2 LITERATURE SEARCH STRATEGY

Literature search was conducted in March 2016. It was carried out in two databases with separate search strategies. The first one was performed in 'Scopus' which is a large abstract and citation database of peer-reviewed literature. The second search was conducted in a KFV-internal literature database ('DOK-DAT').

Database: Scopus **Date:** 18th of March 2016

no.	search terms / logical operators / combined queries	hits
#1	(„speed*" OR „velocity" OR „acceleration" OR „pace")	1,711,852
#2	("road casualties" OR "road fatalities" OR "traffic accident" OR "road crash")	45,483
#3	("road safety" OR "traffic safety") AND ("collision" OR "risk")	4,602
#4	("mean speed" OR "85th percentile speed" OR "speed limit offenders" OR "car" OR "motorcycle" OR "heavy vehicles" OR "heavy trucks" OR "daytime" OR "night" OR "professional drivers" OR "age" OR "sex" OR "weather conditions" OR "highway" OR "motorway" OR "built up area" OR "rural road" OR "urban road" OR "road violation" OR traffic rule")	3,332,419
#5	#1 AND #2 AND #4	2,915
#6	#1 AND #3 AND #4	768
#7	#5 OR #6	**3,284**

Table 7: Used search terms, logical operators, and combined queries of literature search (Scopus).

Detailed search terms, as well as their linkage with logical operators and combined queries are shown in Table 7. Using search fields title, abstract and keywords (TITLE-ABS-KEY) and a general limitation to studies which were published from 1990 to the present led to a huge amount of studies.

Results were limited to "article" and "review" and in a further step to the languages 'English' and 'German'. The quantity of studies was further reduced by limiting source type to "Journal" as well as excluding various countries. As on study scope we only considered European countries, as well as Russia. As a last reduction step we limited remaining studies to subject area "Engineering". This led to a final sample of 423 studies from the literature search in database Scopus (Table 9).

Database: DOK-DAT **Date:** 11th of March 2016

search no.	search terms / operators / combined queries	hits
#1	("mean speed" OR "85th percentile speed" OR "speed limit offenders" OR "car" OR "motorcycle" OR "heavy vehicles" OR "heavy trucks" OR "daytime" OR "night" OR "professional drivers" OR "age" OR "sex" OR "weather conditions" OR "highway" OR "motorway" OR "built up area" OR "rural road" OR "urban road" OR "road violation" OR traffic rule")	9,705
#2 (within #1)	Limit to year: 1990 to 2016	8,063
#3 (within #2)	(„speed*" OR „velocity" OR „acceleration" OR „pace")	919
#4 (within #3)	"road casualties" OR "road fatalities" OR "traffic accident" OR "road crash"	101
#5 (within #3)	("road safety" OR "traffic safety") AND ("collision" OR "crash")	47
#6	#4 OR #5	**148**

Table 8: Used search terms, logical operators, and combined queries of literature search (DOK-DAT).

(German) Search fields 'Titel', 'ITRD Schlagworte' and 'freie Schlagworte' were used. Hits were only limited to the years 1990 to 2016 and got 148 more potential studies (Table 8).

Results Literature Search

Database	Hits
Scopus (remaining papers after several limitations/exclusions)	423
DOK-DAT	148
Recommended studies	137
Total number of studies to screen title/ abstract	**708**

Table 9: Results of both databases after limitations

In all, the literature search led to 708 potential studies for screening (137 studies from reference lists or recommendations were supplemented, additionally).

Screening

Total number of studies to screen title/ abstract	708
De-duplication	4
Exclusion criteria A (speeding as risk factor not / not sufficiently covered)	591
Exclusion criteria B (speeding, but other aspects covered)	30
Exclusion criteria C (speeding, but no codeable data)	48
Remaining studies	34
Not clear (full-text is needed)	34
Studies to obtain full-texts	**34**

Table 10: Screening of abstracts

Total number of studies to screen full-text	34
Full-text could be obtained	32
Reference list examined Y/N	partly
Eligible papers	**32**

Screening of the full texts

Total number of studies to screen full paper	32
Studies with no risk estimates excluded	10
Studies concerning measures excluded	1
Studies covered by meta analysis	1
Studies excluded because more recent information available	1
Studies excluded due to limited time resources	6
Remaining studies	**13**

Number of studies dealing with "speeding"	13
Number of studies dealing with "inappropriate speed"	0
Number of studies dealing with both aspects	3

Table 11: Screening of full texts

Prioritizing Coding
- Prioritizing Step A (meta-analysis)
- Prioritizing Step B (studies published more recently than meta-analysis)
- Prioritizing Step C (sufficient time resources)

Studies are presented in order of publishing year; meta-analysis is mentioned first.

No.	Publication	Coded Y/N	Reason
1.	Elvik, R., Christensen, P., & Amundsen, A. (2004). Speed and road accidents. *TOI Report 740/2004*	Y	Prioritizing Step A Meta-analysis on Power Model
2.	Dingus, T., Guo, F., Lee, S., Antin, J., Perez, M., Buchanan-King, M., & Hankey, J. (2016). Driver crash risk factors and prevalence evaluation using naturalistic driving data. *PNAS Early Edition, 113(10)*, 2636-2641. Retrieved from www.pnas.org/cgi/doi/10.1073/pnas.1513271113	Y	Prioritizing Step B Most recent data; basic prevalence and odds ratio; data from naturalistic driving
3.	Bogstrand, S.T., Larsson, M., Holtan, A., Staff, T., Vindenes, V., & Gjerde, H. (2015). Associations between Driving under the Influence of Alcohol or Drugs, Speeding and Seatbelt Use among Fatally. *Accident Analysis and Prevention 78*, 14–19.	N	No codeable data
4.	Watson, B., Watson, A., Siskind, V., Fleiter, J., & Soole, D. (2015). Profiling high-range speeding offenders. Investigating criminal history, personal characteristics, traffic offences and crash history. *Accident Analysis and Prevention 74*, 87-96.	Y	Prioritizing Step B Speeding, traffic offences and crashes
5.	Bella, F., Calvi, A., & D'Amico, F. (2014). Analysis of Driver Speeds under Night Driving Conditions Using a Driving Simulator. *Journal of Safety Research 49*, 45–52.	N	No codeable data
6.	Elvik, R. (2013). A Re-Parameterisation of the Power Model of the Relationship between the Speed of Traffic and the Number of Accidents and Accident Victims. *Accident Analysis and Prevention 50*, 854–860.	Y	Prioritizing Step B Changes in speed in dependence of initial speed
7.	Viallon, V., & Laumon, B. (2013). Unsafe Driving Behaviors and Hospitalization. *Accident; Analysis and Prevention*, 52, 250–56.	Y	Prioritizing Step B
8.	Manner, H., & Wünsch-Ziegler, L. (2013). Analyzing the Severity of Accidents on the German Autobahn. *Accident Analysis and Prevention 57*, 40–48.	N	No codeable data
9.	Goldenbeld, C., Reurings, M., Van Norden, Y., & Stipdonk, H.	N	Not coded due to time

	(2013). Crash Involvement of Motor vehicles in Relationship to the number and severity of traffic offences. An exploratory Analysis of Dutch Traffic Offenes and Crash Data. *Traffic Injury Prevention*, *14*, 584-591.		resources
10.	Peng, Y., & Boyle, L. (2012). Commercial Driver Factors in Run Off Road Crashes. *Transportation Research Record Journal of the Transportation Research Board No. 2281*, 128-132. Washington D.C.	Y	Prioritizing Step B Speeding and crashes
11.	Siskind, V., Steinhardt, D., Sheehan, M., O'Connor, T., & Hanks, H. (2011). Risk factors for fatal crashes in rural Australia. *Accident Analysis and Prevention 43*, 1082-1088.	Y	Prioritizing Step B Speeding and crashes
12.	Elvik, R. (2009). The Power Model of the relationship between speed and road safety. *TOI Report 1034*/2009.	N	Update on relationship of speed and accidents by Power Model; instead taken Elvik, 2013
13.	Steg, L., & v. Brussel, A. (2009). Accidents, Aberrant Behaviours, and Speeding of Young Moped Riders. *Transportation Research Part F*: *Traffic Psychology and Behaviour*, *12*(6), 503–11.	N	Not coded due to time resources
14.	Skyving, M., Berg, H.-Y., & Laflamme, L. (2009). A Pattern Analysis of Traffic Crashes Fatal to Older Drivers. *Accident Analysis and Prevention*, *41(2)*, 253–58.	N	Not coded due to time resources
15.	Hewson, P. (2008). Quantile Regression Provides a Fuller Analysis of Speed Data. *Accident Analysis and Prevention*, *40*(2), 502–10.	N	Statistical theoretical analysis, application in a measure
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29.	Steensberg, J. (1994). Accidental Road Traffic Deaths-Prospects for Local Prevention. *Accident Analysis and Prevention, 26(*1), 1–9.	N	No codeable data
30.	Rajalin, S. (1994). The Connection between Risky Driving and Involvement in Fatal Accidents. *Accident Analysis and Prevention, 26(5),* 555–62.	Y	Prioritizing Step C One study on speeding and crashes, another on risky driving and speeding offences
31.	West, R., French, D., Kemp, R., & Elander, J. (1993). Direct Observation of Driving, Self Reports of Driver Behaviour, and Accident Involvement. *Ergonomics, 36(5)*, 557–67.	Y	Prioritizing Step C Observed speeding, reported speeding, reported crashes
32.	Nilsson, G. (1982). The effects of speed limits on traffic accidents in Sweden. *National Swedish Road and Traffic Research Institute (VTI)*. Sweden.	Y	Prioritizing Step C One of the first studies on the relationship speed and accidents

Summary of study results

Table 12: Summary of study results (sorted by name of first author)

Author(s), Year, Country	Exposure variable	Dependant / outcome type	Effects on Road Safety		Main outcome description
Dingus et al., 2016, USA	Speeding over limit and too fast for conditions	Observed crashes	↗	OR=12.8, CI=95% CI=10.1-16.2	Risk to be involved in a crash when speeding is 12.8 times higher
	Speeding in unsafe in work zone	Observed crashes	↗	OR=14.2, CI=95% CI=3.9-52.0	Risk to be involved in a crash when speeding in work zones is 14.2 times higher
	Driving too slowly	Observed crashes	↗	OR=2.3, CI=95%: 1.1-4.8	Risk to be involved in a crash when driving too slowly is 2.3 times higher
Elvik, 2008, Norway	Speeding over limit 80 km/h vs. no speeding	Number of fatal injuries	↘	AMF=0,781, CI=95%	The elimination of speeding results in a reduction of the mean speed of travel from 78.5 to 74.3 km/h; fatalities could be reduced by about 22% (estimated by applying the Power model; exponent 4.5)
	Speeding over limit 80 km/h vs. no speeding	Number of severe injuries	↘	AMF=0,848, CI=95%	The elimination of speeding results in a reduction of the mean speed of travel from 78.5 to 74.3 km/h; severe injuries could be reduced by about 15% (estimated by applying the Power model; exponent 3.0)
	Speeding over limit 80 km/h vs. no speeding	Number of minor injuries	↘	AMF=0,921, CI=95%	The elimination of speeding results in a reduction of the mean speed of travel from 78.5 to 74.3 km/h; minor injuries could be reduced by about 8% (estimated by applying the Power model; exponent 1.5)
Elvik, 2013, Norway	Initial speed lowered from 115 km/h to 105 km/h	Relative number of accidents	↘	AMF=0,728	27% less accidents if mean speed is reduced from 115km/h to 105km/h
	Initial speed lowered from 105 km/h to 95 km/h	Relative number of accidents	↘	AMF=0,679	32% less accidents if mean speed is reduced from 105km/h to 95km/h
	Initial speed lowered from 95 km/h to 85 km/h	Relative number of accidents	↘	AMF=0,697	30% less accidents if mean speed is reduced from 95km/h to 85km/h
	Initial speed lowered from 85 km/h to 75 km/h	Relative number of accidents	↘	AMF=0,652	35% less accidents if mean speed is reduced from 85km/h to 75km/h
	Initial speed lowered from 75 km/h to 65 km/h	Relative number of accidents	↘	AMF=0,822	18% less accidents if mean speed is reduced from 75km/h to 65km/h
	Initial speed lowered from 65 km/h to 55 km/h	Relative number of accidents	↘	AMF=0,829	17% less accidents if mean speed is reduced from 65km/h to 55km/h
	Initial speed lowered from 55 km/h to 45 km/h	Relative number of accidents	↘	AMF=0,672	33% less accidents if mean speed is reduced from 55km/h to 45km/h
	Initial speed	Relative number of	↘	AMF=0,578	42% less accidents if mean speed is

Author(s), Year, Country	Exposure variable	Dependant / outcome type	Effects on Road Safety		Main outcome description
	lowered from 45 km/h to 35 km/h	accidents			reduced from 45km/h to 35km/h
	Initial speed lowered from 35 km/h to 25 km/h	Relative number of accidents	↘	AMF=0,686	31% less accidents if mean speed is reduced from 35km/h to 25km/h
Kloeden et al., 2002, Australia	Free travel speed 45 km/h	Relative risk (compared to 60 km/h set as 1)	↘	RR=0,27 CI=95% CI=0,13-0,49	Relative risk at a travelling speed of 45 km/h is 0.27 lower than at 60 km/h
	Free travel speed 50 km/h	Relative risk (compared to 60 km/h set as 1)	↘	RR=0,39 CI=95% CI=0,26-0,54	Relative risk at a travelling speed of 50 km/h is 0.39 lower than at 60 km/h
	Free travel speed 55 km/h	Relative crash risk (compared to 60 km/h set as 1)	↘	RR=0,60 CI=95% CI=0,50-0,69	Relative risk at a travelling speed of 550 km/h is 0,60 lower than at 60 km/h
	Free travel speed 65 km/h	Relative crash risk (compared to 60 km/h set as 1)	↗	RR=1,82 CI=95% CI=1,6-2,15	Relative risk at a travelling speed of 65 km/h is 1,82 higher than at 60 km/h
	Free travel speed 70km/h	Relative crash risk (compared to 60 km/h set as 1)	↗	RR=3,57 CI=95% CI=2,7-5,28	Relative risk at a travelling speed of 70 km/h is 3.57 higher than at 60 km/h
	Free travel speed 75 km/h	Relative crash risk (compared to 60 km/h set as 1)	↗	RR=7,63 CI=95%; CI=4,66-15,55	Relative risk at a travelling speed of 75 km/h is 7.63 higher than at 60 km/h
	Free travel speed 80km/h	Relative crash risk (compared to 60 km/h set as 1)	↗	RR=17,66 CI=95%; CI=8,08-55,49	Relative risk at a travelling speed of 70 km/h is 3.57 higher than at 60 km/h
	Free travel speed 85 km/h	Relative crash risk (compared to 60 km/h set as 1)	↗	RR=44,36 CI=95%; CI=13,73-236,10	Relative risk at a travelling speed of 85 km/h is 44,36 higher than at 60 km/h
	Free travel speed 90 km/h	Relative crash risk (compared to 60 km/h set as 1)	↗	RR=120,82 CI=95%; CI=22,98-1,222.70	Relative risk at a travelling speed of 90 km/h is 120,82 higher than at 60 km/h
Nilsson, 2004, Sweden	Increase speed limit from 90 km/h to no limit	injury accidents	↗	13.1% accident increase	Increase of speed limit from 90 to no limit leads to 13% more injury accidents
		Fatal accidents	↗	30% accident increase	Increase of speed limit from 90 to no limit leads to 30% more fatal accidents
	Increase speed limit from 110 km/h to no limit	injury accidents	↘	9.5% accident reduction	Increase of speed limit from 110 to no limit leads to 9.5% less injury accidents
		Fatal accidents	↘	10% accident reduction	Increase of speed limit from 110 to no limit leads to 10% less fatal accidents
	Increase speed limit from 90 km/h to 110 km/h	Injury accidents	↗	24.7% accident increase	Increase of speed limit from 90 to 110 km/h leads to 24.7% more injury accidents
		Fatal accidents	↗	21.4% accident increase	Increase of speed limit from 90 to 110 km/h leads to 21.4% more fatal accidents

Author(s), Year, Country	Exposure variable	Dependant / outcome type	Effects on Road Safety		Main outcome description
	Increase speed limit from 70 km/h to 90 km/h	Injury accidents	↗	23.8% accident increase	Increase of speed limit from 70 to 90 km/h leads to 23.8% more injury accidents
		Fatal accidents	↗	42.5% accident increase	Increase of speed limit from 70 to 90 km/h leads to 42.5% more fatal accidents
	Increase speed limit from 110 km/h to 130 km/h	Injury accidents	↗	16.6% accident increase	Increase of speed limit from 110 to 130 km/h leads to 16.6% more injury accidents
		Fatal accidents	↗	12.5% accident increase	Increase of speed limit from 110 to 130 km/h leads to 12.5% more fatal accidents
	Lowering speed limit from 110 km/h to 90 km/h	Injury accidents	↘	30% accident reduction	Lowering speed limit form 110 km/h to 90 km/h leads to 30% less injury accidents
		Fatal accidents	↘	50% accident reduction	Lowering speed limit form 110 km/h to 90 km/h leads to 50% less fatal accidents
	Same speed limit (90 km/h)	Injury accidents	↘	3% accident reduction	Same speed limit in observation period shows a 3% reduction in injury accidents
		Fatal accidents	↘	5.9% accident reduction	Same speed limit in observation period shows a 5.9% reduction in fatal accidents
Peng et al., 2012, USA	Speeding of trucks	Single vehicle ROR crashes (trucks); PDO accidents	↗	Relative pro-portion=0,194	19.4% of ROR drivers had a PDO due to own speeding
		Single vehicle ROR crashes (trucks); injury and fatal accidents	↗	Relative pro-portion=0.36	36% of ROR drivers had a injury/fatal accident due to own speeding
	Trucks driving with a speed over posted speed of 50 mph	Single vehicle ROR crashes (trucks); PDO accidents	↗	Relative pro-portion=0.3626	36% of ROR drivers had a PDO due to own speeding (posted speed ≥50 mph).
		Single vehicle ROR crashes (trucks); injury and fatal accidents	↗	Relative pro-portion=0,7256	72.56% of ROR drivers had a injury/fatal accident due to own speeding (posted speed ≥50 mph)
	Speeding of trucks	Single vehicle ROR crashes (trucks); injury and fatal accidents	↗	OR=3,89 p<0,0001; CI=95%, CI=2,67-5,66	Trucks speeding have a 3.89 times higher risk to have an injury or fatal ROR crash
Rajalin, 1994, Finnland	Number of speeding offences	Fatal accidents	↗	OR=1,84 p<0,0001; CI=95%, CI=1,48-2,29	Drivers with speeding offences have a 1.84 times higher risk to be involved in a fatal accident compared to randomly selected control group.
	High risk driver stopped at road side for risky driving	Number of speeding offences	↗	OR=3.53 CI=95%, CI=2.67-4.74	High risk drivers have significantly (3.53 times) more speeding offences than control group
Siskind et al., 2011, Australia	speeding	Fatal crashes	↗	Relative pro-portion=0.187; sign.	18.7% of all fatal units were related to speeding
			↗	RR=2.39 p=0,001	Relative risk to have a fatal crash when

Author(s), Year, Country	Exposure variable	Dependant / outcome type	Effects on Road Safety		Main outcome description
				CI=95%, CI=1.61-3.55	speeding is 2.39
	speeding	Non fatal crashes	-	Relative proportion=0.066	6.6% of all non-fatal units were related to speeding
	Travelling over speed limit	Fatal crashes	↗	Relative proportion=0.067	6.7% of all fatal units were related to travelling over speed limit
	Travelling over speed limit	Non fatal crashes	-	Relative proportion=0.009	0.9% of all non fatal units were related to travelling over speed limit
	Speeding at having a limit 70-90 km/h	Fatal crashes	-	RR=2.0; p=0.09 CI=95%, CI=0,9-4,44	Drivers speeding over a limit of 70-90 km/h have a 2 times higher risk to be involved in a fatal crash.
	Speeding at having a limit 100-110 km/h	Fatal crashes	↗	RR=3.53 p=0,001 CI=95% CI=1.73-7.22	Drivers speeding over a limit of 100-110 km/h have a 3.53 times higher risk to be involved in a fatal crash
Viallon et al., 2013, France	Speeding <10 km/h over limit	Fatal crashes in 2001 and 2010	↗	Relative proportion 2001= 0.07 Relative proportion 2001= 0.13	Fatal crashes due to low level speeding increased from 7% in 2001 to 13% in 2010.
	Speeding 10-20 km/h over limit	Fatal crashes in 2001 and 2010	↘	Relative proportion in 2001 = 0.13 Relative proportion in 2010 = 0.09	Fatal crashes due to speeding with 10 to 20 km/h decreased from 13% in 2001 to 9% in 2010.
	Speeding >20 km/h over limit	Fatal crashes in 2001 and 2010	↘	Relative proportion in 2001 = 0.25 Relative proportion in 2010 = 0.06	Fatal crashes due to speeding over 20 km/h decreased from 25% in 2001 to 6% in 2010.
Vorko-Jović et al., 2005, Croatia	speeders	Fatal injury	↗	Relative proportion 0.655	65.5% of all fatalities are caused by exceeding the upper limit of speed
			↗	OR=2.56, p=0.0012 CI=95%, CI=1,43-4,61	Fatal outcomes are 2.56 times more frequent than non-fatal (reference group is a speeders group as well)
	speeders	Fatal and severe injuries	↗	OR=1.47 p=0,04, CI=95% CI=1.02-2.11	Risk of fatal or severe injury is 1.47 times higher
	speeders	male	↗	Relative proportion=0.72	70.2 % of all fatalities caused by exceeding the upper limit of speed are caused by male drivers
	Male speeders	Fatal injury	↗	OR=2.99 p=0.000842 CL=95% CI=1.538-5.814	for males the risk of fatal outcomes is 2.99 times more frequent than non-fatal

Author(s), Year, Country	Exposure variable	Dependant / outcome type	Effects on Road Safety		Main outcome description
Watson et al., 2015, Australia	Repeat high range speeding offenders	Previous crash involvement	↗	OR=3.85 p=0,0010 CL=99% CI=2.52-5.88	Repeat high range speeding offenders have a 3.85 higher probability to have a previous crash involvement than low range offenders.
			↗	OR=1.83 p=0.0010 CL=99% CI=1.54-1.93	Repeat high range speeding offenders have a 1.83 higher probability to have a previous crash involvement than other offenders.
West et al., 1993, UK	Reported prior accident involvement	Observed preferred speed on first section of motorway	↗	r=0.47 p<0.01	Preferred speed on first section is significantly associated with accident involvement
		Observed maximum speed on first section of motorway	↗	r=0.42 p<0.01	Maximum speed on first section is significantly associated with accident involvement
		Observed preferred speed on final section of motorway	↗	r=0.43 p<0.01	Preferred speed on final section is significantly associated with accident involvement
		Observed maximum speed on final section of motorway	↗	r=0.37 p<0.01	Observed maximum speed on final section of motorway is significantly correlated to reported accident involvement
		Observed preferred speed on motorway	↗	Slope (logistic regression) B=0.44; p=0.018	Observed preferred speed is a significant independent predictor for accident involvement
		Observed maximum speed	-	Slope (logistic regression), B=-0.19; p>0.05	Observed maximum speed is no significant predictor for accident involvement
	Self reported speed	Preferred speed on first section of motorway	↗	r=0.57 p<0.01	Preferred speed on first section of motorway is significantly correlated to self reported speed
		Maximum speed on first section motorway	↗	r=0.55 p<0.01	Maximum speed on final section motorway is significantly related to self reported speed
		Preferred speed on final section motorway	↗	r=0.62 p<0.01	Preferred speed on final section motorway is significantly related to self-reported speed
		Maximum speed on final section motorway	↗	r=0.65 p<0.01	Maximum speed on final section motorway is significantly related to self-reported speed

*Significant effects on road safety are coded as: positive (↘), negative (↗) or non-significant (-)

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Traffic rule violations - Red Light Running

Driving/riding through an intersection or crossing the road when the light is on red

1 Summary

Goldenbeld, C. & van Schagen, I. , August 2016

1.1 COLOUR CODE: RED

Red light running can lead to two basic types of traffic conflicts at intersections: right-angle and left turn-opposed conflicts. Red light running is a traffic violation that is associated with very serious crash outcomes (fatality or serious injury). Red-light-running related crashes compose a substantial part of urban road safety. It has been estimated that when a pedestrian crosses an intersection at red light his relative crash risk is eight times higher compared to a legal crossing at green (or amber) light.

1.2 KEYWORDS

traffic rule violations, red light running, car drivers, cyclists, pedestrians

1.3 ABSTRACT

Red light running is a risky traffic violation leading to traffic conflicts at intersections that may result in death or serious injury. It has been estimated that pedestrians' relative crash risk is eight times higher when they cross an intersection at red light instead of green (or yellow) light. Relative risk estimates for red light running by drivers and cyclists have not yet been made. Red light running is fairly scarce amongst drivers (a few drivers per 1,000 vehicles), but fairly frequent among cyclists and pedestrians (percentages may run up to over 50% at specific days, times and locations). Red light running is influenced by several factors, including age and gender, static and dynamic intersection characteristics, day and time, and weather. Most research has been done in busy, large metropolitan city areas in China, Europe, and the USA.

1.4 BACKGROUND

What is red light running?

Red light running is entering an intersection any time after the signal light has turned red. A vehicle (or cyclist) is said to "enter" the intersection when it crosses the stop line or an equivalent location on the intersection approach (Bonneson & Zimmerman, 2004). Similarly, red light running of pedestrians can be defined as entering the road, either at an intersection or midblock, any time after the pedestrian signal has turned red. There are some qualifications to this simple definition. Road users who are inadvertently in an intersection when the signal changes, (waiting to turn left, for example), cannot be considered as red light runners. At locations where a right turn on red is permitted, drivers who fail to come to a complete stop before turning may be considered red light runners.

How does red light running affect road safety?

There are two common types of road safety conflict due to a red light violation: right-angle and left turn-opposed conflicts (Bonneson & Zimmerman, 2004). These two conflicts tend to occur at different times during the red indication. A right-angle conflict occurs after the driver/cyclist in a conflicting traffic stream reacts to the signal's change to green and travels into the intersection. Thus, the right-angle conflict is likely to occur after the first few seconds of red have lapsed. A left-turn-opposed conflict occurs when: (1) a left-turn movement is permitted to turn through gaps in the opposing through traffic stream, and (2) the left-turn completes the permitted turn just after the light changes to red. Drivers of left-turning vehicles waiting in the intersection at the end of the phase may unintentionally turn in front of an opposing through vehicle, believing that its driver will stop for the red indication. Thus, left-turn conflicts are likely to occur soon after the start of red (possibly prior to the end of the all-red interval) (Bonneson & Zimmerman, 2004).

How many road users engage in red light running?

- For car drivers, studies show that the rate of red light violation per 1000 vehicles varies between 1.3 and 5.3 in the USA and Australia (Australia: 3.9; Oxnard, California: 1.3; Arlington, Virginia: 3; Fairfax, Virginia: 3.7 ; Texas:4.1; Tuscaloosa, Alabama: 5.3; as reported in Attawi, 2014). European figures are not available.
- Cyclists frequently engage in red light running in large city areas. Richardson (2015) lists results for several studies: Beijing, China (two studies: 50%, 64%), London, UK (two studies: 16%, 17%), Melbourne, Australia (three studies: 7%, 9%, 37%), Michigan, USA (one study: 23%), Oregon, USA (one study: 10%).
- Pedestrians also frequently engage in red light running, with red light running violations reported for about one third of pedestrians in Lille (Dommes et al., 2015), for 20% of pedestrian crossings in Brisbane Queensland (King et al., 2009), and 13.5% of pedestrians in Tel Aviv, Israel (Rosenbloom, 2009).

Which factors influence the frequency of red light running?

The frequency of red light running is influenced by many personal as well as road and traffic related factors, for example:

- For car drivers the frequency has been found to depend on the following (intersection) factors: traffic volume, cycle length, advance detection for green extension, speed, signal coordination, approach grade, yellow interval duration, proximity of other vehicles, presence of heavy vehicles, delay, intersection width, and signal visibility (Bonneson & Zimmerman, 2004).
- For cyclists, Meel (2013) identified the following characteristics that were associated with increased red light running rates: male cyclists, young adults, experienced cyclists, bad weather, long waiting times, reduced credibility/low conflicting traffic flow, short crossing distance, herding (when there are other people violating the red light they are more likely to also violate the red light) and a low percentage of trucks and buses.

1.5 OVERVIEW RESULTS

- It has been estimated that the relative crash risk of red light violation for pedestrians is eight times higher than for legal crossing at signalised intersections. Relative risk estimates for red light running by drivers and cyclists have not yet been made.
- Whereas red light running by drivers is infrequent – a few drivers per 1000 vehicles – cyclists and pedestrians have been shown to be frequent red light violators – with percentages running over 50% at specific days, times and locations.
- Red light running is associated with various static and dynamic characteristics of intersections, traffic composition, personal characteristics, day, time and weather, and with social-cultural factors.
- A strong predictor for red light running by drivers is loss of attentional visual field (AVF) (especially in the vertical meridian).
- The red light running of cyclists can be distinguished into risk taking red light running where the cyclist does not stop at all when the light is red, and opportunistic red light running where the violation occurs after the cyclist has stopped.

1.6 NOTES ON RESEARCH AND ANALYSIS METHOD

It should be noted that studies on red light running are generally limited in scope (observations on a few intersections in one city area) and that the studied intersections are not randomly selected, i.e. studies tend to focus on the busier and more complex intersections in urban environments. Furthermore, most studies look at the prevalence of red light running; there are hardly any studies that assessed the effect on the accident risk of red light running.

2 Scientific Details

2.1 DESCRIPTION OF CODED STUDIES

Table 1 presents information on the main characteristics of the 14 coded studies. 3 studies concerned drivers (D), 5 cyclists (C), 4 pedestrians (P), 1 all road users (A), and 1 bus drivers (B).

Table 1: Overview of characteristics of 14 coded studies

Study	Mode	Main study method and road user	Measurement
Porter & England, 2000, USA,Virginia	D	The study focused on RLR of *drivers* on 6 intersections in 3 Southeast Virginia cities. Appr. 44,000–115,000 vehicles enter each of these intersections daily. 2 four-way intersections for each city were chosen.	Observations were carried out between February and April, 1997. Weekday observations were scheduled so that of 6 intersections, one from each city, were observed daily during a continuous 2-hour period between 3 p.m. and 6 p.m. (the hours within which most weekday crashes occurred in Virginia).
Rosenbloom et al., 2004, Israel	P	This observational study investigated *pedestrian behaviour*, including red light running, as a function of gender, age, and type of cultural environment (secular city vs religious orthodox city).	The sample consisted of 1047 *pedestrians* who were observed at 2 busy urban intersections. The observations were conducted in 3 separate intervals at 2 busy intersections in Ramat-Gan (secular area) and Bnei-Brak (ultra-orthodox area) during the afternoon hours.
King et al., 2009, Australia, Brisbane	P	Observation survey of *pedestrian behaviour* at 6 signalised intersections in the Brisbane Central Business District, having high volumes of pedestrians and vehicles.	Each intersection was observed for one half-hour period during 5 different time periods over the day; early morning (8 a.m.–10 a.m.), mid-morning (10 a.m.–12 p.m.), midday (12 p.m.–2 p.m.), mid-afternoon (2 p.m.–4 p.m.), and late afternoon (4 p.m.–6 p.m.), on Thursdays and Fridays in 2 successive weeks in November.
Rosenbloom, 2009, Israel, Tel Aviv	P	An observational study that compared the road behaviour of individual *pedestrians* at an intersection with a traffic signal to that of groups of pedestrians (at the same intersection).	1392 *pedestrians* were unobtrusively observed in an urban setting at a pedestrian street crossing of undivided streets; 842 were female (60.5%) and 550 were male (39.5%). the observations took place between 7:30 and 8:30 in the morning.
West et al., 2010, USA, Maryland	D	Multiple measures of vision and cognition were collected at the baseline examination of a population of 1,425 *drivers* aged 67-87 years in greater Salisbury, Maryland.	Each *driver* had real-time data collected on 5 days of driving performance at baseline and again at 1 year. Failure to stop at a red traffic light was the primary outcome.
Johnson et al., 2011, Australia	C	A cross-sectional observational study was conducted using a covert video camera to record *cyclists* at 10 sites across metropolitan Melbourne, Australia from October 2008 to April 2009.	Observations of *cyclists* were made at 10 sites along the most frequently used on-road commuter routes in metropolitan Melbourne. All sites were within 5 km of the CBD, had 2 lanes of forward travel, 4 lanes of cross traffic, a pedestrian crossing and a tram line parallel to the right vehicular lane. 3 groups of predictor variables were recorded: location, cyclist characteristics, and other road users.

Wu et al., 2012, China	C	A cross-sectional observational study on *cyclists* was conducted at 3 four-armed signalized intersections in Beijing. Two criteria were used to select the sites: 1. typical intersection design; 2. a high number of two-wheeled traffic.	The riders (both e-bike riders and cyclists) arriving during red light phases were videotaped and coded. The coded variables described the riders' individual characteristics (gender, age group, vehicle type), the riders' movement information and situational factors (cross traffic volume, group size, number of riders waiting upon arrival, and number of riders crossing against the red light).
Gates et al., 2014, USA	D	Naturalistic *driver* behavioural data were collected at 72 signalized intersection approaches selected from 4 regions of the US; data were collected with consumer-grade high definition video camera installed for 3 to 5 h at each of the 72 study approaches.	Data were obtained for 6,208 vehicles that were approaching a study intersection during the yellow interval, including 3,575 (57.6%) vehicles that stopped, 2,533 (40.8%) vehicles that entered the intersection before the end of the yellow indication, and 100 (1.6%) vehicles that committed RLR by entering after the end of the yellow indication.
Pai & Jou, 2014 Taiwan	C	The research used video cameras to collect the data (e.g., *bicyclist* attributes, temporal factors, roadway characteristics, and weather factors) at several selected junctions, Toayuan County, Taiwan.	12,447 observations on *bicyclists* crossings; the survey was carried out on 8 intersections, four 3-arm and four 4-arm, four with 50 km/hr and four with 60 km/hr speed limit, with crossing distance ranging from 23 to 43 meter, with peak hour traffic volumes of first stream (closest to bicyclists) ranging 2100 - 4000, and off peak hours 700 -2000)
Dommes et al., 2015 France	P	The study combined observational data with questionnaires answered by 422 French adult *pedestrians*. 15 urban crosswalks at 6 different signalized intersections in Lille (France) served as experimental sites. 13 behavioural indicators were extracted and demographical, contextual and mobility-associated variables were examined	All sites were on two-way streets, with no pedestrian refuge islands; all had zebra crossings, pedestrian and traffic lights, and a speed limit of 50 km/h on each road segment. Traffic density was available for each observed crosswalk in three categories (AADT): from 1500 to 6000 vehicles per day (4 crosswalks), from 6001 to 13,000 vehicles per day (4 crosswalks) and from 13,001 to 30,000 vehicles per day (7 crosswalks).
Richardson& Caulfield, 2015, Ireland, Dublin	C	An observational survey and an online questionnaire; 2061 *cyclists* (18+ yrs), completed an online survey with questions regarding the frequency with which respondents stopped at red lights and the reason(s) for cycling through red light.	4 intersections in Dublin, 2 with cycle track and 2 with cycle lanes; all 4 sites were surveyed on the same day; each site observed twice from 8 to10 am in half-hour intervals spread out over the eight surveys; thus, each site was surveyed for a total of 4h.
Wang, 2015, China, Changsha City	B	Observational study to record three types of traffic violations among *bus drivers* in Changsha City, China: illegal stopping at bus stations, violating traffic light signals, and distracted driving.	The study included 256 round-trip observations on 32 bus routes, recording the bus driver behaviour at 7,612 bus stations, 5,656 road intersections, and 14,384 road sections; the study collected valid records from 7,611 bus stations, 5,612 road intersections, and 14,277 road sections.
Yan, 2015, China	A	Portable digital devices were used to record red-light running violations at 5 selected intersections. In total, 162.124 vehicles and 31.649 pedestrians were recorded, including 117.557 cars, 11.946 coaches, 333 trucks, 27.974 motorcycles	Observations were conducted on 3 types of days (weekday, weekend, holiday). The selections of weekday, weekend and holiday were determined at random. For each selected day, the researchers conducted the observations in 4 time periods, including 2 peak hours (7:30–8:30

		and 4314 bicycles. *Cars, pedestrians, and motorcycles* were most observed accounting for 60.7%, 16.3 and 14.4%.	am and 5:30–6:30 pm) and two off-peak hours (9:30–10:30 am and 3:30–4:30 pm). In total, the traffic flows of 60 h were recorded at the five intersections.
Yang et al., 2015, China	C	A cross-sectional observational study was conducted at six signalized intersections in Beijing, China.	A total of 2322 two-wheeled riders approaching the intersections during red light periods were observed with hidden cameras. The overall proportion of riders' red-light running behaviour was 61.1% and varied from 46.4% to 72.1% across sites. Cyclists were less likely to cross against the red light than e-bikers (55% vs. 67%).

Description of main research methods

The direct effect of red light running on road safety has most often been studied in general or in-depth accident analysis. There are almost no studies that provide a relative risk estimate for red light running (exception King et al., 2009).

The prevalence of red light running is generally assessed in observational studies, with video cameras or human observers (Johnson et al., 2011; Rosenbloom et al., 2004, Rosenbloom, 2009; Wu et al.,2012; Pai & Jou, 2014; Dommes et al., 2015; Richardson et al., 2015; Yan et al., 2015). Many studies focus on the factors that influence red light running rates. The variables typically include characteristics of road users (e.g. age, gender), characteristics of intersections (e.g. traffic volume, signal phasing), social factors (e.g. presence and behaviour of other pedestrians/cyclists) and other circumstances (e.g. times and day, weather conditions).

Other research methods included the use of naturalistic driving data (Gates et al., 2014), observing bus driving behaviour along bus routes (Wang et al., 2015), combining cognitive and visual tests with driver behaviour data (West et al., 2010). Only one study investigated the extent to which red light running was associated with increased crash risk (King et al., 2009).

Most of the red light running studies have been conducted on a limited number of intersections in large metropolitan city areas. It should be noted that these intersections are often not representative for a city. Many studies focus on high-volume intersections in busy business or shopping areas. The types of intersections studied differ within one study and between studies which complicates comparing (discriminating or generalising) research findings.

2.2 RESULTS

- Red light running is fairly scarce amongst drivers (a few drivers per 1000 vehicles), but fairly frequent among both cyclists and pedestrians - percentages may run up to over 50% at specific locations, days and times.
- Most studies report considerable variation in red light running between intersections.
- The one study that linked red light running with crash risk found that pedestrians crossing against a red light had a crash risk that was eight times higher than crossing at a green light.
- An important cognitive function of drivers that is related to red light running is loss of attentional visual field (AVF).
- Pedestrian red light running is less clearly linked to demographic factors and traffic volume than cyclists and cars red light running.
- Besides traffic related factors, red light running of pedestrians and cyclists may be influenced strongly by social-cultural factors.

Modifying conditions

Research on red light running of drivers, cyclists and pedestrians showed that in general red light running depends upon age, gender, visual function, type and time of day, weather conditions, and several static or dynamic characteristics (traffic volume, signal phasing) of the intersection.

Bonneson & Zimmerman (2004) summarised the engineering factors that influence the red light running as follows:

Category	Factor*	Red-Light violations tend to decrease when
Traffic characteristics	Approach traffic volume	...traffic volumes decrease.
	Approach speed	...speeds decrease.
	Heavy-vehicle percentage	...fewer trucks are present.
Signal operation	<u>Signal cycle length</u>	...cycle length increases, provided the *v/c ratio*** is less than 0.65. ...cycle length decreases, provided the *v/c ratio* is more than 0.65.
	<u>Yellow interval duration</u>	...yellow interval is increased (provided it does not exceed 5.5 s)
	<u>Phase termination by max-out</u>	...advance detection for green extension is used, provided it does not frequently extend to the maximum green limit (i.e., max-out).
Motorist information	Signal visibility	..signal visibility is improved (e.g., better signal head location, more heads, line of sight between signal and driver is improved)
	Signal conspicuity	...signal conspicuity is improved (e.g., use LED indications, 12" lenses, signal back plates, or dual red indications).
	Advance warning	...advance warning signs are added, especially if used with flashers that are active during the last few seconds of green.
Traffic operation	Approach delay	...delay decreases, especially if the *v/c* ratio is high.
	<u>Signal coordination</u>	...progression bands are adjusted so platoons do not arrive near the end of green.
Geometry	Approach grade	...grade is increased.
	Clearance path length	...distance travelled through intersection is short.
Enforcement	Threat of citation	...it is perceived that a violation is likely to result in a citation.
*** Underlined factors typically have an effect only on violations occurring just after the onset of red. ** "v/c"ratio = volume-to-capacity ratio.**		

Furthermore, studies show that drivers seem to be more likely to run a red light when they:

- were unbuckled (Porter, 2000),
- suffered from loss of AVF (West et al., 2010),
- drove as part of a platoon (Gates et al, 2014),
- encountered signals with shorter yellow duration (Gates et al., 2014),
- encountered good weather conditions (Wang et al., 2015).

Cyclists seem to be more likely to run a red light when they:
- were male (Pai & You 2014; Richardson et al., 2015; Wu et al., 2012),
- were younger (Rosenbloom et al., 2004; Wu et al., 2012),
- encountered low traffic volume (Johnson et al., 2011; Pai & Jou, 2014),
- encountered fine weather (Pai & Jou, 2014),
- did not wear a helmet (Pai & Jou, 2014),
- cycled alone (Wu et al., 2012),
- had to cross a T/Y-intersection (Pai & Jou, 2014).

Pedestrians seem to be more likely to cross against a red light when they:
- were male (Rosenbloom et al., 2004; Rosenbloom, 2009),
- were part of an ultra-orthodox environment (Rosenbloom et al., 2004),
- crossed alone (Dommes et al., 2015).

On a number of variables studies showed contradictory results, for example:
- Some studies have found age and gender effects for pedestrians crossing red lights (Rosenbloom et al., 2004; Rosenbloom, 2009), other studies have not (Dommes et al., 2015).
- Wu et al. (2012) found no effect of cycling an electric bike (versus normal bike) on red light running, Pai & You (2014) found that riders on electric bikes engage in more red light running.

Besides the physical environment, the social-cultural environment also exerts considerable influence on red light crossing. Rosenbloom (2004) found that pedestrians in an orthodox environment were more like to cross against red than those in a secular area. In a later study, Rosenbloom (2009) found that a larger group of pedestrians waiting for red light decreased the prevalence of red light running.

An important theoretical distinction is the distinction between red light running by cyclists as risk taking and opportunistic behaviour. The risk-taking cyclists are those who ignore the red light and travel through the junction without stopping (perhaps slowing down); the opportunistic cyclists originally wait at a red light, but become too impatient and subsequently cross the junction by seeking gaps among crossing traffic.

Conclusions

- The relative crash risk of red light violation for pedestrians is 8 times higher than that for legal crossing at signalised intersections. Relative risk estimates for red light running by drivers and cyclists have not yet been made.
- Whereas red light running by car drivers is infrequent – a few drivers per 1000 vehicles – cyclists and pedestrians have been shown to be frequent red light violators – with percentages running over 50% at specific days, times and locations.
- Red light running is associated with various static and dynamic characteristics of intersections, personal characteristics, day, time and weather, and with social-cultural factors.
- Red light running by drivers is increased by driving in platoon and by shorter yellow duration of signals.
- A strong human function/competence predictor for red light running by drivers is loss of attentional visual field (AVF) (especially in the vertical meridian).
- Red light running of drivers, cyclists is promoted by good weather.
- Both cyclists and pedestrians waiting for a red light, or cyclists and pedestrians transgressing a red light, can influence red light running behaviour of others.
- The red light running of cyclists can be theoretically distinguished into risk taking red light running where the cyclist does not stop at all when the light is red, and opportunistic red light running where the violation occurs after the cyclist has stopped.

3 Supporting Documents

3.1 LITERATURE SEARCH STRATEGY

The literature on red light running and traffic risk was searched for in the international database Scopus on 23 March 2016. Scopus is the largest international peer-reviewed database. The literature was searched over the period 1999-2016; the search terms were searched in title, abstract and keywords. **Table 2** describes the search terms and logical operators and the number of hits for three searches on red light running and risk for drivers, cyclists and pedestrians.

Database: Scopus, Date: 23 March 2016

Table 2: Used search terms and logical operators

	Search terms/logical operators/combined queries	hits
1	The search for red light running and drivers used the following combination of key words: (TITLE-ABS-KEY ("red light running" OR "red light infringement" OR "red light negation" OR "red light violation" OR "red light offence" OR "red light crossing" OR "cross red light" OR "traffic light") AND TITLE-ABS-KEY (driver)) AND PUBYEAR > 1999	590
2	Search red light running and cyclists: This search used the following combination of keywords: (TITLE-ABS-KEY ("red light running" OR "red light infringement" OR "red light negation" "traffic light") AND TITLE-ABS-KEY (bicycle OR cyclist OR cycling OR riding OR "cyclist behaviour")) AND PUBYEAR > 1999	67
3	Search red light running and pedestrians: This search used the following combination of keywords: (TITLE-ABS-KEY ("red light running" OR "red light infringement" OR "red light negation" OR "red light violation" OR "red light offence" OR "red light crossing" OR "cross red light" OR "traffic light") AND TITLE-ABS-KEY (pedestrian OR "pedestrian behaviour")) AND PUBYEAR > 1999	231

In a first screening round, the 590, 67, and 231 references for drivers, cyclists, and pedestrians were screened on potential relevance for coding. **Table 3** presents the results from this first screening round.

The main criteria for exclusion for coding were:
A = Paper concerns testing or evaluation of an intervention, method, or model.
B = Red light running is not directly investigated in the paper, is a side issue (if at all subject).
C = Non-English language or duplicate.

Table 3: Initial selection of studies after the first screening round

		Exclusion criteria			
Topic	**hits**	**A**	**B**	**C**	**Initially selected**
Red light running drivers	590	367	195	8	20
Red light running cyclists	67	20	33	3	11
Red light running pedestrians	231	99	112	9	11
				Total	40

		Exclusion criteria			
Topic	**hits**	**A**	**B**	**C**	**Initially selected**
					(42 minus 2 duplicates)

In a second screening round, the 40 references were checked with the same criteria on full-text copies of the papers. **Table 4** presents the results of the second screening round and describes the final decisions concerning coding of the studies. Eventually 14 studies were coded of which 3 concerned drivers, 5 cyclists, 4 pedestrians, 1 bus drivers and 1 all road users.

Table 4: Selection of studies for coding after the second screening round

	Full reference	Coding priority	Coded
1	Akaateba, M.A., Amoh-Gyimah, R., & Amponsah, O. (2015). Traffic safety violations in relation to drivers' educational attainment, training and experience in Kumasi, Ghana. Safety Science, 75, 156-162.	Given that the study was done in Ghana and that the study is self-report only this study has *low priority* for coding.	No
2	Bell, M.C., Galatioto, F., Giuffrè, T., Tesoriere, G. (2012). Novel application of red-light runner proneness theory within traffic microsimulation to an actual signal junction. Accident Analysis & Prevention, 46, 26-36	No. Study is too much theoretically oriented. Not suitable for coding.	No
3	Bendak, S.(2011). An in-depth analysis of red light crossing problem in Saudi Arabia. Advances in Transportation Studies, 25, 67-74.	An analysis of variance was done to determine if there were significant differences in red light crossing rates between the three regions of Saudi Arabia, between cities and country towns, between peak and off-peak times and due to differences in light cycle rates. Given that the study was done in Saudi-Arabia we do not rank it as among highest priority *(low priority*).	No
4	Cai, Y., Wang, X., Chen, X. (2009). Investigation of the relationship between red-light-running frequencies and intersection features. Proceedings of the 9th International Conference of Chinese Transportation Professionals, ICCTP 2009: Critical Issues in Transportation System Planning, Development, and Management, 358, 769-776.	This study is very technical, the specific method deviates from methods in earlier studies, the results have not been published in a peer reviewed scientific journal, the results are only based on 5 intersections in Florida. Low priority.	No
5	Chen, P.-L., Pai, C.-W., Jou, R.-C., Saleh, W., & Kuo, M.-S. (2015). Exploring motorcycle red-light violation in response to pedestrian green signal countdown device. Accident Analysis & Prevention, 75, 128-136.	This study focuses very specifically on motorcyclists response to green signal countdown device (GSCD) at intersections in Taiwan. Its results cannot be compared with most other studies. *Low priority.*	No
6	Elmitiny, N., Yan, X., Radwan, E., Russo, C., & Nashar, D. (2010). Classification analysis of driver's stop/go decision and red-light running violation. Accident Analysis and Prevention, 42, 101-111.	Although this study seems relevant for the subject, it is almost impossible to code since the results are analysed by a classification tree model. The results cannot be expressed in measures of effects. *Low priority*.	No

	Full reference	Coding priority	Coded
7	Gates, T.J., Savolainen, P.T., & Maria, H.-U. (2014). Prediction of driver action at signalized intersections by using a nested logit model (2014) Transportation Research Record, 2463, 10-15.	Yes	Yes
8	Lu, G., Wang, Y., Wu, X., & Liu, H.X. (2015). Analysis of yellow-light running at signalized intersections using high-resolution traffic data. Transportation Research Part A, 73, 39-52	Main outcome variable is yellow light running rather than red light running. Therefore low priority.	No
9	Palat, B., & Delhomme, P. (2016). A simulator study of factors influencing drivers' behavior at traffic lights. Transportation Research Part F, 37, 107-118.	Main outcome variable is yellow light running rather than red light running. Therefore low priority.	No
10	Palat, B., & Delhomme, P. (2012). What factors can predict why drivers go through yellow traffic lights? An approach based on an extended Theory of Planned Behavior. Safety Science, 50, 408-417	Main outcome variable is yellow light running rather than red light running. Therefore low priority.	No
11	Porter, B.E., & England, K.J. (2000). Predicting Red-Light Running Behavior: A Traffic Safety Study in Three Urban Settings. Journal of Safety Research, 31, 1-8.	Yes	Yes
12	Rittger, L., Schmidt, G., Maag, C., & Kiesel, A. (2015). Driving behaviour at traffic light intersections. Cognition, Technology and Work, 17, 593-605.	This simulator study focused on specific driving behaviour when approaching traffic light intersections. The researchers measured driving speed and acceleration and deceleration behaviour as indicators for driving efficiency. Given the fact that the study was a simulator study and that the main outcome variables were related to speed changes, we accorded the study *low priority* for coding.	No
13	Schattler, K.L., & Datta, J.K. (2004). Driver behavior characteristics at Urban signalized intersections. Transportation Research Record, 1862, 17-23.	A series of evaluation studies were performed in Michigan to test the effectiveness of change and clearance intervals calculated according to ITE guidelines on late exits (LE) and red light violations (RLV) at nine signalized intersections in Detroit, Michigan. This study used 4 approaches at four test intersections where engineering treatments have been applied (16 total test sites) and 4 approaches at 5 control intersections. Basically this is a measure evaluation study belonging to measures part of SafetyCube.	No
14	Wang, Q., Zhang, W., Yang, R., Huang, Y., Zhang, L., Ning, P., Cheng, X., Schwebel, D.C., Hu, G., & Yao, H. (2015). Common traffic violations of bus drivers in urban China: An observational study. PLoS ONE, 10 (9), art. no. e0137954 .	Yes	Yes
15	West, S.K., Hahn, D.V., Baldwin, K.C., Duncan, D.D., Munoz, B.E., Turano, K.A., Hassan, S.E., Munro, C.A., Bandeen-Roche, K. (2010). Older drivers and failure to stop at red lights. Journals of Gerontology - Series A Biological Sciences and Medical Sciences, 65, 179-183.	Yes	Yes

	Full reference	Coding priority	Coded
16	Yan, F., Li, B., Zhang, W., & Hu, G. (2014). Red-light running rates at five intersections by road user in Changsha, China: An observational study. Accident Analysis & Prevention, article in Press.	Yes	Yes
17	Yao, H.(2015). Common traffic violations of bus drivers in urban China: An observational study. PLoS ONE, 10 (9), art. no. e0137954	Is equal to Wang et al 2015 (mentioned above)	No
18	Yuan, L., Yuan, H.-W., & Wu, Z. (2009). The research of unintentional red running violation owing to dilemma zone 2009 2nd International Conference on Intelligent Computing Technology and Automation, ICICTA 2009, 4, art. no. 5288398, 708-710	This article includes a theoretical computational analysis. It does not present behavioural data. It cannot be coded in terms of effects.	No
19	Yousif, S., Alterawi, M., Henson, R.R. (2014). Red light running and close following behaviour at urban shuttle-lane roadworks. Accident Analysis & Prevention, 66, 147-157	This article concerns tailgating and red light running at temporary traffic lights near road zones. Low priority.	No
20	Zhang, L., Wang, L., Zhou, K., Zhang, W.-B., & Misener, J.A. (2010). Use of field observations in developing collision-avoidance system for arterial red light running. Transportation Research Record, 2189, 78-88.	No, this study is too much oriented towards specific measures (to be coded at later stage SafetyCube project that deals with measures)	No
21	Bai, L., Liu, P., Chen, Y., Zhang, X., & Wang, W. (2013). Comparative analysis of the safety effects of electric bikes at signalized intersections. Transportation Research Part D: Transport and Environment, 20, 48-54.	This paper studies traffic conflicts at signalised intersections. The main analysis concentrates on predicting traffic conflicts from number and type of roads u7sers on intersection and media type of cross streets. Basically the main unit of analysis is larger than red light running. Low priority.	No
22	Guo, Y., Liu, P., Bai, L., Xu, C., Chen, J. (2014). Red light running behavior of electric bicycles at signalized intersections in China. Transportation Research Record, 2468, 28-37.	Yes	No
23	Huan, M., Yang, X.-B., Jia, B. (2013). Red-light running behavior of non-motor vehicles based on survival analysis (2013) Beijing Ligong Daxue Xuebao/Transaction of Beijing Institute of Technology, 33, 815-819.	Paper not in English language (in Chinese).	No
24	Johnson, M., Newstead, S., Charlton, J., & Oxley, J. (2011). Riding through red lights: The rate, characteristics and risk factors of non-compliant urban commuter cyclists. Accident Analysis & Prevention, 43, 323-328.	Yes	Yes
25	Pai, C.-W., & Jou, R.-C. (2014). Cyclists' red-light running behaviours: An examination of risk-taking, opportunistic, and law-obeying behaviours. Accident Analysis & Prevention, 62, 191-198.	Yes	Yes
26	Richardson, M., & Caulfield, B. (2015). Investigating traffic light violations by cyclists in	Yes	Yes

	Full reference	Coding priority	Coded
	Dublin City Centre. Accident Analysis & Prevention, 84, 65-73.		
27	Wu, C., Yao, L.,& Zhang, K.(2012). The red-light running behavior of electric bike riders and cyclists at urban intersections in China: An observational study. Accident Analysis & Prevention, 49, 186-192.	Yes	Yes
28	Yang, X., Huan, M., Si, B., Gao, L., & Guo, H. (2012). Crossing at a red light: Behavior of cyclists at urban intersections. Discrete Dynamics in Nature and Society, 2012, art. no. 490810	The central variable in this research is waiting time of cyclists at signalised intersections. The analysis is done by a Cox proportional hazard duration model. Although the outcome variable is linked with red light running, the outcomes of this study are difficult to compare with other research.	No
29	Yang, X., Huan, M., Abdel-Aty, M., Peng, Y., & Gao, Z. (2015). A hazard-based duration model for analyzing crossing behavior of cyclists and electric bike riders at signalized intersections. Accident Analysis & Prevention, 74, 33-41.	Yes	Yes
30	Dommes, A., Granié, M.-A., Cloutier, M.-S., Coquelet, C., & Huguenin-Richard, F. (2015). Red light violations by adult pedestrians and other safety-related behaviors at signalized crosswalks. Accident Analysis & Prevention, 80, 67–75.	Yes	Yes
31	King, M.J., Soole, D., & Ghafourian, A. (2009). Illegal pedestrian crossing at signalised intersections: Incidence and relative risk. Accident Analysis & Prevention, 41, 485–490.	Yes	Yes
32	Koh, P.P., & Wong, Y.D. (2014). Gap acceptance of violators at signalised pedestrian crossings. Accident Analysis & Prevention, 62, 178-185.	No central variable is gap acceptance. No data on red light running.	No
33	Kroher, M. (2014). Should I stay or should I go? Deviant behavior at traffic lights [Should I stay or should I go? Abweichendes Verhalten im Straßenverkehr] Soziale Welt, 65, 201-220.	Not in English language (German language).	No
34	Li, B. (2013). A model of pedestrians' intended waiting times for street crossings at signalized intersections. Transportation Research Part B: Methodological, 51, 17-28.	Not relevant for SafetyCube purpose. The main outcome of this study is a statistical model of intended waiting times of pedestrians. The authors argue that a exponential distribution though often used is not the best model for waiting time.	No
35	Li, B. (2014). A bilevel model for multivariate risk analysis of pedestrians' crossing behavior at signalized intersections. Transportation Research Part B, 65, 18-30.	In this paper, the author proposes a multivariate method to investigate pedestrians' risk exposure associated with unsafe crossings. The proposed method consists of two hierarchically inter-connected generalized linear models that characterize two different facets of the unsafe crossing behaviour. Given the highly technical nature of the paper it is not suitable for coding.	No

	Full reference	Coding priority	Coded
36	Rosenbloom, T. (2009). Crossing at a red light: Behaviour of individuals and groups. Transportation Research Part F, 12, 389-394.	Yes	Yes
37	Rosenbloom, T. (2011). Traffic light compliance by civilians, soldiers and military officers. Accident Analysis & Prevention, 43 , 2010-2014.	The specific hypotheses from his study concerning differences red light running between civilians and military officers are not that interesting for the SafetyCube project. This study provides little new information compared with Rosenbloom 2009 on civilian crossing behaviour. Low priority.	No
38	Rosenbloom, T., Nemrodov, D., Barkan, H. (2004). For heaven's sake follow the rules: Pedestrians' behavior in an ultra-orthodox and a non-orthodox city. Transportation Research Part F, 7, 395-404.	Yes	Yes
39	Thouez, J.P., Lord, D., Bergeron, J., Bourbeau, R., Bussière, Y., Bélanger-Bonneau, H., Rannou, A., & Latremouille, M.E. (2003). Physical and environmental characteristics of signalized intersections and pedestrian behaviour. Advances in Transport, 14, 143-148.	This study provides rather weak description of analysis and of statistical results. Therefore we rank it as *low priority*.	No
40	Wang, Q., Zhu, S., Ma, Y., He, Q., Tan, A., & Hu, G. (2011). Investigation of traffic law violations among middle school students in Hunan province and the influencing factors. Journal of Central South University (Medical Sciences), 36, 229-234.	This paper is in Chinese language with only abstract in English.	No

3.2 BACKGROUND CHARACTERISTICS OF THE CODED STUDIES

The main study approach to investigate red light running by drivers, cyclists or pedestrians is an observational study with video cameras or human observers (Johnson et al., 2011; Rosenbloom, 2005, 2009; Wu et al.,2012; Pai, 2014; Dommes et al., 2015; Richardson et al., 2015; Yan et al., 2015). Most of these studies – in Australia, Europe, China and the USA - have been conducted on intersections in a large metropolitan city area. The variables in these studies typically include characteristics of road users (e.g. age, gender, type of vehicle), characteristics of intersections (e.g. traffic volume, signal phasing), social factors (e.g. presence and behaviour of other pedestrians/cyclists) and other circumstances (e.g. times and day of the measurements, weather conditions). Some other types of research into red light running included naturalistic driving data (Gates et al., 2014), observation of bus driving behaviour along bus routes (Wang et al., 2015), a study combining cognitive and visual tests with driver behaviour data (West et al., 2010), and a red light running relative risk study (King et al., 2009). Nearly all studies have focused on the personal or environmental factors that influence the prevalence of red light running. Only one study investigated the extent to which red light running was associated with increased crash risk (King et al., 2009).

It should be noted that in most studies red light running is studied at a limited group of intersections that cannot be regarded as representative for the city. Many studies focus on high-volume intersections in busy business or centre districts. The types of intersections studied differ within a study and between studies which complicates comparing (discriminating or generalising) research findings. **Table 4** presents information on the main characteristics of the coded studies. Study sample characteristics are further described in **Table 5**.

Table 5: Background characteristics of coded studies.

Author, Year, Country	Study type	Sample/Measurement	Analysis
Porter & England, 2000, USA, Virginia	The study focused on RLR on 6 intersections in 3 Southeast Virginia cities. Appr. 44,000–115,000 vehicles enter each of these intersections daily. 2 four-way intersections for each city were chosen. Other criteria for choosing the sites included: (a) distance apart (the sites had to be in different segments of the city); and (b) space at the intersection for data collectors to park their cars unobtrusively to watch traffic flow.	Observations were carried out between February and April, 1997. Weekday observations were scheduled so that of 6 intersections, one from each city, were observed daily during a continuous 2-hour period between 3 p.m. and 6 p.m. These hours were those during which most weekday crashes occurred in Virginia. Each intersection was observed every other weekday, counterbalanced to account for differences in driving across the week.	A hierarchical forward-step logistic regression model was used to test predictors of yellow- versus red-light runners. The demographic data were collected only for these drivers, and the test between yellow- and red-light runners was thought to be more conservative to understand RLR.
Rosenbloom et al., 2004, Israel	This observational study investigated pedestrian behaviour, including red light running, as a function of gender, age, and type of cultural environment (secular city vs religious orthodox city).	The sample consisted of 1047 pedestrians who were observed at 2 busy urban intersections. The observations were conducted in 3 separate intervals at 2 busy intersections in Ramat-Gan (secular area) and Bnei-Brak (ultra-orthodox area) during the afternoon hours.	The effect of the location, gender and age was estimated by Chi square test for independence.
King et al., 2009, Australia, Brisbane	Observation survey of pedestrian behaviour at 6 signalised intersections in the Brisbane. The sites were located in the Brisbane Central Business District, having high volumes of pedestrians and vehicles.	Each intersection was observed for one half-hour period during 5 different time periods over the day; early morning (8 a.m.–10 a.m.), mid-morning (10 a.m.–12 p.m.), midday (12 p.m.–2 p.m.), mid-afternoon (2 p.m.–4 p.m.), and late afternoon (4 p.m.–6 p.m.), on Thursdays and Fridays in 2 successive weeks in November.	For calculation of relative risks, the two "red man" categories were combined, and the risk per crossing event was calculated, i.e. number of crashes per unit time in that behavioural category divided by number of crossings per unit time for the category. Next, relative risk was calculated for each illegal behaviour by dividing its risk by the risk involved in legal crossing.
Rosenbloom, 2009, Israel, Tel Aviv	An observational study that compared the road behaviour of individual pedestrians at an intersection with a traffic signal to that of groups of pedestrians (at the same intersection).	1392 pedestrians were unobtrusively observed in an urban setting at a pedestrian street crossing of undivided streets; 842 were female (60.5%) and 550 were male (39.5%). the observations took place between 7:30 and 8:30 in the morning.	RLR (crossed–did not cross) was analysed using a logistic regression, for the relative contributions of the pedestrian's gender, the number of pedestrians who were waiting at the crossing when the pedestrian arrived, the number pedestrians who joined afterwards, the traffic volume on the red-light phase, and the occurrence of another pedestrian crossing on a red light.
West et al.,, 2010, USA, Maryland	Multiple measures of vision and cognition were collected at the baseline examination of a population of 1,425 drivers aged 67-87 years in greater Salisbury, Maryland. Each driver had	The researchers recruited participants from a complete listing of all Department of Motor Vehicle Administration (DMVA) licensees aged 67 – 87 years who resided in ZIP codes of the greater Salisbury metropolitan area. Of 8,380	The incidence rate ratio was used as the measure of association. Variables found to be associated with failure in measurement round 1 were used in predictive models of failure to stop at a red light in round 2.

	real-time data collected on 5 days of driving performance at baseline and again at 1 year. Failure to stop at a red traffic light was the primary outcome.	registered licensees, 4,503 (54%) returned postcards. Of 4,503, 6.0% were no longer driving, 1.6% were deceased, and 2.3% were no longer living in the eligible area. Of the remainder, 42% agreed to participate and 83% of them were recruited to the clinic examination (N = 1,425).	
Johnson et al., 2011 Australia, Melbourne	A cross-sectional observational study was conducted using a covert video camera to record cyclists at 10 sites across metropolitan Melbourne, Australia from October 2008 to April 2009.	Observations of cyclists were made at 10 sites along the most frequently used on-road commuter routes in metropolitan Melbourne. All sites were within 5 km of the CBD, had 2 lanes of forward travel, 4 lanes of cross traffic, a pedestrian crossing and a tram line parallel to the right vehicular lane. Morning observation sites were in-bound and afternoon observation sites were out-bound. Site gradient was flat with the exception of the continuous site (type 3) which had one downhill (morning) and one uphill (afternoon) site. 3 groups of predictor variables were recorded: location, cyclist characteristics, and other road users.	A single binary logistic regression analysis model was used; the model included all available predictor variables and selected interactions simultaneously. The location variables/categories were time (AM/PM), gradient (flat/downhill/uphill) and cycling facility type (standard/ centre/ continuous).The cyclist variables/ categories were: gender (male/female), bicycle type (road bike: drop handlebars; flat bar/ mountain bike; other: included recumbent bikes, folding bikes/ladies bikes) and clothing (full cycling: jersey and cyclist pants/half cycling: either jersey or cyclist pants / non-cycling: all other clothing), helmet use (yes/no), direction of travel (left/ straight); The road user variables/ categories were: nr. of other cyclists, nr. of cross vehicles (count from left and right), and presence/ absence of a vehicle at the intersection (yes/no); the traffic volume (count) was categorised (0, 1–10, 11–20, 21+).
Wu et al., 2012, China	A cross-sectional observational study was conducted at three four-armed signalized inter-sections in Beijing. Two criteria were used to select the sites: 1. the selected sites should represent the typical intersection design characteristics and traffic conditions of urban areas in Beijing; 2. there has to be a reasonably high number of two-wheeled traffic (both electric bikes and regular bicycles) during the observation period.	All road users who entered the intersection were recorded on video, but only the riders (both e-bike riders and cyclists) arriving during red light phases were coded. The researchers restricted the coding process to include only riders traveling through the intersection. Left-turners were excluded because of the limited field of view of the cameras, while riders making right turns were also ignored because they are not subjected to the traffic signal control according to the road rules in China. The first set of variables described the riders' individual characteristics, including gender, estimated age group, and vehicle type. The second set of variables focused on the riders' movement information, including the times of arrival at and departure from the stop line, the time when crossing is completed, and the status of the traffic light at each of these times. The last set of variables of concern were situational factors, including cross traffic volume, group size, number of	To analyse the factors that are associated with RLR behaviour, a logistic regression analysis was conducted. The model included all variables simultaneously. The outcome measure for was red-light compliance (yes/no). Non-compliance (RLR) was defined as riding across the stop line when the traffic light is red. The regression analysis included 10 predictor variables: 1. Rider type (E-bike riders vs. Cyclists), 2. Gender, 3. Age group Young vs. old, 4. Age group Middle-aged vs. old; 5. No. of riders waiting upon arrival, 6. No. of riders crossing against traffic light; 7. Intersection site (Y–Y vs. X–Z); 8. Intersection site (Z–X vs. X–Z), 9. Cross traffic volume Low vs. high, 10. Cross traffic volume Median vs. high.

		riders waiting upon arrival, and number of riders crossing against the red light.	
Gates et al., 2014, USA	Naturalistic driver behavioural data were collected at 72 signalized intersection approaches selected from four regions of the United States. Data were obtained for 6,208 vehicles that were approaching a study intersection during the yellow interval.	Driver behavioural data were collected by use of a consumer-grade high definition video camera installed for 3 to 5 h at each of the 72 study approaches. Data were obtained for a total of 6,208 first-to-stop or last-to-go vehicles, including 3,575 (57.6%) vehicles that stopped, 2,533 (40.8%) vehicles that entered the intersection before the end of the yellow indication, and 100 (1.6%) vehicles that committed RLR by entering after the end of the yellow indication.	a nested logit model was estimated; the elasticity values for continuous variables may be interpreted to be the effect (in percentage) that a 1% change in the independent variable has on the probability of the respective driver action; (pseudo) elasticity values for the categorical variables may be interpreted as the effect (in percentage) that a change between levels (i.e., from 0 to 1) has on the probability of the respective driver action.
Pai & Jou, 2014 Taiwan	The current research used video cameras to collect the data (e.g., bicyclist attributes, temporal factors, roadway characteristics, and weather factors as independent variables) at several selected junctions, Toayuan County, Taiwan.	12,447 observations on bicyclists crossings; the survey was carried out on 8 intersections, four 3-arm and four 4-arm, four with 50 km/hr and four with 60 km/hr speed limit, with crossing distance ranging from 23 to 43 meter, with peak hour traffic volumes of first stream (closest to bicyclists) ranging from 2100 to 4000, and off peak hours from 700 to 2000).	A mixed logit model was assessed to explore the effects of various characteristics (characteristics cyclists, weather, speed limit, type junction etc.) on 3 behaviours (risk-taking, opportunistic, law-obeying). To uncover the marginal effect of the explanatory variables, the researchers examined the change in estimated probability of crossing behaviours when a variable changes its value from zero to one (= "the direct pseudo-elasticity of the probability with respect to the explanatory variable".
Dommes et al., 2015 France	The study combined observational data with questionnaires answered by 422 French adult pedestrians. 13 behavioural indicators were extracted (12 before and while crossing, and red light violation), and the roles of several demo-graphical, contextual and mobility-associated variables were examined	15 urban crosswalks located at 6 different signalized intersections in the city of Lille, in the north of France, were chosen as experimental sites. All were on two-way streets, with no pedestrian refuge islands. They all had zebra crossings, pedestrian and traffic lights, and a speed limit of 50 km/h on each road segment. Traffic density was available for each observed crosswalk in three categories (AADT): from 1500 to 6000 vehicles per day (4 crosswalks), from 6001 to 13,000 vehicles per day (4 crosswalks) and from 13,001 to 30,000 vehicles per day (7 crosswalks).	regression analysis was carried out to examine illegal crossings at red lights; for the logistic regression analysis, the predictive factors were automatically entered one at a time using the forward stepwise method, where non-significant predictive factors were removed until the final model yielded only the most significant effects
Richardson & Caulfield, 2015, Ireland, Dublin	An observational survey and an online questionnaire.	4 intersections in Dublin, 2 with cycle track and 2 with cycle lanes; all 4 sites were surveyed on the same day; each site observed twice from 8 to 10 am in half-hour intervals spread out over the eight surveys; thus, each site was surveyed for a total of 4h. 2061 cyclists, all aged 18 or older, completed an online survey with questions regarding the frequency with which respondents stopped at red lights and the reason(s) for cycling through a red light.	Multinomial logistic (MNL) regression was used to analysis the data since some of the dependent variables examined had more than two outcomes e.g. cyclist behaviour. MNL regression measured the extent to which each independent variable (e.g. age, gender) played a part in predicting the likely value of the dependent variable e.g. cyclists who broke the lights.

Wang et al., 2015, China, Changsha City	Observational study to record three types of traffic violations among bus drivers in Changsha City, China: illegal stopping at bus stations, violating traffic light signals, and distracted driving.	the study included 256 round-trip observations on 32 bus routes, recording the bus driver behaviour at 7,612 bus stations, 5,656 road intersections, and 14,384 road sections. After excluding rare missing records due to the crowded buses that prohibited valid data collection, the study had collected valid records from 7,611 bus stations, 5,612 road intersections, and 14,277 road sections.	Poisson regression examined factors that predicted bus driver violations. First, an ordinary logistic regression model was developed to identify the significant variables from the aspects of driver characteristics, driving conditions, and vehicle types. In order to account for unobserved heterogeneity among different types of intersections, a random effects logistic regression model was also adopted.
Yan et al., 2015, China	Portable digital devices were used to record red-light running violations at five selected intersections.	Observations were conducted on 3 types of days (weekday, weekend, holiday). The selections of weekday, weekend and holiday were determined at random. For each selected day, the researchers conducted the observations in 4 time periods, including 2 peak hours (7:30–8:30 am and 5:30–6:30 pm) and two off-peak hours (9:30–10:30 am and 3:30–4:30 pm). In total, the traffic flows of 60 h were recorded at the five inter-sections. In total, 162.124 vehicles and 31.649 pedestrians were recorded, including 117.557 cars, 11.946 coaches, 333 trucks, 27.974 motorcycles and 4314 bicycles. In general, cars, pedestrians, and motorcycles were most observed accounting for 60.7%, 16.3 and 14.4%.	the violation rate of RLR was calculated as the numbers of vehicles or pedestrians being observed running red light divided by total number of vehicles or pedestrians x 100%; also an adjusted violation rate ratio (VRR) was used to quantify the effects of type of day and time period based on an Poisson regression model.
Yang et al. 2015 China	A cross-sectional observational study was conducted at six signalized intersections in Beijing, China. Field observations with video recordings were used.	The cameras were hid behind the intersection stop line so that it would not be visible. The data collection was conducted on weekdays during the daytime (i.e., 7:00 a.m.–6:30 p.m.) in good weather conditions.	In this study, the length of time is the waiting duration of a rider who arrives at the intersection during the red light period. The waiting time for each rider was taken as the difference between the arrival time at the intersection and the departure time when he/she begins to cross the intersection. The waiting time can be classified into uncensored data and censored data. It is defined as uncensored data if the rider terminates the waiting duration to cross the intersection during the red light period. Otherwise, it is considered as censored data as long as the rider terminates the waiting duration to cross the intersection during the green light period. The Cox proportional hazards model is the most commonly used semi-parametric model in which exp(βX) is used as the function form of the covariate influence. The researchers expanded proportional hazards model to include an unobserved random effect, called a frailty, allows for modelling association between individual duration times within a group.

3.3 OVERVIEW OF THE RESULTS OF THE ANALYSED STUDIES

Table 6: Main results of coded studies

Author, Year, Country	**Main RLR outcomes and modifying conditions**
Porter & England, 2000, USA, Virginia	- Safety-belt use and ethnicity were the only demographic variables to predict RLR after controlling for contextual predictors; drivers who were unbuckled were 1.32 times as likely as those who were buckled to run the red light; non-Caucasians were 1.19 times as likely as Caucasians to run red lights. - Weather was not important, but the city and time factors were significant. - City differences may likely have resulted from intersection size and volume differences (i.e., larger inter-sections and higher volumes seemed to be related to higher RLR rates). - Time represented RLR variations during the late afternoon and rush hour periods; the odds ratio for time was 0.9979: red-light running tended to decrease the later the observation became.
Rosenbloom et al., 2004, Israel	- Males were more inclined to RLR than women ($X2(1) = 19.78$, $p < 0.01$). - Pedestrians in Bnei-Brak (ultra-orthodox) were more likely to RLR than pedestrians in Ramat-Gan ($X2(1) = 48.962$, $p < 0.01$). - Age was a factor in the RLR rate in Ramat-Gan ($X2(2) = 6.939$, $p < 0.05$), but not in Bnei-Brak. In Ramat-Gan, the elderly and children appear to adopt safer patterns than adults (0%, 3.9%, 8.6%, respectively, for running a red light). - Beyond age and gender, pedestrians in the orthodox environment committed about three times more violations than those in the secular environment.
King et al., 2009, Australia, Brisbane	- The risk ratios showed that crossing against the lights and crossing close to the lights both exhibit a crash risk per crossing event approximately eight times that of legal crossing at signalised intersections (8.1 resp. 7.8).
Rosenbloom, 2009, Israel, Tel Aviv	- 13.5% of the pedestrians arriving in the red-light phase crossed the street on a red light. - The more pedestrians present at the curb, the lower was the rate of people crossing on red. - No evidence for the hypothesis of the study that the probability that someone will cross the street when the light is red is higher in a situation where another pedestrian is already crossing on red than in a situation where the other people on the curb are waiting for the green light. - A higher rate of males crossed the street on a red light than females, independent of whether they were individuals or in a group. - Traffic volume did not predict pedestrians' behaviour.
West et al.,, 2010, USA, Maryland	- Of those who encountered a traffic light at round 1, 3.8% of persons failed to stop appropriately (assessed over a 5-day period); offenders were modestly clustered, with 15% of offenders failing 10% or more of the traffic lights they encountered. - Mean failure rates for drivers encountering 1 – 6, 7 – 11, 12 – 17, 18 – 27, >27 traffic lights were 0, 0.0035, 0.0018, 0.0024, 0.0020. - At round 1; race, the cognitive measure of attention, and AVF (= attentional visual field) were significantly related to failure to stop at a red light. - In the multivariate analysis, ethnicity (black/whites), pain, and visual attention (AVF) were significant predictors of red light running at round 1. In neither round was age (between the ages of 67 and 87 years) or the measure of psychomotor speed significantly related to failure to stop at a red light. Loss of AVF was related to failure to stop at a red light at both rounds. - The stronger predictor of failure to stop at a red light was the loss of AVF in the vertical meridian. The researchers hypothesize that, as older drivers approach an intersection and are paying attention to surrounding cars and traffic flow; the loss of vertical attentional field would hamper detection of the high-hanging traffic signal, which may have changed colour.
Johnson et al., 2011 Australia, Melbourne	- The rate of red light non-compliance was 7% (n=4225 cyclists). - Cyclists turning left were 28.4 times more likely to RLR than cyclists riding straight. - Females had odds of RLR of 0.60 compared with males. - Cyclists at the centre facility had a 2.6 higher odds of RLR than cyclists at the standard facility site. - RLR was most likely when the cross traffic volume was low and decreased when cross traffic volume increased. - When compared to cyclists at the intersection alone, odds of RLR were 0.39 compared when a driver was present and 0.26 when other cyclists were present.
Wu et al.,	- More than half (56%) of the two-wheelers crossed the intersection against a red light.

2012, China	- A lower proportion of older riders ran against the red lights than that of the younger groups. - The RLR probability of a rider was higher when she or he was alone, when there were fewer riders waiting, and when there were riders already crossing on red. - Two-wheelers' crossing behaviour was categorised into 3 distinct types: law-obeying (44%), risk-taking (31%) and opportunistic (25%). - Males were more likely to act in a risk-taking manner than females, and so were the young and middle-aged riders compared with the old ones. - The rider type (e-bike riders vs. cyclists) did not predict RLR decisions after the effects of other variables were statistically controlled.
Gates et al., 2014, USA	- Drivers were 125.5% more likely to commit RLR when they approached signals with yellow durations of less than or equal to 4.5s than when they approached signals with longer yellow durations. - Drivers were 41% more likely to commit RLR if they were traveling as a part of a platoon of vehicles. - RLR was also found to be 21% more likely to occur at locations with speed limits ≤ 40 mph. - Drivers were more likely to commit RLR when they were located a greater distance from the intersection at the onset of the yellow indication. The elasticity for this variable suggests that for drivers traveling through the intersection, each 1% increase in distance from the intersection at the onset of the yellow indication results in a 9% increase in the likelihood that RLR will be committed. - Go-through drivers approaching the intersection at a lower rate of speed before the yellow indication were also found to have a greater likelihood of RLR, likely because of the greater travel time to the intersection. A 3% increase in RLR was estimated for every 1% decrease in approach speed.
Pai & Jou, 2014 Taiwan	- Off-peak hours were associated with an increase in the probability of RLR risk-taking behaviours (19%). - Male cyclists are associated with an increased probability of RLR risk-taking behaviours (46%). - Bicyclists of pupils in uniform (6-18 yrs.) were found to be more likely to have risk-taking and opportunistic behaviours (79% and 85% respectively) than the other age groups. - Bicyclists carrying passengers were less violation-prone (89% and 81% for risk-taking and opportunistic behaviours). - Riders of electric bicycles were more likely than those of traditional bikes to engage in RLR risky behaviours (i.e., 33% and 41% for risk-taking and opportunistic behaviours). - Un-helmeted cycling was associated with an increase in the probability of RLR risk-taking and RLR opportunistic behaviours, 76% and 79% respectively. - Fine weather was found to result in an increased likelihood of RLR risk-taking behaviours (9%). - Roadways with speed limits of 60 km/h increased the probabilities of risk-taking and opportunistic behaviours (72% and 76% respectively). - Roadways with red lights that endure 30s had higher probability of opportunistic behaviours (74%). - Bicyclists travelling through T/Y intersections tended to engage in more risk-taking behaviours (113%). - There appears to be an increased likelihood of risk-taking and opportunistic behaviours when traffic volume is low (<15 min–1), resp. 69% and 53%. - Countdown signals with duration of 30s were associated with bicyclists' RLR opportunistic behaviours (41%).
Dommes et al., 2015 France	- Demographic factors, age and gender, did not explain RLR; neither did traffic density or variables linked to individual mobility. - Two of the contextual factors explained RLR: the probability of crossing against the light was larger when pedestrians crossed alone rather than in groups, and when vehicles were parked near the crosswalks. - The probability of RLR was associated with 3 precursor behaviours: pedestrians who crossed against the signal were more likely to look toward the traffic before crossing but less likely to look toward the light or toward the ground before crossing. - RLR was associated with three behaviours during the crossing phase: pedestrians who crossed against the light where more likely to run while crossing, to look toward the traffic while crossing, and to cross diagonally.
Richardson & Caulfield, 2015, Ireland, Dublin	- An average of 61.9% of cyclists break the lights in Dublin City Centre (n = 3064). - An average of 97.8% of cycle track users broke the lights with the large majority of violations occurring during the pedestrian green phase (n = 1677). - The average RLR rate by cycle lane users was significantly lower at 18.6%, with the majority breaking the lights during a motorist phase (n = 1387). - Males were the most likely to break lights.

Wang et al., 2015, China, Changsha City	- Of 5,612 observations at road intersections, 2.2% were coded as the bus driver 'running traffic lights' (95% CI: 1.9%- 2.7%) . - The incidence rate of RLR was lower on cloudy days compared to sunny days (adjusted Incidence Rate Ratio (IRR): 0.60).
Yan et al., 2015, China	- The overall violation rates were much higher for motorcyclists, bicyclists and pedestrians than for motor vehicle drivers (18.54–18.74 vs. 0.14 per 100 vehicles/pedestrians). - The violation rate for motor vehicle drivers on holiday was 1.89 times that on weekday (95% CI: 1.33–2.70). - The violation rate of RLR for motorcyclists was higher in off-peak hours than in peak hours (adjusted VRR: 1.11; 95% CI: 1.06–1.18), but lower on weekends and on holiday than on weekdays (adjusted VRRs: 0.80, 95% CI: 0.75–0.85; 0.65, 95% CI: 0.61–0.69). - The violation rate was 32% lower on weekends than on weekdays (adjusted VRR: 0.68; 95% CI: 0.57–0.81) for bicyclists. - For pedestrians, the violation rates were higher on weekends and on holiday and in off-peak hours than those on weekdays and in peak hours, having adjusted VRR of 1.09, 1.67 and 1.30, respectively.
Yang et al. 2015 China	- 2322 two-wheeled riders approaching the intersections during red light periods were observed in Beijing, China. - The RLR behaviour of most riders was dependent on waiting time; they were inclined to terminate waiting behaviour and run against the traffic light with the increase of waiting duration; over half of the observed riders could not endure 49s or longer. 25% of the riders could endure 97s or longer. - Rider type, gender, waiting position, conformity tendency and crossing traffic volume were identified as having significant effects on riders' waiting times and RLR violation hazards.

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Risk Taking - Overtaking

Passing a slower moving vehicle by entering the opposing traffic lane

1 Summary

Soteropoulos, A., July 2016

1.1 COLOUR CODE: YELLOW

Research shows compared to other vehicle manoeuvres (risky) overtaking tends to increase accident severity. Regarding accident frequency however it seems that only a small share of crashes occurs while overtaking another vehicle. In addition, some situational factors (traffic volume, speed) and driver characteristics (age, gender) seem to influence (the frequency of) risky overtaking.

1.2 KEYWORDS

Overtaking, passing, risk, road safety, lane changing

1.3 ABSTRACT

Overtaking is known as one of the most complex manoeuvres for road users. From studies in the international literature, it appears indeed that compared to other vehicle manoeuvres, (risky) overtaking significantly increases accident severity, however regarding accident frequency – although associated with a higher crash risk in one study – it seems that only a small share of crashes occurs while overtaking another vehicle. Moreover, studies indicate that various situational factors and driver characteristics – especially age – seem to influence (the frequency of) risky overtaking: younger drivers tend to be more likely to engage in risky overtaking manoeuvres, than older drivers. This seems to be also the case for other situational factors (traffic volume, speed) and driver characteristics (gender).

1.4 BACKGROUND

How is (risky) overtaking defined?

Overtaking is a complex task, in which the driver needs to monitor the interaction with a lead vehicle, estimate the time to collision of any oncoming vehicle and take into account the time required to complete the overtake based on their own speed and skill level (Jamson et al., 2012). The overtaking task can be divided in five different phases, where different subtasks have to be made (Hegeman et al., 2005). Furthermore, different overtaking strategies can be distinguished: accelerative overtakes (increasing velocity throughout the manoeuvre), flying overtakes (no braking beforehand to follow the vehicle in front), piggy-back overtakes (following another overtaking vehicle) and multiple overtakes (passing more than one vehicle) (Clarke et al., 1998). For indicating the riskiness of overtaking manoeuvres, several parameters such as the distance of passing, the lateral distance or the safety margin to the overtaking vehicle are used (Bella, 2001, Papakostopoulos et al., 2015).

What is the effect of (risky) overtaking on road safety?

Overtaking, because of its complexity, is potentially one of the most dangerous manoeuvres for road users, since it can put your vehicle into the path of oncoming traffic often at high speeds and the speed of both vehicles combined creates a much more serious impact in the event of a head-on collision (A9 Safety Group, 2016).

Which factors influence the effect of overtaking on road safety?

When overtaking several situational factors and driver characteristics play a decisive role. Regarding driver characteristics; age, gender, annual mileage, attitude or behaviour seem to be relevant to the frequency of risky overtaking (Leung and Starmer, 2005, Havârneanu and Havârneanu, 2012, Sümer et al., 2006, Forward et al., 2009). Regarding situational factors; traffic volume, traffic scenery or speed related factors appear to influence the frequency of risky overtaking (Bella, 2011, Papakostopoulos et al., 2015, Bar-Gera and Shinar, 2005). For motor vehicles overtaking bicycles, infrastructure factors such as road/lane type and width particularly tend to influence the frequency of risky overtaking (Shackel and Parking, 2014, Love et al., 2012).

How is the effect of (risky) overtaking on road safety measured?

International literature indicates that regarding the effects of (risky) overtaking on road safety roughly two kinds of studies exist, (1) studies investigating the effect of risky overtaking on accident frequency or accident severity (mostly observational), and (2) studies instead investigating the relationship between different situational factors in an overtaking task, or driver characteristics and parameters which are potential indicators of risky overtaking (mostly experimental). Overall, studies mostly applied multivariable linear statistical models, such as logistic or ordered probit models, or used driving simulators. Research on risky overtaking was mostly conducted in the United Kingdom or other European countries as well as in the United States. Most research focuses on motor vehicles overtaking other motor vehicles, however some studies also focus on motor vehicles overtaking cyclists.

1.5 OVERVIEW OF RESULTS

Regarding the effects of (risky) overtaking on road safety, it appears that compared to other vehicle manoeuvres, overtaking significantly increases accident severity. However regarding accident frequency, although it was associated with a higher crash risk in one study, it seems that only a small share of crashes occur while overtaking another vehicle. Studies which instead investigate the relationship between different situational factors in an overtaking task, or driver characteristics and parameters which indicate effects regarding risky overtaking, showed that in particular age is significantly (negatively) associated with risky overtaking, meaning that younger drivers tend to be more likely to engage in risky overtaking manoeuvres than older drivers. In addition, it seems that other situational factors such as traffic volume and speed as well as other driver characteristics like gender also seem to influence the frequency of risky overtaking.

2 Scientific Details

2.1 THEORETICAL BACKGROUND

Overtaking is one of the most complex tasks for road users. In an overtaking manoeuvre, the driver needs to monitor their interaction with a lead vehicle, estimate the time to collision of any oncoming vehicle and take into account the time required to complete the overtake based on their own speed and skill level (Jamson et al., 2012). The overtaking task can be divided in five different phases, where different subtasks have to be made (Hegeman et al., 2005).

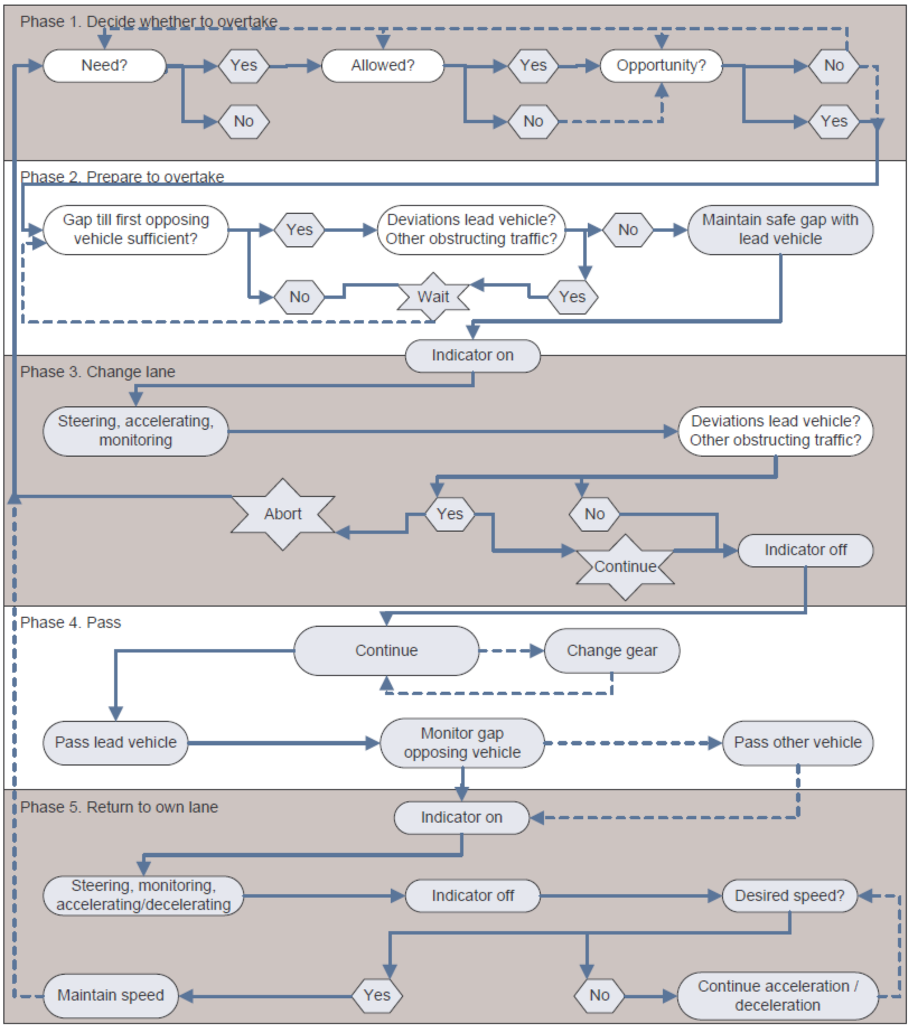

Figure 1: Phases of the overtaking task on roads with opposing traffic (Hegeman et al. 2005)

Furthermore, different overtaking strategies can be distinguished: accelerative overtakes, flying overtakes, piggy-back overtakes and multiple overtakes (Clarke et al,. 1998). At *accelerative overtakes* the over-taker approaches the lead vehicle, has to wait for an overtaking opportunity and therefore adjusts its speed to the speed of the lead vehicle. After some time it is able to overtake the lead vehicle and the over-taker will then accelerate during the overtaking manoeuvre. At *flying overtakes* the over-taker drives with its desired speed and observes the lead vehicle and is directly able to overtake the lead vehicle without adjusting its speed. At *piggy-back overtakes*, a vehicle overtakes the lead vehicle and the over-taker follows this vehicle; the over-taker stays behind the preceding vehicle, while they both overtake the lead vehicle. At *multiple overtakes*, the over-taker overtakes one or more vehicles behind the lead vehicle and in the same move, it also overtakes the lead vehicle – the minimal number of vehicles that are overtaken is 2 (Hegeman et al., 2005).

2.2 METHODOLOGY

Literature search was carried out in two databases (Scopus and a KFV-internal literature database) with separate search strategies (for a detailed description see "Supporting documents").

Description of studies

The following table gives an overview on study samples and design of the coded studies on (risky) overtaking.

Table 1: Information on sample and design of coded studies focussing on motor vehicles overtaking other motor vehicles

Author(s), year, country	Sample, method/design and analysis	Risk group/ cases	Control group/ controls	Research conditions
Bar-Gera & Shinar, 2005, Israel	Experimental Study, Simulator Study additional Logistic Regression	N=19 young drivers (22-29 years) with at least four years of driving experience		different designed speed differences to vehicle ahead; controlling for relative speed of simulated vehicle and stabilization distance
Bella, 2011, Italy	Experimental Study, Simulator Study	N=32 Drivers with a driving experience of at least three years		Four different scenarios (primary differed in traffic volume) – influence on driver behaviour in the passing manoeuvre
Dingus et al., 2016, USA	Naturalistic driving data, case-control study (3 year period) Odds ratios	N= 905 Drivers with crash events	N= 3500 Drivers (alert attentive sober driving episodes in same length as crash exposure)	SHRP 2 NDS database
Forward, 2009, Sweden	Experimental Study Questionnaire Hierarchical multiple regression	N=275 participants between 20 and 75 years		Influence of specific factors (e.g. attitude, subjective norms) on intention to overtake
Garder, 2006, USA	Observational Study	N= 3136 head-on crashes in Maine, USA		Crashes were analysed regarding the (primary) contributing factors for fatal and non-fatal crashes
Gray et al., 2008, United Kingdom	Observational Study, Ordered probit Model	N=n/a (all accidents involving young male drivers between 1991 and 2003 in UK)		Probability of each outcome of dependent variable estimated based upon changes in each of the independent variables in turn
Havârneanu & Havârneanu, 2012, Romania	Experimental Study Questionnaire Multiple stepwise linear regression	N=605 drivers with a driving licence		Influence of specific factors for deviant behaviour in the context of legal overtaking (=illegal overtaking)

Author(s), year, country	Sample, method/design and analysis	Risk group/ cases	Control group/ controls	Research conditions
Jamson et al., 2012, UK	Experimental Study, Simulator Study	N=26 drivers in possession of a full driving licence and driving for at least three years		Several scenarios of a 2+1 road section (variation in length) – influence of Intelligent Speed Adaption on driver's overtaking decisions
Leung & Starmer, 2005, Australia	Single-blind randomized study; Experimental Study; Simulator Study	N=16 mature drivers (25-35 years)	N=16 young drivers (18-21 years)	Different experimental tasks (time-to-collision estimations, overtaking manoeuvre) – influence of age (combined with modest dose of alcohol) on the performance of tasks
Papakostopoulos et al., 2015, Greece	Naturalistic Observation; Observational Study	N=45 analysed cases of overtaking		Influence of three different traffic scenes on the overtaking manoeuvre
Sümer et al., 2006, Turkey	Experimental Study Questionnaire Hierarchical regression analysis	N=785 drivers		Influence of driving skills and safety skills as well as demographic and exposure variables on overtaking tendencies
Zhang et al., 2000, Canada	Observational Study; Cross-sectional Multivariate unconditional logistic regression	N=711 fatal injury crashes and 17367 minimal-injury crashes involving elderly drivers aged 65+		Controlling for confounding factors using the multivariate unconditional logistic regression analysis

Table 2: Information on sample and design of coded studies focussing on motor vehicles overtaking cyclists

Author(s), year, country	Sample, method/design and analysis	Risk group/ cases	Control group/ controls	Research conditions
Love et al., 2012, USA	Experimental Study Multiple linear regression	N=586 motor vehicle passes, 5 cyclists		Influence of lane width and bicycle infrastructure on vehicle passing distance (motor vehicles overtaking cyclists)
Shackel & Parkin, 2014, UK	Experimental Study	N=500 overtaking instances		Influence of road layout and vehicle and driver factors on behaviour of motor vehicles overtaking cyclists

Description of the main research methods

There are two main approaches for investigating the effects of (risky) overtaking on road safety: mostly experimental studies and observational studies are used to investigate the effects of (risky) overtaking, and overall most studies applied multivariable linear statistical models.

Most of the observational studies (Garder, 2006, Zhang et al., 2000, Gray et al., 2008) mainly investigate the effects of (risky) overtaking on accident frequency or accident severity, using logistic or ordered probit models or only undertaking a crash data analysis regarding contributing factors. Two observational studies (Dingus et al., 2016, Papakostopoulos et al., 2015) used naturalistic observations.

The experimental studies however mostly rather investigated the relationship between different situational factors in an overtaking task (e.g. traffic volume, speed etc.) or driver characteristics (e.g. age, gender etc.) and parameters which indicate effects regarding risky overtaking (e.g. distance of passing, safety margin to overtaking vehicle, illegal overtaking, time to collision), indicating which "conditions" contribute to (risky) overtaking behaviour. Most studies deployed hierarchical and multiple linear regression models (Forward, 2009, Havârneanu and Havârneanu, 2012, Love et al., 2012, Sümer et al., 2006) or used driving simulators (Bella, 2011, Jamson et al., 2012, Leung and Starmer, 2005, Bar-Gera and Shinar, 2005).

The studies identified mostly focus on motor vehicles overtaking other motor vehicles, however, some studies also focus on motor vehicles overtaking cyclists (Shackel and Parkin, 2014, Love et al., 2012). Most research has been done in the United Kingdom (3 studies) and the United States (2 studies). But also European countries like Italy (1 study), Greece (1 study), Sweden (1 study) and Romania (1 study) or countries like Australia (1 study), Canada (1 study), Israel (1 study), and Turkey (study) were part of the examination.

2.3 OVERVIEW RESULTS

The following tables present information on the main outcomes of all coded studies. The coded studies were quite different in design and methods, so it was not feasible to give a summarized analyse in terms of vote and count results.

Table 3: Study results regarding (risky) overtaking

Author(s), Year, Country	**Exposure variable**	**Dependant / outcome type**	**Effects on Road Safety**		**Main outcome - Description**
Bar-Gera & Shinar, 2005, Israel	Speed difference to vehicle ahead	Frequency of passing manoeuvres	–	Values for relative difference = -0.2424 – 0.3939	Non-significant positive association of speed difference to vehicle ahead and frequency of passing manoeuvres
Bella, 2011, Italy	Traffic volume	Following gap, Distance of passing, Time to collision	↗	Values for Absolute Difference = 2.40 – 122.00	Significant decrease of the following gap, the distance of passing and the time to collision with an increase in traffic volume
Dingus et al., 2016, USA	Illegal/unsafe passing	Observed crashes	↗	OR = 14.4 CI=95% CI=7.2-28.8	Risk of being involved in a crash when overtaking is 14.4 times higher.
Forward, 2009, Sweden	Attitude, Perceived ease (TPB), Descriptive Norm, Past behaviour	Dangerous Overtaking	↗	values for r = 0.30 – 0.55 values for p =<0.001	Statistically significant relevance of attitude, perceived ease, descriptive norm and past behaviour for the intention to perform a dangerous overtaking
	Subjective Norm (TPB), Age	Dangerous Overtaking	–	values for r = 0.06 – 0.09	Non-statistically significant relevance of subjective norm and age for the intention to perform a dangerous overtaking
Garder, 2006, USA	Improper overtaking/passing	Fatal and non-fatal head-on crashes	–	values for relative Proportion = 0.0714 – 0.526	Only 7.14% of fatal crashes and 5.26% of non-fatal crashes occurred while overtaking another vehicle.
Gray et al., 2008, United Kingdom	Overtaking (compared to going ahead – UK & London)	Injury severity	↗	r = 0.0521 – 0.0943	Significant higher injury severity when overtaking compared to going ahead

Havârneanu & Havârneanu, 2012, Romania	Usual deviant behaviour	Illegal overtaking	↗	r = 0.04, p<0.01	Significant positive association between usual deviant behaviour and illegal overtaking
	Risk perception, Age	Illegal overtaking	↘	values for r = -0.06 - -.,02 values for p= <0.01	Significant negative association between risk perception and age and illegal overtaking
Jamson et al., 2012, UK	Intelligent Speed Adaption (ISA) - mandatory	overtaking attempts, successful overtaking	↗	values for OR = 3.33 – 6.10 values for p =<0.001	Drivers become less inclined to carry out overtaking when mandatory ISA was active and when they did, the outcome was less likely to be successful and more likely to lead to an abandonment of overtaking.
Leung and Starmer, 2005, Australia	Overtaking - participant age (mature to young)	Speed	↘	Absolute Difference = .3.19, p<0.05	Mature drivers tended to speed to a greater extent compared to young drivers but also demonstrated more caution by making it a priority to return to their own lane as quickly as possible.
Love et al., 2012, USA	Lane width, Bicycle lane streets (compared to standard lanes)	Vehicle passing distance	↘	values for p = <0.0001	Significant increase of vehicle passing distance with increasing lane width and for bicycle lane streets (compared to standard lanes)
	Sharrows (compared to standard lanes)	Vehicle passing distance	–	p=0.28	Non-significant increase of vehicle passing distance for bicycle lane streets (compared to standard lanes)
Papakostopoulos et al., 2015, Greece	Opposite traffic situation (oncoming vehicle to no-oncoming vehicle; new-oncoming vehicle to no-oncoming vehicle)	Safety Margin to Opposite vehicle and to overtaking vehicle, Lateral distance to overtaking vehicle	↗	values for absolute difference = -6.06 - -0.06	Significantly lower safety margin to the opposite vehicle and to the overtaking vehicle and significantly lower lateral distance to overtaking vehicle in the traffic situation with oncoming and new-oncoming vehicle than in the traffic situation with no oncoming vehicle.
	Opposite traffic situation (oncoming vehicle to no-oncoming vehicle)	Safety Margin to vehicle ahead	–	values for absolute difference = 1.14 – 1.26	Non-significantly higher safety margin to the vehicle ahead in the traffic situation with oncoming and new-oncoming vehicle than in the traffic situation with no oncoming vehicle.
Shackel & Parkin, 2014, UK	Lane width, Exceedance of speed limit, Overtaking vehicle type, Oncoming vehicle proximity and type, Road markings, Overtaking vehicle in platoon	Overtaking Speed, overtaking distance	↗	values for p = p<=0.001 - <=0.05	Results overall show that overtaking speeds were influenced by road infrastructure factors and tended to be greater with bigger lane widths, but slower if the centre-line was absent. Wider roads were associated with an increase of the overtaking distance between vehicles and cyclists (especially increase from critical to spacious lane width). However, the speeds are also more likely to increase with lane width.
Sümer et al, 2006, Turkey	Education, annual mileage, driving skills	Overtaking tendencies	↗	values for r = 0.10 – 0.30 values for p = <0.001 - <0.01	Significantly higher overtaking tendencies with a higher level of education, higher annual mileage and higher driving skills
	Age, Gender (female), Safety skills, Interaction	Overtaking tendencies	↘	values for r = -0.35 - -0.11	Significantly lower overtaking tendencies with higher age, gender (female), higher safety skills and higher interaction between

	between driving and safety skills			values for p = <0.001 – 0.01	driving and safety skills
Zhang et al., 2000, Canada	Overtaking (compared to slowing down)	Injury severity –fatal, major and minor (compared to minimal)	↗	values for OR = 0.96 (minor) – 5.58 (fatal)	Significantly higher risk of fatality and major injury but significantly lower risk of minor injury when vehicles were overtaking compared to vehicles which had slowed down just prior to collision

*Significant effects on road safety are coded as: decreased risk (↘), increased risk (↗) or non-significant (–)

Studies on the effects of (risky) overtaking on road safety either investigate the effect of (risky) overtaking on accident frequency and accident severity or rather investigate the relationship between different situational factors in an overtaking task or driver characteristics and parameters which indicate effects regarding risky overtaking.

Studies on accident severity mainly show that compared to other vehicle manoeuvres, overtaking increases accident severity. Results of Zhang et al. (2000) for example indicate that vehicles which were overtaking another vehicle are associated with a significant increased risk of fatality (OR = 5.6), when compared to vehicles which had slowed down just prior to the collision. This is also the case for serious injuries, however not as highly (OR = 1.29). In addition, a study by Gray et al. (2008), focusing on young male drivers, found that compared to going ahead, overtaking significantly increased injury severity of accidents involving young male drivers in Great Britain and London. In detail, overtaking was associated with a 24% (Great Britain) and 15% (London) higher likelihood of a fatality than going ahead.

Two studies were found regarding accident frequency. Results of Dingus et al. (2016) (using naturalistic driving data) indicated that the risk of being involved in a crash when overtaking is 14.4 times higher, although the prevalence of overtaking within the naturalistic driving data was only 0.18%. However another study (Garder, 2006), which only involved undertaking a crash data analysis, found that only 7.14% of fatal crashes and 5.26% of non-fatal crashes occurred while overtaking another vehicle. Thus, less than 8% of fatalities involved someone overtaking another vehicle.

In studies which instead investigate the relationship between different situational factors in an overtaking task, or driver characteristics and parameters which are potential indicators of (risky) overtaking, various different factors and characteristics were analysed. In order to provide a better overview, summarized results are presented for driver characteristics and situational factors separately.

<u>Driver characteristics</u>
Studies focusing on the relationship between driver characteristics and parameters which are potential indicators of (risky) overtaking analysed driver characteristics such as age, gender, attitudes, or annual mileage.

Leung and Starmer (2005), focusing on the age of drivers, found that while executing an overtaking manoeuvre, mature drivers tended to speed to a greater extent than young drivers. However the mature drivers also demonstrated more caution by making it a priority to return to their own lane as quickly as possible, which although they tended to hurry the manoeuvre by speeding excessively, was interpreted as safer behaviour. In contrast, the younger drivers spent relatively more time in the opposite lane, which was interpreted as riskier behaviour. Results of Havârneanu and Havârneanu (2012) indicated that age (as well as risk perception) was found to negatively correlate with illegal overtaking, suggesting that in less rational circumstances, young drivers are more likely to engage in an illegal overtaking manoeuvre compared to older drivers. Younger drivers are more likely to illegally pass slower vehicles when the traffic situation appears to be safe (lower age is accompanied by lower risk perception and higher usual deviance). In addition, Sümer et al. (2006) found that age was significantly negatively associated with overtaking tendencies, meaning the higher the age, the lower the overtaking tendencies.

In the study by Forward et al. (2009), which focussed on factors that explain the intention to perform dangerous overtakings, the results indicate that attitudes and perceived ease (both contained within the theory of planned behaviour) as well as past behaviour had significant relevance for the intention to perform dangerous overtakings. This could in total account for 33% (attitudes and perceived ease) and 17% (past behaviour) of the intention to perform dangerous overtakes.

Results of Havârneanu and Havârneanu (2012) indicate that the more distinct the usual deviant behaviour, the significantly higher the number/probability of illegal overtakings.

Sümer et al. (2006) found that the level of education, annual mileage and driving skills were significantly positively associated with overtaking tendencies, meaning the higher the level of education (highly educated participants were mostly young drivers), the annual mileage and the driving skills, the higher the overtaking tendencies. Moreover it was found that gender, safety skills and the interaction between driving and safety skills were significantly negatively associated with overtaking tendencies, meaning the higher the safety skills, the lower the overtaking tendencies. For gender, the negative association indicated that female drivers overtake less often than males, and for the interaction between driving and safety skills, the negative association indicated that the drivers with high driving skills reported the highest level of overtaking at the low levels of safety skills.

<u>Situational factors</u>
Studies focusing on the relationship between situational factors in an overtaking task and parameters which are potential indicators of (risky) overtaking analysed situational factors such as speed (or speed related factors), traffic volume, traffic scenery, or road/lane width and type.

In a study by Bar-Gera and Shinar (2005), which focussed on the speed difference to the vehicle ahead, it was found that with increasing speed difference to the vehicle ahead, more passing manoeuvres were observed, although it was not statistically significant. However, if the speed difference to the vehicle ahead was 3.2 km/h (the vehicle ahead was faster), in 50% of these cases passing manoeuvres were observed. In addition – although effect sizes were not mentioned – the authors stated that the tendency of drivers to pass vehicles that travel in front of them is (statistically significant) related to drivers' speed variability. The results of Jamson et al. (2012), which focussed on the influences of mandatory Intelligent Speed Adaption (ISA), indicated that drivers become less inclined to carry out overtaking when mandatory Intelligent Speed Adaption was active (odds ratio = 3.33). When they did overtake the outcome was less likely to be successful (odds ratio = 6.10) and more likely to lead to an abandonment of overtaking. The safety of the overtaking was compromised in terms of their interaction with the lead vehicle by leaving a smaller safety margin as they pulled out and then back in again, and drivers with mandatory ISA active spent a greater amount of time in the hatched area.

Bella (2011), focusing on the relation between traffic volume and passing manoeuvre parameters, found that with a higher traffic volume, the analysed passing manoeuvre parameters (following gap, distance of passing and time to collision) significantly decreased. Thus, the author concluded that the higher the traffic volume, the significantly riskier the passing manoeuvre.

Results of Papakostopoulos et al. (2015), which focussed on the influence of different traffic scenes during overtaking, indicated that changes in the traffic scene during overtaking causes an overreaction by the overtaking drivers, especially in terms of the safety margins to the vehicle being overtaken, compared to drivers that do not experience any change during overtaking. To clarify, a significantly lower safety margin was found for the opposing vehicle as well as the overtaking vehicle in a traffic situation with an oncoming vehicle compared with a traffic situation with no oncoming vehicle. Also the lateral distance between the overtaking vehicle and the overtaken vehicle was significant lower in a traffic situation with an oncoming vehicle than in the traffic situation with no oncoming vehicle.

Shackel and Parkin (2014), focusing on motor vehicles overtaking bicycles, found that overtaking speeds were influenced by road infrastructure factors and tended to be greater with bigger lane widths, but slower if the centre-line was absent. Wider roads were associated with a significant increase of the distance of overtaking vehicles from cyclists (especially the increase from critical to spacious lane width); however, the speeds were also more likely to increase with lane width. In addition, the results of Love et al. (2012) indicate that an increase in lane width increased vehicle passing distance significantly, and that bicycle lane streets (compared to standard lanes) increased vehicle passing distance significantly as well, while shared lane marking did not. Thus, the authors conclude that decreasing lane width and the absence of bicycle lanes appear to be risk factors for dangerous passes by motorists overtaking bicycles.

Modifying conditions

Conditions that might influence (or contribute to) risky overtakings are, as described earlier, driver characteristics and situational factors. Several studies (Leung and Starmer, 2005, Havârneanu and Havârneanu, 2012, Sümer et al., 2006), for example, indicate that age is significantly negatively associated with risky overtakings, meaning that younger drivers tend to be more likely to engage in risky overtaking manoeuvres than older drivers. Moreover, gender also seems to influence the frequency of overtakings, for example Sümer et al. (2006) indicated that male drivers overtake significantly more often than females, meaning that they have a higher exposure of being in the path of oncoming traffic while overtaking. In addition, it appears that situational factors such as traffic volume and speed related factors also seem to influence the frequency of risky overtakings (Bella, 2011, Bar-Gera and Shinar, 2005). For motor vehicles overtaking bicycles, infrastructure factors such as road/lane type and width particularly tend to influence the frequency of risky overtakings in terms of smaller vehicle passing distances (Shackel and Parking, 2014, Love et al., 2012).

Conclusion

General – From the literature search for studies on the effects of risky overtaking on road safety, it appears that generally two kinds of studies exist, (1) studies investigating the effect of (risky) overtaking on accident frequency or accident severity (mostly observational), and (2) studies investigating the relationship between different situational factors in an overtaking task or driver characteristics and parameters which are potential indicators of risky overtaking (mostly experimental).

Main results – From studies focusing on accident severity, it appears that compared to other vehicle manoeuvres, overtaking significantly increases accident severity. Regarding accident frequency, although one study described a higher crash risk for overtaking, it seems that only a small share of crashes occur while overtaking another vehicle. Studies which investigate the relationship between different situational factors in an overtaking task, or driver characteristics and parameters which are potential indicators of risky overtaking, showed that in particular age is significantly negatively associated with risky overtaking. This implies that younger drivers are more likely to engage in risky overtaking manoeuvres than older drivers. In addition, it seems that other driver characteristics such as gender, as well as other situational factors such as traffic volume and speed related factors, also appear to influence the frequency of risky overtaking.

Biases and transferability – In general studies provide a variety of different kinds of effects because parameters which were potential indicators of risky overtaking (e.g. distance of passing, safety margin to overtaking vehicle, illegal overtaking, time to collision etc.) were very different. Moreover in some studies, most of the effects are only shown in diagrams and were therefore not codeable or only p-values and conclusions for the effects were mentioned but not the effects in particular. In addition, because of self-reported data in the questionnaire, one study mentioned a possible social acceptability bias for responses. Since the considered studies are from several countries, national specifications and regional circumstances may have had an effect on the analysis as well.

3 Supporting Documents

3.1 LITERATURE SEARCH STRATEGY

A literature search was conducted in March 2016. It was carried out in two databases with separate search strategies. The first one was performed in 'Scopus' which is a large abstract and citation database of peer-reviewed literature. The second literature search was conducted in a KFV-internal literature database ('DOK-DAT').

Database: Scopus **Date:** 31st of March 2016

no.	search terms / logical operators / combined queries	hits
#1	"overtak*" OR "passing" OR "tailgat*" OR "headway" OR "lane keep*" OR "lane chang*" OR "car follow*" OR "following situation"	97,455
#2	"road casualties" OR "road fatalities" OR "traffic accident" OR "road crash" OR "road violation" OR "traffic rule" OR "rear end crashes"	46,264
#3	("road safety" OR "traffic safety") AND ("risk" OR "collision")	4,629
#4	#1 AND #2	550
#5	#1 AND #3	180
#6	#4 OR #5	**668**

Table 4: Used search terms, logical operators, and combined queries of literature search (Scopus).

Detailed search terms, as well as their linkage with logical operators and combined queries are shown in **Table 4** and **Table 5**. Using search fields title, abstract, and keywords (TITLE-ABS-KEY) and a general limitation to studies which were published from 1990 to current led to a huge amount of studies.

Results were limited to "article" and "review" and in a further step to the languages "English" and "German". Quantity of studies was further reduced by limiting source type to "Journal" as well as excluding various countries. As on study scope we only considered European countries, as well as Russia. As a last reduction step we limited remaining studies to the subject areas "Engineering" and "Psychology". This led to a final sample of 204 studies from the literature search in database Scopus (**Table 6**).

Database: DOK-DAT **Date:** 31st of March 2016

search no.	search terms / operators / combined queries	hits
#1	"overtak*" OR "passing" OR "tailgat*" OR "headway" OR "lane keep*" OR "lane chang*" OR "car follow*" OR "following situation"	488
#2 (within #1)	Limit to year: 1990 to 2016	386
#3 (within #2)	"road casualties" OR "road fatalities" OR "traffic accident" OR "road crash" OR "road violation" OR "traffic rule" OR "rear end crashes"	14

#4 (within #2)	("road safety" OR "traffic safety") AND ("collision" OR "crash")	15
#5	#3 OR #4	**29**

Table 5: Used search terms, logical operators, and combined queries of literature search (DOK-DAT).

(German) Search fields 'Titel', 'ITRD Schlagworte' and 'freie Schlagworte' were used. Hits were only limited to the years 1990 to 2016 and got 29 more potential studies (**Table 6**).

Results Literature Search

Database	Hits
Scopus (remaining papers after several limitations/exclusions)	204
DOK-DAT	29
Total number of studies to screen title/ abstract	**233**

Table 6: Results of both databases after limitations

Overall, the literature search led to 233 potential studies for screening.

Screening

Total number of studies to screen title/ abstract	233
-De-duplication	7
-not relevant studies excluded	138
-Studies with no risk estimates excluded	3
-Studies concerning measures excluded	20
Remaining studies	**48**
Not clear (full-text is needed)	19
Studies to obtain full-texts	**67**

Table 7: Number of studies to obtain full-texts

Eligibility

Total number of studies to screen full-text	67
Full-text could be obtained	67
Reference list examined Y/N	No
Eligible papers	**67**

Table 8: Number of studies to screen full-texts

Screening of the full texts

Total number of studies to screen full paper	67
-Studies with no risk estimates excluded	32
-Studies concerning measures excluded	13
Remaining studies	**22**
Number of studies dealing with "headway distance"	8
Number of studies dealing with "risky overtaking"	13
Number of studies dealing with both aspects	1

Table 9: Screening of full texts

Prioritizing Coding

- Prioritizing Step A (meta-analysis)
- Prioritizing Step B (studies published more recently than meta-analysis)
- Prioritizing Step C (sufficient time resources)

List of references resulting from search strategy

No.	Publication	Coded Y/N	Reason
1.	Bar-Gera, H., & Shinar, D. (2005). The tendency of drivers to pass other vehicles. Transportation Research Part F: Traffic Psychology and Behaviour, 8(6), 429–439.	Y	Prioritizing Step B
2.	Bella, F. (2011). How traffic conditions affect driver behavior in passing maneuver. Advances in Transportation Studies, (SPEC), 113–126.	Y	Prioritizing Step B
3.	Dingus, T., Guo, F., Lee, S., Antin, J., Perez, M., Buchanan-King, M., & Hankey, J. (2016). Driver crash risk factors and prevalence evaluation using naturalistic driving data. PNAS Early Edition, 113(10), 2636-2641.	Y	Prioritizing Step B
4.	Forward, S. E. (2009b). The theory of planned behaviour: The role of descriptive norms and past behaviour in the prediction of drivers' intentions to violate. Transportation Research Part F: Traffic Psychology and Behaviour, 12(3), 198–207.	Y	Prioritizing Step B
5.	Gårder, P. (2006). Segment characteristics and severity of head-on crashes on two-lane rural highways in Maine. Accident Analysis and Prevention, 38(4), 652–661.	Y	Prioritizing Step B
6.	Havârneanu, G. M., & Havârneanu, C. E. (2012). When norms turn perverse: Contextual irrationality vs. rational traffic violations. Transportation Research Part F: Traffic Psychology and Behaviour, 15(2), 144–151.	Y	Prioritizing Step B
7.	Jamson, S., Chorlton, K., & Carsten, O. (2012). Could Intelligent Speed Adaptation make overtaking unsafe? Accident Analysis and Prevention, 48, 29–36.	Y	Prioritizing Step B
8.	Kay, J. J., Savolainen, P. T., Gates, T. J., & Datta, T. K. (2014). Driver behavior during bicycle passing maneuvers in response to a Share the Road sign treatment. Accident Analysis and Prevention, 70, 92–99.	N	Countermeasure
9.	Leung, S., & Starmer, G. (2005). Gap acceptance and risk-taking by young and mature drivers, both sober and alcohol-intoxicated, in a simulated driving task.	Y	Prioritizing Step B

	Accident Analysis and Prevention, 37(6), 1056–1065.		
10.	Love, D. C., Breaud, A., Burns, S., Margulies, J., Romano, M., & Lawrence, R. (2012). Is the three-foot bicycle passing law working in Baltimore, Maryland? Accident Analysis and Prevention, 48, 451–456.	Y	Prioritizing Step B
11.	Mundutéguy, C., & Ragot-Court, I. (2011). A contribution to situation awareness analysis: Understanding how mismatched expectations affect road safety. Human Factors, 53(6), 687–702.	N	No codeable data
12.	Papakostopoulos, V., Nathanael, D., Portouli, E., Marmaras, N. (2015). The effects of changes in the traffic scene during overtaking. Accident Analysis and Prevention 79; 126-132.	Y	Prioritizing Step B
13.	Shackel, S. C., & Parkin, J. (2014). Influence of road markings, lane widths and driver behaviour on proximity and speed of vehicles overtaking cyclists. Accident Analysis and Prevention, 73, 100–108.	Y	Prioritizing Step B
14.	Sümer, N., Özkan, T., & Lajunen, T. (2006). Asymmetric relationship between driving and safety skills. Accident Analysis and Prevention, 38(4), 703–711.	Y	Prioritizing Step B
15.	Zhang, J., Lindsay, J., Clarke, K., Robbins, G., Mao, Y. (2000). Factors affecting the severity of motor vehicle traffic crashes involving elderly drivers in Ontario. Accident Analysis and Prevention 32, 117-125.	Y	Prioritizing Step B

Table 10: List of references resulting from search strategy

3.2 SUMMARY OF STUDY RESULTS

Table 9: Summary of study results (sorted by name of first author)

Author(s), Year, Country	**Exposure variable**	**Dependant / outcome type**	**Effects on Road Safety**		**Main outcome - Description**
Bar-Gera & Shinar, 2005, Israel	Speed difference to vehicle ahead (-6,4 km/h to 0 km/h)	Frequency of passing manoeuvres	–	Relative difference = 0.3939	Non-significant higher frequency of passing manoeuvres when speed difference to vehicle ahead was -6.4 km/h compared to 0 km/h
	Speed difference to vehicle ahead (-3,2 km/h to 0 km/h)	Frequency of passing manoeuvres	–	Relative difference = 0.3181	Non-significant higher frequency of passing manoeuvres when speed difference to vehicle ahead was -3.4 km/h compared to 0 km/h
	Speed difference to vehicle ahead (3,2 km/h to 0 km/h)	Frequency of passing manoeuvres	–	Relative difference = -0.2424	Non-significant lower frequency of passing manoeuvres when speed difference to vehicle ahead was 3.2 km/h compared to 0 km/h
Bella, 2011, Italy	Traffic volume low to traffic volume medium	Following gap	↗	Absolute Difference = 7.80	Significant decrease of the following gap with an increase in traffic volume
	Traffic volume low to traffic volume heavy	Following gap	↗	Absolute Difference = 8.00	Significant decrease of the following gap with an increase in traffic volume
	Traffic volume low to traffic volume high	Following gap	↗	Absolute Difference = 10.80	Significant decrease of the following gap with an increase in traffic volume
	Traffic volume low to traffic volume medium	Distance of passing	↗	Absolute Difference = 55.00	Significant decrease of the distance of passing with an increase in traffic volume

	Traffic volume low to traffic volume heavy	Distance of passing	↗	Absolute Difference = 85.00	Significant decrease of the distance of passing with an increase in traffic volume
	Traffic volume low to traffic volume high	Distance of passing	↗	Absolute Difference = 122.00	Significant decrease of the distance of passing with an increase in traffic volume
	Traffic volume low to traffic volume medium	Time to collision	↗	Absolute Difference = 2.40	Significant decrease of the time to collision with an increase in traffic volume
	Traffic volume low to traffic volume heavy	Time to collision	↗	Absolute Difference = 2.63	Significant decrease of the time to collision with an increase in traffic volume
	Traffic volume low to traffic volume high	Time to collision	↗	Absolute Difference = 2.65	Significant decrease of the time to collision with an increase in traffic volume
Dingus et al., 2016, USA	Illegal/unsafe passing	Observed crashes	↗	OR = 14.4 CI=95% CI=7.2-28.8	Risk to be involved in a crash when overtaking is 14.4 times higher.
Forward, 2009, Sweden	Attitude (Theory of planned bahviour - TPB)	Dangerous Overtaking	↗	r = 0.30, p<0.001	Statistically significant relevance of attitude for the intention to perform a dangerous overtaking
	Subjective Norm (TPB)	Dangerous Overtaking	–	r = 0.09	Non-statistically significant relevance of subjective norm for the intention to perform a dangerous overtaking
	Perceived ease (TPB)	Dangerous Overtaking	↗	r = 0.32, p<0.001	Statistically significant relevance of perceived ease for the intention to perform a dangerous overtaking
	Descriptive norm	Dangerous Overtaking	↗	r = 0.37, p<0.001	Statistically significant relevance of descriptive norm for the intention to perform a dangerous overtaking
	Age	Dangerous Overtaking	–	r = 0.06	Non-statistically significant relevance of age for the intention to perform a dangerous overtaking
	Past behaviour	Dangerous Overtaking	↗	r = 0.55, p<0.001	Statistically significant relevance of past behaviour for the intention to perform a dangerous overtaking
Garder, 2006, USA	Improper overtaking/passing	Crashes (fatal head-on crashes)	–	Relative Proportion = 0.0714	Only 7.14% of fatal crashes occurred while overtaking another vehicle.
	Improper overtaking/passing	Crashes (non-fatal head-on crashes)	–	Relative Proportion = 0.526	Only 5.26% of non-fatal crashes occurred while overtaking another vehicle.
Gray et al., 2008, United Kingdom	Overtaking (compared to going ahead – UK)	Injury severity	↗	r = 0.0943	Significant higher injury severity when overtaking compared to going ahead
	Overtaking (compared to going ahead – London)	Injury severity	↗	r = 0.0521	Significant higher injury severity when overtaking compared to going ahead
Havârneanu &	Usual deviant behaviour	Illegal overtaking	↗	r = 0.04, p<0.01	Significant positive association between usual deviant behaviour and illegal overtaking (the

Havârneanu, 2012, Romania					more distinct the usual deviant behaviour, the higher the number/probability of illegal overtakings)
	Risk perception	Illegal overtaking	↘	$r = -0.06$, $p<0.01$	Significant negative association between risk perception and illegal overtaking (the lower the risk perception, the higher the number/probability of illegal overtakings)
	Age	Illegal overtaking	↘	$r = -0.02$, $p<0.01$	Significant negative association between age and illegal overtaking (the lower the age, the higher the number/probability of illegal overtakings)
Jamson et al., 2012, UK	Intelligent Speed Adaption (ISA) - mandatory	overtaking attempts	↗	OR = 3.33, $p<0.001$	Drivers become less inclined to undertake overtaking when mandatory Intelligent Speed Adaption was active.
	Intelligent Speed Adaption (ISA) - mandatory	Successful overtaking	↗	OR = 6.10, $p<0.001$	When drivers overtake when mandatory Intelligent Speed Adaption was active the outcome was less likely to be successful and more likely to lead to an abandonment of overtaking.
Leung and Starmer, 2005, Australia	Overtaking - participant age (mature to young)	Speed	↘	Absolute Difference = 3.19, $p<0.05$	Mature drivers tended to speed to a greater extent compared to young drivers but also demonstrated more caution by making it a priority to return to their own lane as quickly as possible. (low exposure, safer behaviour with increasing age)
Love et al., 2012, USA	Lane width	Vehicle passing distance	↘	$p<0.0001$	Significantly increase of vehicle passing distance with increasing lane width
	Bicycle lane streets (compared to standard lanes)	Vehicle passing distance	↘	$p<0.0001$	Significantly increase of vehicle passing distance for bicycle lane streets compared to standard lanes)
	Sharrows (compared to standard lanes)	Vehicle passing distance	–	$p=0.28$	Non-significantly increase of vehicle passing distance for bicycle lane streets compared to standard lanes)
Papakostopoulos et al., 2015, Greece	Opposite traffic situation (oncoming vehicle to no-oncoming vehicle)	Safety Margin to Opposite vehicle	↗	Absolute Difference = -6.06	Significant lower safety margin to the opposite vehicle in the traffic situation with oncoming vehicle than in the traffic situation with no oncoming vehicle. (significant difference through ANOVA)
	Opposite traffic situation (new-oncoming vehicle to no-oncoming vehicle)	Safety Margin to Opposite vehicle	↗	Absolute Difference = -3.31	Significant lower safety margin to the opposite vehicle in the traffic situation with new-oncoming vehicle than in the traffic situation with no oncoming vehicle. (significant difference through ANOVA)
	Opposite traffic situation (oncoming vehicle to no-oncoming vehicle)	Safety Margin to overtaking vehicle	↗	Absolute Difference = -0.06	Significant lower safety margin to the overtaking vehicle in the traffic situation with oncoming vehicle than in the traffic situation with no oncoming vehicle. (significant difference through ANOVA)
	Opposite traffic situation (new-oncoming vehicle to no-oncoming vehicle)	Safety Margin to overtaking vehicle	↗	Absolute Difference = -0.07	Significant lower safety margin to the overtaking vehicle in the traffic situation with new-oncoming vehicle than in the traffic situation with no oncoming vehicle. (significant difference through ANOVA)

	Opposite traffic situation (oncoming vehicle to no-oncoming vehicle)	Safety Margin to vehicle ahead	–	Absolute Difference = 1.26	Non-significant higher safety margin to the vehicle ahead in the traffic situation with oncoming vehicle than in the traffic situation with no oncoming vehicle. (significant difference through ANOVA)
	Opposite traffic situation (new-oncoming vehicle to no-oncoming vehicle)	Safety Margin to vehicle ahead	–	Absolute Difference = 1.14	Non-significant higher safety margin to the vehicle ahead in the traffic situation with new-oncoming vehicle than in the traffic situation with no oncoming vehicle. (significant difference through ANOVA)
	Opposite traffic situation (oncoming vehicle to no-oncoming vehicle)	Lateral distance to overtaking vehicle	↗	Absolute Difference = -0.41	Significant lower lateral distance between the overtaking vehicle and the overtaken vehicle in the traffic situation with oncoming vehicle than in the traffic situation with no oncoming vehicle. (significant difference through ANOVA)
	Opposite traffic situation (new-oncoming vehicle to no-oncoming vehicle)	Lateral distance to overtaking vehicle	↗	Absolute Difference = -0.39	Significant lower lateral distance between the overtaking vehicle and the overtaken vehicle in the traffic situation with new-oncoming vehicle than in the traffic situation with no oncoming vehicle. (significant difference through ANOVA)
Shackel & Parkin, 2014, UK	Lane width (spacious to critical) and road markings (single lane) – 20 km/h speed limit	Overtaking Speed	↗	p<=0.05	Although there are a lot of effects and comparisons for overtaking speed and distance in relation to configuration of lines or road markings etc. shown in this study, results overall show, that overtaking speeds were influenced by road infrastructure factors and tended to be greater with wider lane widths, but slower if the centre-line was absent. Wider roads were associated with an increase of the distance of overtaking vehicles from cyclists (especially increase from critical to spacious lane width). However the speeds are also more likely to increase with lane width. In the study only significant differences are described: outcome values (speed & distance) are significantly greater in test group conditions (exposure) than in reference group conditions.
	Lane width (spacious to critical) and road markings (cycle lane to single lane) – 20 km/h speed limit	Overtaking Speed	↗	p<=0.05	
	Exceedance of speed limit (above limit to below limit) – 20 km/h speed limit	Overtaking Speed	↗	p<=0.001	
	Overtaking vehicle type (LGV to cars) – 20 km/h speed limit	Overtaking Speed	↗	p<=0.05	
	Oncoming vehicle proximity (far distant to middle distant) – 20 km/h speed limit	Overtaking Speed	↗	p<=0.001	
	Lane width (spacious to tight) and road markings (single lane) – 30 km/h speed limit	Overtaking Speed	↗	p<=0.05	
	Lane width (spacious to critical) and road markings (single lane) – 30 km/h speed limit	Overtaking Speed	↗	p<=0.001	
	Road markings (single lane to no centre-line) – 30 km/h speed limit	Overtaking Speed	↗	p<=0.001	
	Road markings (cycle lane to no centre-line) –	Overtaking Speed	↗	p<=0.001	

	30 km/h speed limit				
	Road markings (dual lane to no centre-line) – 30 km/h speed limit	Overtaking Speed	↗	p<=0.001	
	Lane width (spacious to critical) and road markings (single lane) – 30 km/h speed limit	Overtaking Speed	↗	p<=0.001	
	Lane width (spacious to critical) and road markings (cycle lane to single lane) – 30 km/h speed limit	Overtaking Speed	↗	p<=0.001	
	Lane width (spacious to tight) and road markings (single lane to no-centre lane) – 30 km/h speed limit	Overtaking Speed	↗	p<=0.001	
	Lane width (spacious to tight) and road markings (cycle lane to no-centre lane) – 30 km/h speed limit	Overtaking Speed	↗	p<=0.05	
	Lane width (tight) and road markings (single lane to no-centre lane) – 30 km/h speed limit	Overtaking Speed	↗	p<=0.05	
	Lane width (tight to critical) and road markings (single lane) – 30 km/h speed limit	Overtaking Speed	↗	p<=0.05	
	Exceedance of speed limit (above limit to below limit) – 30 km/h speed limit	Overtaking Speed	↗	p<=0.001	
	Overtaking vehicle type (cars to rigid) – 30 km/h speed limit	Overtaking Speed	↗	p<=0.05	
	Overtaking vehicle type (private hire taxis to rigid lorries) – 30 km/h speed limit	Overtaking Speed	↗	p<=0.05	
	Overtaking vehicle type (LGV to rigid lorries) – 30 km/h speed limit	Overtaking Speed	↗	p<=0.001	
	Overtaking vehicle type (cars to buses) – 30 km/h speed limit	Overtaking Speed	↗	p<=0.001	
	Overtaking vehicle type (private hire taxis to buses) – 30 km/h speed limit	Overtaking Speed	↗	p<=0.05	
	Overtaking vehicle type	Overtaking	↗	p<=0.001	

	(LGV to buses) – 30 km/h speed limit	Speed			
	Overtaking vehicle in platoon (alone to in platoon) – 30 km/h speed limit	Overtaking Speed	↗	p<=0.001	
	Oncoming vehicle proximity (far distant to middle distant) – 30 km/h speed limit	Overtaking Speed	↗	p<=0.001	
	Oncoming vehicle type (articulated lorry to bicycle) – 30 km/h speed limit	Overtaking Speed	↗	p<=0.05	
	Oncoming vehicle type (articulated lorry to car) – 30 km/h speed limit	Overtaking Speed	↗	p<=0.001	
	Oncoming vehicle type (articulated lorry to hackney taxi) – 30 km/h speed limit	Overtaking Speed	↗	p<=0.05	
	Oncoming vehicle type (articulated lorry to private hire taxi) – 30 km/h speed limit	Overtaking Speed	↗	p<=0.05	
	Oncoming vehicle type (articulated lorry to LGV) – 30 km/h speed limit	Overtaking Speed	↗	p<=0.001	
	Oncoming vehicle type (articulated lorry to buses) – 30 km/h speed limit	Overtaking Speed	↗	p<=0.001	
	Oncoming vehicle type (rigid lorry to LGV) – 30 km/h speed limit	Overtaking Speed	↗	p<=0.05	
	Road markings (dual lane to single lane) – 30 km/h speed limit	Overtaking Distance	↗	p<=0.001	
	Road markings (dual lane to cycle lane) – 30 km/h speed limit	Overtaking Distance	↗	p<=0.001	
	Road markings (dual lane to no centre-line) – 30 km/h speed limit	Overtaking Distance	↗	p<=0.05	
	Lane width (tight to critical) and road markings (dual lane to single lane) – 30 km/h speed limit	Overtaking Distance	↗	p<=0.001	
	Lane width (tight to spacious) and road markings (dual lane to	Overtaking Distance	↗	p<=0.05	

	cycle lane) – 30 km/h speed limit				
	Lane width (critical to tight) and road markings (dual lane to no centre-line) – 30 km/h speed limit	Overtaking Distance	↗	$p<=0.05$	
	Lane width (critical) and road markings (dual lane to single lane) – 30 km/h speed limit	Overtaking Distance	↗	$p<=0.001$	
	Lane width (critical) and road markings (dual lane to cycle lane) – 30 km/h speed limit	Overtaking Distance	↗	$p<=0.05$	
	Lane width (critical to spacious) and road markings (dual lane to single lane) – 30 km/h speed limit	Overtaking Distance	↗	$p<=0.05$	
	Lane width (critical to spacious) and road markings (dual lane to cycle lane) – 30 km/h speed limit	Overtaking Distance	↗	$p<=0.001$	
	Lane width (spacious to critical) and road markings (single lane) – 30 km/h speed limit	Overtaking Distance	↗	$p<=0.001$	
	Oncoming vehicle in platoon (single vehicle to in platoon) – 30 km/h speed limit	Overtaking Distance	↗	$p<=0.05$	
Sümer et al, 2006, Turkey	Education	Overtaking tendencies	↗	$r = 0.10$, $p<0.01$	Significant higher overtaking tendencies with a higher level of education (highly educated participants were mostly young drivers)
	Age	Overtaking tendencies	↘	$r = -0.17$, $p<0.001$	Significant lower overtaking tendencies with higher age (negative association)
	Annual mileage	Overtaking tendencies	↗	$r = 0.12$, $p<0.001$	Significant higher overtaking tendencies with higher annual mileage (positive association)
	Gender	Overtaking tendencies	↘	$r = -0.18$, $p<0.001$	Significant negative association between overtaking tendencies and gender (female drivers overtake less often than males)
	Driving skills	Overtaking tendencies	↗	$r = 0.30$, $p<0.001$	Significant higher overtaking tendencies with higher driving skills (positive association)
	Safety skills	Overtaking tendencies	↘	$r = -0.35$, $p<0.001$	Significant lower overtaking tendencies with higher safety skills (negative association)
	Interaction between driving and safety skills	Overtaking tendencies	↘	$r = -0.11$, $p<0.01$	Significant lower overtaking tendencies with higher interaction between driving and safety skills (drivers with high driving skills reported the highest level of overtaking at the low

					levels of safety skills)
Zhang et al., 2000, Canada	Overtaking (compared to slowing down)	Injury severity – fatal (compared to minimal)	↗	OR = 5.58	Significant higher risk of fatality when vehicles were overtaking compared to vehicles which had slowed down just prior to collision
	Overtaking (compared to slowing down)	Injury severity – major (compared to minimal)	↗	OR = 1.29	Significant higher risk of major injury when vehicles were overtaking compared to vehicles which had slowed down just prior to collision
	Overtaking (compared to slowing down)	Injury severity – minor (compared to minimal)	↗	OR = 0.96	Significant lower risk of minor injury when vehicles were overtaking compared to vehicles which had slowed down just prior to collision (overtaking is associated with a higher injury severity)

*Significant effects on road safety are coded as: positive (↘), negative (↗) or non-significant (–)

Table 11: Outcomes on coded studies that deal with (risky) overtaking

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Coded studies

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Risk taking - Close Following Behaviour

Risk taking behaviour where the driver travels in close proximity to the vehicle in front. Also known as a short headway distance.

1. Summary

Aigner-Breuss, E., Russwurm, K., August 2016

1.1. COLOUR CODE: YELLOW

Although following too closely is seen as one of the main reasons for rear end crashes, studies that evaluate the risk of this behaviour in connection to accidents are rare. However, if headway distances are so short that it is no longer possible to stop in time in the case of an emergency stop, it can be presumed as risky. Quite a proportion of drivers engage in such a behaviour. Results of one study indicate a higher crash risk for short headways.

1.2. KEYWORDS

Close following behaviour, tailgating, headway distance, time headway, too short headways, risky behaviour, risk taking

1.3. ABSTRACT

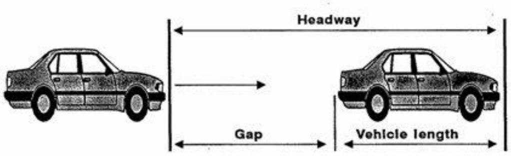
Headway is the distance from a following vehicle to a lead vehicle in a traffic following situation. A minimum headway distance of two seconds to the vehicle in front is generally recommended as safe. Considerably shorter headways for a longer period are seen as risky and addressed as tailgating. Headway distance is mainly measured in seconds (time headway), which is independent from velocity, or meters (headway distance). The prevalence of close following behaviour in traffic differs considerably depending on the location, traffic situation, time of the day and type of measurement (prevalence of risky drivers, prevalence of driving time).

Studies which evaluate the risk of this behaviour in connection to accidents are rare. One naturalistic driving study shows an increased crash risk for close following behaviour with a low prevalence of this behaviour present in the driving condition. Several driving characteristics and situational factors such as age, personality, weather and presence of roadworks seem to have an effect on the choice of headway distance.

1.4. BACKGROUND

How are headway distance and close following defined?

Headway is the distance from a following vehicle to a lead vehicle in a traffic following situation. Evans (1991) defines headway as "the elapsed time between the front of the lead vehicle passing a point on the roadway and the front of the following vehicle passing the same point".



Tailgating, close following, too short headways

In the literature, different designations for short distances can be found such as tailgating, close following or too short headways, which are used synonymously in this paper. In addition, the used definitions vary and might be imprecisely formulated. Michael, Leeming, and Dwyer (2000) define tailgating as a headway considerably less than two seconds. Tailgating is also used for headway distances too short to stop in time in the case of an emergency stop. Most traffic regulations emphasize that a driver has to be able to stop their vehicle within a defined period (distance or time). Additionally it refers only to tailgating when it occurs for a longer period. Short headways for a short time are considered part of normal driving behaviour (SWOV, 2012).

Safe headway distance -2-second rule

Based on the driver's reaction time, researchers and several driver training programs agree on the advice to maintain a minimum headway distance of two seconds to the vehicle in front, commonly known as the "2-second rule". The total time of an emergency stop is the reaction time of the driver plus the breaking time to decelerate the vehicle. Reaction times vary between drivers, they are determined by the driver's alertness, the expectation, and the complexity of the traffic situation (SWOV, 2012). The total time for an emergency stop requires more time, but the two seconds are a sufficient safe following distance as all passenger cars brake with similar deceleration rates. Buses and HGVs carrying freight have a longer breaking distance.

In different countries, there are different recommendations and regulations for the recommended safe distance.

What is the effect of close vehicle following behaviour on road safety?

Many researchers agree that tailgating is a cause of rear-end collisions and short headway times increase the risk of rear-end collisions and multiple collisions (Evans, 1991; Michael, Leeming, & Dwyer, 2000; SWOV, 2012). The estimated numbers rank between 70% and 80%.

Early studies support these findings and show that there is a difference between accident-free drivers and accident-involved drivers in their headway times. Accident-involved drivers are more likely to follow with a short distance (Evans & Wasielewski, 1982). These findings support the influence of driver characteristics.

Which factors influence the effect of close vehicle following behaviour on road safety?

Choice of headway is linked to the context and depends on driver characteristics. Factors related to the driver include among others age, gender, risky driving, distance perception, intoxication, fatigue and usage of mobile phones. For example, young men tend to have shorter headway distances than other drivers (Simons-Morton et al., 2005). The parameters under external conditions can be traffic density, weather, speed limits, road type, oncoming traffic and vehicle type of the lead and following vehicle. A list of influencing factors can be found in chapter 3.

How is the effect of close vehicle following behaviour on road safety measured?

Headway is most commonly measured as time headway in seconds and stays constant over speed. Headway distance usually refers to the measured distance in meters and depends on the velocity.[1]

Usually a driver wants to drive at their desired driving speed. Following situations occur, when a driver arrives behind a vehicle at a lower speed and needs to react to this situation. In low traffic flow there might be sufficient opportunity for overtaking and maintaining the speed. If traffic flow is high, there might be reasons to follow but there might be an impact on the motivation and willingness to take risks (Talbot, Meesmann, Boets, & Welsh, 2010).

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[1] Some literature refers instead of meters to car-lengths. Risto and Martens (2013) compared the use of time or distance instructions in their study.

How frequent does close vehicle following behaviour occur?

Close following in traffic seems to be a frequent behaviour. The proportion of drivers showing such a driving behaviour differs considerably depending on several factors such as location, traffic situation, time of the day and type of measurement. An Italian study (Bella et al., 2014) analysed data from traffic control systems on different sites. 12% to 63% of the vehicles had a time headway shorter or equal to 2 seconds, and 1% to 25% a time headway shorter or equal to 1 second. Mostly headway time is measured at a specific site, if the presence of close following behaviour is calculated for the driving in general, it is much lower. A naturalistic driving study including data from more than 3,500 participants found a very low prevalence of close following behaviour (0.07%) present during the normal driving condition (Dingus et al.,2016).

With increasing traffic, the average headway decreases (SWOV, 2012). Wang and Song (2011) observed that on urban Rhode Island highways 60% of drivers showed tailgating behaviour during the rush hours and 40% during non-rush hours. The average headway decreases as well with increasing speed, at 90 km/h, the average headway of passenger cars is less than one second (SWOV, 2012). In addition, car following behaviour differs among countries (Marsden, McDonald, & Brackstone, 2003).

1.5. OVERVIEW OF THE RESULTS

The close following situation is a complex process and varies according to local conditions and hence, is challenging to investigate. Studies are rare that quantify the effect of close following on road safety in terms of crash risk. Most identified studies focused on the influence of several driving characteristics and situational factors on headway choice.

Among the identified studies, one naturalistic driving study shows an increased crash risk for following too closely.

Concerning driving characteristics, age and personality seem to have an effect on close following behaviour. Drivers who showed once a risky driving behaviour tend to have more traffic offences in the past and differed significantly from non-risky drivers in their further police records. In addition, it was found that teens had a higher rate of following too closely than other drivers.

Among the situational factors there is an indication that weather, especially fog, provokes some groups of drivers into risky behaviour of following too closely to be safe. As well, roadworks seem to decrease headway distances after the roadworks.

It has to be noted that 1) described results are from single studies and 2) several studies, which investigate further influencing factors like expectation or assessment of the braking distance, could not be included due to the used research methods.

2. Scientific Details

2.1. THEORETICAL BACKGROUND

A large number of different theories and traffic safety models based on two different perspectives have been developed. 1) Traffic engineers focused on engineering factors such as the influence of acceleration and deceleration on traffic streams, while 2) traffic psychologists are interested in describing the influence of human factors involved in the driving process such as abilities, errors or risk taking. Furthermore, car-following models can be divided into several main categories such as stimulus-based models, safety distance models and action point models (Saifuzzaman & Zheng, 2014).

However, there are several different explanations for following behaviour at unsafe distances. Evans (2011) for instance describes following too closely as a habit: drivers are habitually following too closely, because they have done so without any negative consequences in the past. Drivers do not expect a sudden deceleration of the leading car, is another explanation. The Risk Homeostasis Theory as another example proposes that drivers seek to maintain a preferred target level of risk of being involved in an accident. The awareness of the risk being involved in an accident is an important factor in many other theories, as well. A recent overview about car following models can be found in Saifuzzaman & Zheng, 2014.

2.2. METHODOLOGY

Literature search was carried out in two databases (Scopus and a KFV-internal literature database) with separate search strategies (for a detailed description see "Supporting documents").

Description of studies

Table 1 provides further description of the background characteristics of the coded studies that deal with close following behaviour (sorted by year of publication and author).

Author, year, country	Sample, method/design and analysis	Risk group/ cases	Control group/ controls
Dingus et al., 2016, USA	Naturalistic driving data, case-control study (3 year period) Odds ratios	N= 905 Drivers with crash events	N= 3,500 Drivers with no crash events
Summala et al., 2014, Finland	Quasi-experimental design, comparing police records from risk taking drivers and control drivers, samples were taken from normal traffic flow 24 years earlier, Longitudinal Analysis adjusted for age and mileage	N=134 risky drivers stopped by the police	N= 121 non risky drivers stopped by the police
Yousif et al.,2014, UK	Observational study, comparing headway distances before and after the roadworks	N=4,574 drivers following in an platoons with time headway ≤6s after crossing an urban shuttle-lane	N=3,547 drivers following in an platoons with time headway ≤6 sec before approaching

		roadworks	an urban shuttle-lane roadworks
Broughton et al., 2007, USA	Simulator experiment comparing three conditions of reduced visibility at two speed conditions, ANOVA with repeated measures	N=31 participants (students) driving under two fog conditions (moderate fog, dense fog)	N=16 (students) participants driving under clear conditions
Simons-Morton et al., 2005, USA	Observational study, Chi square tests to test bivariate comparisons of proportions	N=471 teenage drivers	N=2251 drivers in general traffic
Rajalin et al., 1997, Finnland	Quasi-experimental design, comparing police records of last 3 years from close following drivers and control drivers, samples were taken from normal traffic flow on two-lane highways, ANOVA, Adjusted for mileage, effects of gender	N=157 drivers with a following distance 0.8 sec or shorter	N= 178 drivers with a following distance 2-5 sec

Table 1: Characteristics of coded studies that deal with risk taking in car following situations

Description of the main research methods

As shown before, the following situation is a complex process and varies according to local conditions and hence, is challenging to investigate. Links to real crashes in studies concerning close following behaviour are rare.

There are two main approaches for investigating the effects of close following behaviour (tailgating) on road safety: mostly experimental studies and observational studies.

The studies identified mainly investigated the relationship between different situational factors and headway distance (e.g. fog, road networks) or driver characteristics (e.g. age, expectations), indicating which "conditions" contribute to close following behaviour. Some studies focused on the driver personality, exploring if risky driving is a stable behaviour over time. In these studies, long-term effects of risky behaviour were investigated by linking the amount of traffic offences to this behaviour. Only one study provided information on the association between close following behaviour and increased crash risk (Dingus et al., 2016).

The focus of most identified studies was close following behaviour itself, some used a concept of "risky driving", which enclosed different variables among them close following behaviour.

The observational studies investigated headway distances with video cameras in real traffic situations. One purpose was to identify the amount of drivers following in a safe headway distance versus the drivers with a critical headway distance for road safety, and as second step explore if situational or personal factors influences the choice of headway distance (Simons-Morton et al. 2005, Yousif et al. 2014).

One study used naturalistic driving data, evaluating several risk factors including "following too closely" during the seconds leading to a crash (Dingus et al., 2016).

Other research methods included the use of driving simulators. There is a risk that the obtained results cannot be transferred to the real driving situation. Risto & Martens (2014) compared driver headway choice in a driving simulator and in an instrumented vehicle. Results show no difference between headway choice in the simulator and on a real road and hence provide support for the use of driving simulator studies on headway choice (Risto & Martens, 2014). The simulator studies investigated factors associated with following distances. However, due to the lack of a neutral "control group" most driving simulators studies had to be excluded.

2.3. OVERVIEW OF RESULTS

Table 2 presents information on the main outcomes of coded studies on close following behaviour (tailgating) while driving (sorted by publication year and author). The coded studies were quite different in design and methods, so it was not feasible to give a summarized analysis in terms of vote and count results.

Author, Year, Country	Exposure variable	Outcome variable	Effects on Road Safety		Main outcome description
Dingus, 2016, USA	Following too closely	Observed Crashes	↗	OR=13.5, CI=95%: 4.4-41.4	Risk to be involved in a crash when "following too closely" is 13.5 times higher
Summala et al., 2014, Finland	Risky driving[2]	Police recorded number of traffic offences (2009-2011)	↗	OR=1.59, CI=1.03-2.46, p<0.05	Risky drivers have significant more reported offenses in their driver records (adjusted for age and mileage).
	Risky driving	Police recorded traffic offences Type of offence: traffic violations	↗	OR=1.62, CI=1.01-2.46, p<0.05	Risky drivers have significant more traffic violation
	Risky driving	Police recorded traffic offences Type of offence: endangering traffic safety	–	OR=1.91, CI=0.69-5.29,	Non-significant effect on road safety
Yousif et al.,2014, U.K.	Urban shuttle-lane roadworks	Percentage of drivers tailgating (headway <2 sec)	↗		Increased tailgating behaviour with a headway shorter than 2 sec after crossing the roadworks site (24% before vs 38% after).
Yousif et al., 2014, U.K.	Urban shuttle-lane roadworks	Percentage of drivers tailgating (headway ≤1.5 sec)	↗		Increased tailgating behaviour with a headway shorter than 1.5 sec after crossing the roadworks site (8% before vs 13% after).
Broughton et al., 2007, USA	Fog	Time Headway in sec	↗		At 50 mph fog divided the participants into two groups: one who stayed within the visible range to the lead car and too short headways for adequate safety and one group who stayed beyond the visible range.
Simons-Morton et al., 2005, USA	Driver age	Headway in sec	↗		The mean headway of teenage driver is 0.17 sec shorter than for general traffic.
Simons-Morton et al., 2005, USA	Driver age	Risky behaviour (15 mph over the speed limit and/or headway <1 sec)	↗	$X^2(2)=8.21$, p<0.02	Significant difference between teen drivers and general traffic: 14.4% of teen drivers show risky behaviour in comparison to 9.6% of drivers in general traffic

2 Risky driving cover speeding, crossing of no-passing lanes, close following and/or driving in the left lane or middle of the road.

Author, Year, Country	Exposure variable	Outcome variable	Effects on Road Safety		Main outcome description
Rajalin et al., 1997, Finnland	Close following	Traffic offences	↗	$X^2(3)$=18.78, p=0.0003	close-following driver had significantly more traffic offences than control drivers, close follower have 2.0 more offences than control drivers when adjusted mileage in the last three years

*Significant effects on road safety are coded as: positive (↘), negative (↗) or non-significant (–)
Table 1: Main outcomes on coded studies that deal with close following behaviour (tailgating) while driving

The one study that linked following too closely with crash risk found that following too closely had a high crash risk, 13.5 times higher than model driving[3], but a low baseline prevalence,0.07% of time the factor was present during normal driving condition (Dingus et al. 2016). Another study (Rajalin et al. 1997) intended to link accident data to close following behaviour but due to the low number of reported accidents in the sample, this couldn't be done.

Driver characteristics

In a follow up study risky drivers (speeding, crossing of no-passing lanes, close following and/or driving in the left lane or middle of the road) had significantly more reported offenses and traffic violations in their driver records (Summala et al. 2014). In addition, the study from Rajalin et al. (1997) showed that close-following drivers had significantly more traffic offences than control drivers did. The close follower had 2.0 times more offences than control drivers when adjusted for mileage in the last three years.

The influence of the age of the driver was investigated by one study (Simons-Morton et al., 2005). Results showed a significant difference between teen drivers and other drivers: 14.4% of teen drivers show risky behaviour in comparison to 9.6% of drivers in general traffic. The mean headway of teenage drivers was 0.17 seconds shorter than in other drivers.

Situational factors

One study (Broughton et al., 2005) investigated the car following behaviour under conditions of reduced visibility (two fog conditions) in a simulator experiment. At higher speeds (50 mph) and the fog condition two different groups concerning car following behaviour could be separated. One group of drivers followed within the visible range to the lead vehicle and too short headways for adequate safety, whereas other drivers increased the headway distance.

The effect of urban shuttle-lane roadworks on following behaviour was explored by one study (Yousif et al., 2014). The study found an increased number of drivers with headways shorter than 2 seconds after the roadworks.

2.4. CONCLUSION

Although following too closely is seen as one of the reasons for rear end crashes, studies, which evaluate the risk of this behaviour in connection to accidents are rare. One naturalistic driving study shows an increased crash risk (13.2 times higher than model driving) however with a low prevalence of this behaviour present in the driving condition (Dingus et al., 2016).

[3] model driving were short, free of safety-critical events and comprises normal driving episodes, thus representing the exposure of risk factors during normal driving conditions

Concerning driving characteristics and situational factors; age, personality, fog and presence of roadworks seem to have an effect on the choice of headway distance. Two studies showed that risky behaviour seems to be a stable behaviour (Summala et al., 2014; Rajalin et al., 1997). Drivers who showed once a risky driving behaviour tend to have more traffic offences in the past and differed significantly from non-risky drivers in their further police records. Age also could have an influence as teens showed a higher rate of following too closely than other drivers (Simons-Morton et al., 2005). Fog provoked two different following behaviours by participants of the study (Broughton et al., 2007), with one group of drivers engaged in a risky driving behaviour following within the sight distance but in a too short headway to be safe. Roadworks seem to decrease the headway distances significantly with a higher amount of unsafe headway distances shorter than 2 seconds after the roadworks (Yousif et al., 2014).

Further influencing factors like expectation or assessment of the braking distance are investigated in several other studies, which were excluded due to the used research methods.

Biases:

- One driving simulator study had included undergraduate students as participants. Results may not be generalizable.
- Due to the study interest, studies with control groups are rather rare.

3. Supporting Documents

3.1. ADDITIONAL INFORMATION ABOUT HEADWAY MEASUREMENT

Difference between time headway and headway distance
Time headway is independent on different speeds. The time interval that has to be estimated does not change with increasing or decreasing speed and stays constant while the total physical headway distances changes.

Example:
2 seconds at 10 m/s → 20 meter of distance
2 seconds at 30 m/s → 60 meter of distance

Headway distance is dependent on speed. If the vehicle speed increases, the driver of the following vehicle also needs to increase the target physical distance to maintain a safe margin.

Factors influencing following behaviour

The following table gives a summary on factors, which influence car following behaviour, extracted from different studies (Saifuzzaman & Zheng, 2014, Yousif et al., 2014, Broughton et al.2007, Simons-Morton et al., 2005).

Situation	Driver characteristics
• Road type (urban road, motorway) • Weather (fog, rain, snow) • Vehicle type of lead vehicle (HGV, LGV, motorbike, car, SUV) • Vehicle type of following vehicle • Oncoming traffic • Cumulating row effects (position in the traffic row) • Passenger • Time of the day (rush hour vs. quiet traffic)	• Age • Gender • Risk-taking • Reaction time • Driving needs: e.g. time pressure • Driving skills • Fatigue, drugged driving, usage of mobile phones • Distance perception • Estimation errors • Temporal and spatial anticipation: drivers predict traffic situations

Table 2: Situational factors and driver characteristics influencing car following behaviour

3.2. LITERATURE SEARCH STRATEGY

Literature search was conducted in March 2016. It was carried out in two databases with separate search strategies. The first one was performed in 'Scopus' which is a large abstract and citation database of peer-reviewed literature. The second literature search was conducted in a KFV-internal literature database ('DOK-DAT').

Database: Scopus **Date:** 31st of March 2016

no.	search terms / logical operators / combined queries	hits
#1	"overtak*" OR "passing" OR "tailgat*" OR "headway" OR "lane keep*" OR "lane chang*" OR "car follow*" OR "following situation"	97,455
#2	"road casualties" OR "road fatalities" OR "traffic accident" OR "road crash" OR "road violation" OR "traffic rule" OR "rear end crashes"	46,264
#3	("road safety" OR "traffic safety") AND ("risk" OR "collision")	4,629
#4	#1 AND #2	550
#5	#1 AND #3	180
#6	#4 OR #5	**668**

Table 3: Used search terms, logical operators, and combined queries of literature search (Scopus).

Detailed search terms, as well as their linkage with logical operators and combined queries are shown in **Table 3**. Using search fields title, abstract, and keywords (TITLE-ABS-KEY) and a general limitation to studies, which were published from 1990 to current led to a huge amount of studies.

Results were limited to "article" and "review" and in a further step to the languages "English" and "German". Quantity of studies was further reduced by limiting source type to "Journal" as well as excluding various countries. As on study scope, we only considered European countries, as well as Russia. As a last reduction step, we limited remaining studies to the subject areas "Engineering" and "Psychology". This led to a final sample of 204 studies of literature search in Scopus (**Table 5**).

Database: DOK-DAT **Date:** 31st of March 2016

search no.	search terms / operators / combined queries	hits
#1	"overtak*" OR "passing" OR "tailgat*" OR "headway" OR "lane keep*" OR "lane chang*" OR "car follow*" OR "following situation"	488
#2 (within #1)	Limit to year: 1990 to 2016	386
#3 (within #2)	"road casualties" OR "road fatalities" OR "traffic accident" OR "road crash" OR "road violation" OR "traffic rule" OR "rear end crashes"	14
#4 (within #2)	("road safety" OR "traffic safety") AND ("collision" OR "crash")	15
#5	#3 OR #4	**29**

Table 4: Used search terms, logical operators, and combined queries of literature search (DOK-DAT).

(German) Search fields 'Titel', 'ITRD Schlagworte' and 'freie Schlagworte' were used. Hits were only limited to the years 1990 to 2016 and got 29 more potential studies (**Table 5**).

Results Literature Search

Database	**Hits**
Scopus (remaining papers after several limitations/exclusions)	204
DOK-DAT	29
Total number of studies to screen title/ abstract	**233**

Table 5: Results of both databases after limitations

Overall, the literature search lead to 233 potential studies for screening.

Screening

Total number of studies to screen title/ abstract	**233**
-De-duplication	7
-not relevant studies excluded	138
-Studies with no risk estimates excluded	3
-Studies concerning measures excluded	20
Remaining studies	**48**
Not clear (full-text is needed)	19
Studies to obtain full-texts	**67**

Table 6: Number of studies to obtain full-texts

Eligibility

Total number of studies to screen full-text	**67**
Full-text could be obtained	67
Reference list examined Y/N	No
Eligible papers	**67**

Table 7: Number of studies to screen full-texts

Screening of the full texts

Total number of studies to screen full paper	**67**
-Studies with no risk estimates excluded	32
-Studies concerning measures excluded	13
Remaining studies	**22**
Number of studies dealing with "headway distance"	8
Number of studies dealing with "risky overtaking"	13
Number of studies dealing with both aspects	1

Table 8: Screening of full texts

Prioritizing Coding
- Prioritizing Step A (meta-analysis first)
- Prioritizing Step B (best fitting in coding scheme)
- Prioritizing Step C (published more recently)

List of references resulting from search strategy

No.	Publication	Coded Y/N	Reason
1.	Broughton, K. L. M., Switzer, F., & Scott, D. (2007). Car following decisions under three visibility conditions and two speeds tested with a driving simulator. Accident Analysis and Prevention, 39(1), 106–116.	Y	Prioritizing Step B
2.	Dingus, T., Guo, F., Lee, S., Antin, J., Perez, M., Buchanan-King, M., & Hankey, J. (2016). Driver crash risk factors and prevalence evaluation using naturalistic driving data. PNAS Early Edition, 113(10), 2636-2641.	Y	Prioritizing Step B
3.	Glendon, A. I. (2007). Driving violations observed: An Australian study. Ergonomics, 50(8), 1159–1182.	N	Not codeable data
4.	Muhrer, E., & Vollrath, M. (2010). Expectations while car following-The consequences for driving behaviour in a simulated driving task. Accident Analysis and Prevention, 42(6), 2158–2164.	N	No risk estimates
5.	Rajalin, S., Hassel, S.-O., & Summala, H. (1997). Close-following drivers on two-lane highways. Accident Analysis and Prevention, 29(6), 723–729.	Y	Prioritizing Step B
6.	Simons-Morton, B., Lerner, N., & Singer, J. (2005). The observed effects of teenage passengers on the risky driving behaviour of teenage drivers. Accident Analysis and Prevention, 37(6), 973–982	Y	Prioritizing Step B
7.	Summala, H., Rajalin, S., & Radun, I. (2014). Risky driving and recorded driving offences: A 24-year follow-up study. Accident Analysis and Prevention, 73, 27–33.	Y	Prioritizing Step B
8.	Van Der Hulst, M., Meijman, T., & Rothengatter, T. (1999). Anticipation and the adaptive control of safety margins in driving. Ergonomics, 42(2), 336–345.	N	No control group
9.	Yousif, S., Alterawi, M., & Henson, R. R. (2014). Red light running and close following behaviour at urban shuttle-lane roadworks. Accident Analysis and Prevention, 66, 147–157.	Y	Prioritizing Step B

Table 9: List of references resulting from search strategy

Additional Study

Dingus T.A.; Guo F.; Lee S.; Antin J.F.; Perez M.; Buchanan-King M.; Hankey J. (2016). Driver crash risk factors and prevalence evaluation using naturalistic driving data. PNAS Early Edition. www.pnas.org/cgi/doi/10.1073/pnas.1513271113

3.3. REFERENCES

Coded Studies

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Simons-Morton, B., Lerner, N., & Singer, J. (2005). The observed effects of teenage passengers on the risky driving behavior of teenage drivers. Accident Analysis and Prevention, 37(6), 973–982.

Summala, H., Rajalin, S., & Radun, I. (2014). Risky driving and recorded driving offences: A 24-year follow-up study. Accident Analysis and Prevention, 73, 27–33.

Yousif, S., Alterawi, M., & Henson, R. R. (2014). Red light running and close following behaviour at urban shuttle-lane roadworks. Accident Analysis and Prevention, 66, 147–157.

Further background information

Bella, F., Calvi, A., & D'Amico, F. (2014). An empirical study on traffic safety indicators for the analysis of car-following conditions. Advances in Transportation Studies, 1(SPECIAL ISSUE), 5–16.

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Wang, J.-H., & Song, M. (2011). Assessing Drivers' Tailgating Behavior and the Effect of Advisory Signs in Mitigating Tailgating. Presented at the Driving Assessment 2011: 6th International Driving Symposium on Human Factors in Driver Assessment, Training, and Vehicle Design. Retrieved from http://trid.trb.org/view.aspx?id=1112886

Figure

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Distraction – Cell phone use – Hand Held

Distraction of road users caused by using a cell phone held in their hand (Conversation, talking, locating, dialling)

1. Summary

Ziakopoulos, A., Theofilatos, A., Papadimitriou, E., Yannis, G., August 2016

1.1. COLOUR CODE: RED

The effects of handheld cell phone use for conversation have long related to accidents, with a very large number of literature studies presenting findings to support that. Those studies have good levels of quality, and are overall consistent in their results. Finally, study results and professional practice indicate that handheld cell phone use has a proven relation with accidents.

1.2. KEYWORDS

Cell phone; mobile phone; handheld; crash risk; road safety; road accident; driver distraction

1.3. ABSTRACT

The use of handheld cell phones induces a level of distraction to the person driving. This distraction translates to slower reaction times to events, increased percentages of time with eyes off the road, speeding, increased number of crashes and near misses and also increased crash injury severities. Thirteen high quality studies, including four meta-analyses, regarding various related topics were coded. On a basis of both study and effect numbers, it can be argued that handheld cell phone use creates negative impacts on road safety, with most factors being statistically significant. There were cases, however, that reported no statistically significant relation of cell phone use to various road safety variables (including behavioural factors) or even positive effects from overcompensation. The presence of meta-analyses makes the results generally transferable.

1.4. BACKGROUND

Definition of handheld cell phone use

The presence of this risk factor exists when any vehicle driver is engaged in a conversation on a cellular (mobile) phone device. In the context of road safety, this can mean searching for, dialling from and/or answering the device or simply conversing with it (for instance by being passed on by another passenger). As a variable, it is usually of binary nature (e.g. driver using or not using handheld phones, being exposed or non-exposed to cell phone conversations, etc.).

How does handheld cell phone use affect road safety?

It is generally understood that the use of cell phones that are handheld (i.e. not using a hands-free or Bluetooth device to free the hands of the user) induces a level of distraction to the person driving, which is a major risk factor in road safety. The extra amount of mental workload and cognitive functions that drivers have to undertake reduces their reflexes and slows reaction times to events (both the time to mentally register the effect and the time to physically react to it), as supported by several studies. Another study found a similar increase effect for percentages of time with eyes off the road. This risk factor can also lead to accidents and near misses, and, if they occur, to increased injury severities for those involved, as other studies have demonstrated. Lastly, distractions can lead to acceleration, speed and position variations within the traffic flow which are proven causes of road accidents.

How is the effect of handheld cell phone use on road safety studied?

The international literature has examined a variety of different approaches and ways to study the effect of handheld cell phone use. Sometimes this particular risk factor is examined alongside other similar distraction factors such as hands-free cell phone use and texting, and not solely by itself. Its examination or analysis may be adjusted to the models selected to capture the entire situation for the given case.

Given that it is unethical to conduct experiments on real circumstances (field experiments on the road) because it would compromise the safety of the participants, researchers have two alternative methods available. They involve either examining databases of past accidents and analysing the effect of handheld cell phone use on them, or conducting simulation experiments, which are in a virtual environment where no hazard is present.

As for the analytic part, the binary approach is the most common method, which categorizes drivers as exposed or not exposed to the risk factor that is handheld cell phone use. There have been isolated studies that differentiate between shorter or longer (>5 min.) phone calls but that is usually not the case.

1.5. OVERVIEW OF RESULTS

The effect of handheld cell phone use on road safety is uniformly and collectively negative. Usually when handheld cell phones are involved, the various study findings link them to increased accident or near miss absolute numbers and also frequencies. One study found significantly increased accident injury severity associated with their use.

There are also many behavioural variables examined, mainly in simulator studies where those environments allow for safe and detailed recording and examination of data. The most important are the event response times (which can be split to reaction times and movement times), which have increased statistical significance, along with speed and the percentage of time spent while driving with eyes off the road. On the other hand, lateral positioning or tracking are not significantly affected by the risk factor.

Transferability

Amongst the coded studies are four meta-analyses, which draw from international studies and thus offer a rounded insight on the risk factor at hand. Furthermore, while the majority of studies are conducted in the USA, there are studies in the group from the United Kingdom and Norway. This is a good sample, although there is always room for representation of other areas of the world.

Most studies concerned all motor vehicles for road accidents, combining cars, PTWs, LGVs, HGVs and buses without differentiating for different road users when examining past accidents. Simulation studies are conducted with devices resembling car interiors, therefore it can be said that there is a margin for representing different road users in the literature.

1.6. NOTES ON ANALYSIS METHODS

The methodology applied for capturing the impacts of handheld cell phone use varies considerably among studies in regards to mainly the mathematical models utilised and also the outcomes evaluated as dependent variables.

What is more, the risk factor of handheld cell phone use is sometimes not studied exclusively. This means that in some studies, the presence of other distraction factors is studied alongside this particular risk factor (e.g. consumption of goods). Consequently, the study designs might not always be completely tailored towards capturing the effect of handheld cell phone use. There are studies (including meta-analyses) that are focused exclusively on this risk factor solely, however.

There is some margin for investigating different road user categories and/or other geographical regions. All aforementioned factors make the findings for handheld cell phone use generally transferable, though caution and care against oversimplification are always required.

2. Scientific Overview

2.1. ANALYSIS OF STUDY DESIGNS AND METHODS

After appropriate use of various search tools and databases, thirteen high quality studies were selected and coded for the risk factor of handheld cell phone use. Two of the studies investigated crash counts (Backer-Grøndahl and Sagberg, 2011, Wang et al., 1996) and an additional two studies investigated accident risk (Dingus, 2016, Elvik, 2011).

An additional three studies investigated crashes and near misses, which were widely defined as any circumstance requiring a last-moment physical manoeuvre that challenged the physical limitations of the vehicle to avoid a crash for which the driver was at fault or partially at fault (Klauer et al., 2014, Lansdown, 2012, Simmons et al., 2016). Another study focused on the effect on injury severity from this risk factor (Donmez and Liu, 2015).

There have been a number of studies investigating behavioural indicators, mainly by assessing driver performances. Reaction time when presented with a safety event is a quite popular variable for assessment (Caird et al., 2008, Consiglio et al., 2003, Horrey and Wickens, 2006). It was also examined separately by one study by dividing it into reaction time and movement time (Bellinger et al., 2009). There were additional behavioural variables investigated in some of these studies, such as speed (Caird et al., 2008), and tracking (lane keeping or tracking performance) and overall safety effects (Horrey and Wickens, 2006). Lastly, Fitch et al. (2015) focused on examining the percentage of time that was spent by the drivers with eyes off the road.

In order to examine the relationship between the various handheld cell phone uses and outcome indicators, the studies either deployed multivariate statistical models (ordered logit model, mixed-effects logistic regression analysis etc.) or at least conducted basic descriptive statistical analysis. Sometimes other independent variables were present as well, with some models controlling for them and others studying them independently.

A critical part of this synopsis is the findings of four meta-analyses that were coded alongside the original studies, which by default encompass and analyse several studies from the international literature (Caird et al., 2008, Elvik, 2011, Horrey and Wickens, 2006, Simmons et al., 2016). Though there is some minor overlap between the studies taken into consideration by the authors, it was decided that the findings were too important to exclude, therefore all four meta-analysis are listed here. The meta-analyses have their own methods, such as the random-effects meta-analytic method. It should be mentioned at this point that the meta-analysis of Elvik (2011) does not differentiate between hand-held and hands-free cell phone use, but the value of the results was prioritized and they are presented nonetheless.

Two of the studies which examined crash counts and near misses reported no statistically significant risk by exposure to the handheld cell phone use risk factor itself, but there was increased risk while engaging in auxiliary activities other than conversation (reaching for (Klauer et al., 2014) and dialling the phone (Klauer et al., 2014, Simmons et al., 2016)).

However, a meta-analysis (Elvik, 2011) and another study reported statistically significant accident risk increases for both adequately reported and poorly reported cell phone use during the accident. Similar increases were found by another study (Dingus, 2016), while a different one reached non-significant outcomes (Bellinger et al., 2009) in all aspects. The other two studies investigating similar topics did not go beyond descriptive statistics (Lansdown, 2012, Wang et al., 1996) and do not entail any sort of correlation analysis in this particular aspect. As such, no relevant conclusion can be reached.

The study investigating injury severity found significantly increased severities for young and old drivers engaging in cell phone conversations, while for middle-aged drivers this is not a statistically significant event (Donmez and Liu, 2015). This can be explained by overcompensation. Both middle-aged and older drivers are aware of the dangers that distraction via a cell phone might have and choose to drive more conservatively due to that awareness. The difference is that older drivers have slower reflexes and less cognitive readiness, and therefore are in the end negatively affected as well.

With regards to driver behavioural variables, all studies generally agree that cell phone use is statistically significantly detrimental to event reaction time (Bellinger et al., 2009, Caird et al., 2008, Consiglio et al., 2003, Horrey and Wickens, 2006) and thus has a negative impact on road safety. There have been some estimates that were not statistically significant, and even contradictory (positive), but the consensus appears to be uniform across studies. Furthermore, Caird et al. (2008) reported an increase in speeding of drivers while engaged in handheld cell phone conversations.

Other factors such as tracking, which is defined as lane keeping or tracking performance, (Horrey and Wickens, 2006) were not found to have a statistically significant correlation with handheld cell phone use. Lastly, Fitch et al. (2015) found that locating and answering a handheld phone device had a statistically significant negative effect on the percentage of time that was spent by the drivers with eyes off the road when comparing with a baseline of unimpeded driving.

Limitations

A few limitations can arguably be found in the current literature for the effects of handheld cell phone use on road safety. The first one lies in the design of the studies themselves: Either past data, along with their lack of detail, general limitations and underlying biases have to be relied upon to reach a conclusion, or the researchers must resort to simulators. Simulations are known to either underrepresent real world conditions, making them less believable environments which the drivers may not take entirely seriously, or sometimes cause dizziness or nausea on the participants. Both of these aspects might skew data from relevant experiments.

Secondly, there is a noticeable lack of studies that focus on the indirect effects of this particular risk factor. A common example of this is the case of a non-driver road user engaging in cell phone use, such as a passenger or a pedestrian crossing the street, and the impacts of this activity on road safety.

An overview of the main features of the coded studies (sample, method, outcome and results) is illustrated on Table 1.

#	Author(s); Year; Country;	Sampling frame for handheld cell phone conversation study	Method for handheld cell phone conversation impact investigation	Outcome indicator	Main Result
1	Backer-Grøndahl, A., & Sagberg, F.; 2011; Norway	Accident risk was investigated in a sample of 4307 drivers who were involved in accidents in 2007. In addition, data from a similar survey from 1997 (N = 5007) were used in order to get more observations.	Quasi-induced exposure method	Crash count [Relative risk]	Data from both studies show that handheld telephones impose a statistically significant increased relative risk of crash (detrimental to road safety).
2	Bellinger, D. B., Budde, B. M., Machida, M., Richardson, G. B., & Berg, W. P.; 2009; USA	27 licensed drivers between the ages of 19 and 23 participated in the simulation of the study, from Miami University. They had ranging driving experience and average miles driven per week.	Absolute difference comparison between exposed and non-exposed states	Reaction time; Movement time; Response time [All in absolute difference]	Cellular telephone conversation was found to significantly increase the difference in response time to simulator events.
3	Caird, J. K., Willness, C. R., Steel, P., & Scialfa, C.; 2008; International	A meta-analysis of the effects of cell phones on driving performance was performed. A total of 33 studies collected through 2007 that met inclusion criteria yielded 94 effect size estimates, with a total sample size of approximately 2000 participants.	Meta-analytic correlation analysis [Meta-analysis]	Reaction time; Speed [Correlation coefficients: rc, weighted mean correlations corrected for reliability]	Slower reaction times occurred from conversing on the phone than in baseline conditions, especially in older driver groups. Speed was found elevated from the baseline for all drivers.
4	Consiglio, W., Driscoll, P., Witte, M., & Berg, W. P.; 2003; USA	Using a laboratory station which simulated the foot activity in driving, 22 research participants were requested to release the accelerator pedal and depress the brake pedal as quickly as possible following the activation of a red brake lamp.	Absolute difference comparison between exposed and non-exposed states	Reaction time in a breaking response (releasing throttle and pressing brake) in ms [Absolute difference in mean reaction]	Results indicated that conversation, whether conducted in-person or via a cellular phone caused reaction times to increase.
5	Dingus T.A.; Guo F.; Lee S.; Antin J.F.; Perez M.; Buchanan-King M.; Hankey J.; 2016; U.S.A.	The study used a US dataset comprising 905 injurious and property damage crash events. Crash events were gathered and analysed in detail through video observations and measurements of 3,542 drivers.	Mixed effect random logistics model (& 2-staged stratified random sampling method)	Accident risk [Odds Ratio]	Driver-related factors (i.e., error, impairment, fatigue, and distraction) are present in almost 90% of crashes. Drivers are distracted more than 50% of the time while they are driving, resulting in a crash risk that is 2 times higher than model driving.
6	Donmez B., Liu Z.; 2015; USA	The study aimed to predict injury severity sustained by drivers using data a US national database (2003 to 2008). Various factors were controlled for, but the main focus was on the interaction of driver age and distraction type.	Ordered logit model	Injury severity - Categorical [Odds ratio]	The trends observed for younger and old-age drivers were similar, whereas for middle-aged drivers this certain type of distraction does not appear to have such a negative effect, possibly due to overcompensation.
7	Elvik R.; 2011; Norway	13 studies were examined in two groups: 6 studies that reported the actual use of mobile phones at the	Random effects model combined with the trim-and-	Accident risk [Odds Ratio]	There was a statistically significant increase in risk, which was almost three

#	Author(s); Year; Country;	Sampling frame for handheld cell phone conversation study	Method for handheld cell phone conversation impact investigation	Outcome indicator	Main Result
		time of an accident; 7 studies with less precise information about the use of mobile phones at the time of accident.	fill technique [Meta-analysis]		times the risk run when a mobile phone was not used.
8	Fitch, G. M., Bartholomew, P. R., Hanowski, R. J., & Perez, M. A.; 2015; USA	A naturalistic driving study recorded 204 drivers using video cameras and vehicle sensors for an average of 31 days. A total of 1564 cell phone calls made and 844 text messages sent while driving were sampled and underwent a video review.	Absolute proportion comparisons	Total eyes-off-road time (TEORT) % [Baseline/subtask mean comparisons]	With respect to HH cell phone use, locating the cell phone, dialling, browsing, text messaging, simultaneously browsing and conversing, and ending cell phone use were all found to significantly increase the percentage of time drivers took their eyes off road.
9	Horrey, W. J., & Wickens, C. D.; 2006; International	The performance costs associated with cell phone use while driving were assessed meta-analytically using standardized measures of effect size along five dimensions. Twenty-three studies (contributing 47 analysis entries) met the appropriate conditions for the meta-analysis. The statistical results from each of these studies were converted into effect sizes and combined in the meta-analysis.	Un-weighted and weighted combined effect sizes and corresponding tests of heterogeneity [Meta-analysis]	Response time (reaction time to effects); Tracking (lane keeping or tracking performance); Overall effect on safety (combination of the above) [Product moment correlation coefficient]	There are definite costs associated with cell phone use while driving; primarily in measures of response time to critical road hazards or stimuli. In contrast, the costs associated with lane-keeping or tracking performance are much smaller (and, for the un-weighted means, non-significant).
10	Klauer, S. G., Guo, F., Simons-Morton, B. G., Ouimet, M. C., Lee, S. E., & Dingus, T. A.; 2014; USA	2 studies on the relationship between the performance of secondary tasks were conducted, including cell-phone use, and the risk of crashes and near-crashes. Several instruments were installed in the vehicles of 42 newly licensed drivers and 109 adults with more driving experience.	Mixed-effects logistic-regression analysis	Crash or Near crash [Odds ratio]	Among novice drivers, dialling or reaching for a cell phone were all associated with a significantly increased risk of a crash or near-crash. Among experienced drivers, only cell-phone dialling was associated with an increased risk.
11	Lansdown, T.C.; 2015; United Kingdom	Survey data were collected using an anonymous online questionnaire. 482 respondents contributed to the survey during a 2 month data collection period.	Absolute proportion comparisons	Crashes & Near misses [Absolute proportion frequency]	Results suggest drivers are frequently distracted (in the United Kingdom) while driving. While proportion results are lacking statistical analysis to back this, regression models later in the study support it.
12	Simmons S.M, Hicks A., Caird J.K.; 2016; USA	6 of the studies identified from the literature were included. They use 7 sets of naturalistic driver data and assess the effects of distracting behaviours. 4 studies involved non-commercial drivers of light vehicles and 2 studies involved commercial drivers of trucks and buses.	A random-effects meta-analysis was calculated, stratified by distraction type, using reported (pre-calculated) odds ratios of SCE risk	Crashes and near misses (Safety Critical Event Risk); some studies include all while others at-fault incidents only [Odds ratio]	The results indicate that tasks that require drivers to take their eyes off the road, such as dialling, locating a phone and texting, increase SCE risk to a greater extent than tasks that do not require eyes off the road such as

#	Author(s); Year; Country;	Sampling frame for handheld cell phone conversation study	Method for handheld cell phone conversation impact investigation	Outcome indicator	Main Result
			and their associated 95% confidence intervals. [Meta-analysis]		talking.
13	Wang, J. S., Knipling, R. R., & Goodman, M. J.; 1996; USA	The Crashworthiness Data System (CDS) was employed to obtain more in-depth information on driver inattention related crash causes, including various distractions. This research paper reports the results of the 1995 CDS data collection on this issue.	Absolute proportion comparisons	Crash count [Absolute proportion frequency]	Judging by the percentages, inattention is a major factor on relevant crashes, followed by fatigue and out-of-vehicle distractions.

Table 1: Description of coded studies

2.2. CONCLUSIONS FOR HANDHELD CELL PHONE USE

The identified effects of handheld cell phone use can be summarized as follows:

- 2 studies with a significant increase on accident/crash or near miss counts.
- 2 studies with a significant increase on accident/crash risks.
- 1 study with a non-significant increase on accident/crash or near miss counts.
- 2 studies with only descriptive statistics results on accident/crash or near miss counts.
- 1 study with a significant increase on accident or injury severity.
- 4 studies with a significant increase on reaction time to events, and non-significant effects on other behavioural factors (lateral positioning/tracking). 1 of those studies found a significant increase on speed.
- 1 study with a significant increase on the percentage of time that was spent by the drivers with eyes off the road.

After the results were reviewed together, the following points were observed:

a) There is an adequate number of studies, however;
b) Those studies have not used the same model for analysis but largely different ones.
c) There are different indicators, and even when they coincide they are not measured in the same way.
d) The sampling frames were quite different.
e) The presence of the meta-analyses carry increased weight
f) There is a slight overlap in studies in the four meta-analyses

2.3. DESCRIPTION OF ANALYSIS CARRIED OUT

Review type analysis

After considering the previous points it was decided that a meta-analysis could not be carried out in order to find the overall impact of handheld cell phone use on road safety. The reasons for this is that the four existing meta-analyses that each have several studies carry different weight than the original studies. Despite the large amount of studies, the sampling frames, outcome variables and statistical analyses are all too different for the meta-analyses to be updated or unified, and the small overlap will induce double-counting bias in the end result. Each of the four considered meta-analyses have different strong points and focus on a different detailed aspect for road safety, and they merit examination on their own by specialized researchers.

Taking all the above into consideration, it was decided that both the meta-analysis and the vote count analysis are inappropriate, and thus the review type analysis was selected. Thus the effect of the handheld cell phone use risk factor will be given via a qualitative analysis.

The meta-analyses are the first to be examined as the most wide ranging and critical studies in this group. All four of them found negative outcomes for road safety from the numerous studies they considered (Caird et al., 2008, Elvik, 2011, Horrey and Wickens, 2006, Simmons et al., 2016). Furthermore, this also applies to a large number of original studies, regardless of their focus. This leaves only a small number of studies that had only descriptive statistics as relevant for the scope of this synopsis (Lansdown, 2012, Wang et al., 1996) or that had inconclusive results (Bellinger et al., 2009).

When found to be statistically significant, all variables that were examined yielded negative effects for road safety. Accidents or near misses, both in counts or frequencies, were increased, as were injury severities. Furthermore, response times were found to be slower, and when they were split both the mental reaction times and physical movement times followed that trend. The same result was reported for the percentage of time with eyes off the road. Speeding was found to be increased with statistical significance in one of the meta-analyses. Other behavioural variables were found to be unaffected. The quantitative results of the coded studies alongside with their general effects on road safety are presented on Table 2.

Table 2: Quantitative results of coded studies and impacts on road safety. Key ↑ increased risk; - not significant; ↓ decreased risk

No.	Author(s); Year; Country;	Outcome indicator	Quantitative Estimate	Effect on road safety
1	Backer-Grøndahl, A., & Sagberg, F.; 2011; Norway	Crash count [Relative risk]	RR = 2.34, p>0.05, CI [95%] = [0.85, 6.44] (for 1997 data)	-
			RR = 1.98, p>0.05, CI [95%] = [0.63, 6.24] (for 2007 data)	-
			RR = 2.17, p<0.05, CI [95%] = [1.02, 4.65] (for combined data)	-
2	Bellinger, D. B., Budde, B. M., Machida, M., Richardson, G. B., & Berg, W. P.; 2009; USA	Reaction time [In absolute difference]	Reaction: Abs.Dif = 60 ms, F(1,156)=43.07, p<0.05	↑
		Movement time [In absolute difference]	Movement: Abs.Dif = -18 ms, F(1,156)=3.851, p<0.05	↓
		Response time [In absolute difference]	Response: Abs.Dif = 42 ms, F(1,156)=6.67, p<0.05	↑
3	Caird, J. K., Willness, C. R., Steel, P., & Scialfa, C.; 2008; International [Meta-analysis]	Reaction time; [Correlation coefficient: rc, weighted mean correlations corrected for reliability]	Reaction: rc=0.546, CI [95%] = [0.17, 0.92]	↑
		Speed; [Correlation coefficient: rc, weighted mean correlations corrected for reliability]	Speed: rc=0.394, CI [95%] = [0.26, 0.52]	↑
4	Consiglio, W., Driscoll, P., Witte, M., & Berg, W. P.; 2003; USA	Reaction time in a breaking response (releasing throttle and pressing brake) in ms [Absolute difference in mean reaction]	Reaction: Abs.Dif = 61 ms, p<0.0001	↑
5	Dingus T.A.; Guo F.; Lee S.; Antin	Accident risk [Odds Ratio]	OR=3.60, CI [95%]=[2.90, 4.50], Baseline Prevalence=6.400%	↑

No.	Author(s); Year; Country;	Outcome indicator	Quantitative Estimate	Effect on road safety
	J.F.; Perez M.; Buchanan-King M.; Hankey J.; 2016; U.S.A.			
6	Donmez B., Liu Z.; 2015; USA	Injury severity - Categorical [Odds ratio]	Young: OR=1.33, p<0.0001, CI [95%] = [1.29, 1.38]	↑
			Middle-aged: OR=1.01, p=0.62, CI [95%] = [0.98, 1.04]	-
			Old: OR=1.20, p=0.0001, CI [95%] = [1.08, 1.33]	↑
7	Elvik R.; 2011; Norway	Accident risk for precise phone use data on the instance of the accident [Odds Ratio]	OR=2.86, CI [95%]=[1.72, 4.75], [Results for all phone use]	↑
		Accident risk for imprecise phone use data on the instance of the accident [Odds Ratio]	OR=1.28, CI [95%]=[1.12, 1.46], [Results for all phone use]	↑
8	Fitch, G. M., Bartholomew, P. R., Hanowski, R. J., & Perez, M. A.; 2015; USA	Total eyes-off-road time (TEORT) % [Baseline/subtask mean comparisons]	Proportions (handheld/baseline): Locate-answer: 0.3310 (S.E.=0.0160) / 0.1520 (S.E.=0.0160) [F-stat=105.18]	↑
			Dial: 0.5950 (S.E.=0.0140) / 0.1610 (S.E.=0.0140) [F-stat=498.36]	↑
			Talk-listen: 0.0950 (S.E.=0.0090) / 0.1460 (S.E.=0.0090) [F-stat=14.80]	↓
			End task: 0.4410 (S.E.=0.0200) / 0.1480 (S.E.=0.0100) [F-stat=120.07]	↑
9	Horrey, W. J., & Wickens, C. D.; 2006; International [Meta-analysis]	Response time (reaction time to effects) [Product moment correlation coefficient]	Response time: CC=0.49, p=0.001, CI [95%] = [0.36, 0.61]	↑
		Tracking (lane keeping or tracking performance) [Product moment correlation coefficient]	Tracking: CC=0.25, p<0.001, CI [95%] = [0.00, 0.48]	-
		Overall effect on safety (combination of the above) [Product moment correlation coefficient]	Overall Safety Level: CC=0.44, p<0.001, CI [95%] = [0.33, 0.54]	↑
10	Klauer, S. G., Guo, F., Simons-Morton, B. G., Ouimet, M. C., Lee, S. E., & Dingus, T. A.; 2014; USA	Crash or Near crash [Odds ratio]	Novice: OR=0.61, CI [95%] = [0.24, 1.57]	↑
		Crash or Near crash [Odds ratio]	Experienced: OR=0.76, CI [95%] = [0.51, 1.13]	↑
11	Lansdown, T.C.; 2015; United Kingdom	Crashes & Near misses [Absolute proportion frequency]	Accident frequency = 1.500 Near Miss frequency = 4.300	-
12	Simmons S.M, Hicks A., Caird J.K.; 2016; USA [Meta-analysis]	Crashes and near misses (Safety Critical Event Risk); some studies include all while others at-fault incidents only [Odds ratio]	Dialling: OR=4.04, p=0.0030, CI [95%] = [2.65, 6.16]	↑
			Answering/Locating: OR=3.57, p=0.2860, CI [95%] = [2.52, 5.05]	↑
			Talking: OR=0.89, p=0.1210, CI [95%] = [0.76, 1.05]	↑
13	Wang, J. S., Knipling, R. R., &	Crash count [Absolute proportion frequency]	Talking or Listening to cell phone frequency=0.0010	-

No.	Author(s); Year; Country;	Outcome indicator	Quantitative Estimate	Effect on road safety
	Goodman, M. J.; 1996; USA		Dialling cell phone frequency=0.0005	-

Key ↑ increased risk; - not significant; ↓ decreased risk

Overall estimate for road safety

On a basis of both study and effect numbers, it can be argued that the risk factor of handheld cell phone use has a uniformly negative effect on road safety. However there are cases when its impact is inconclusive, and two isolated positive effects, but these are a minority. As mentioned before, these particular studies have good levels of quality, and are overall consistent in their results. This leads to the assignment of the red colour code for handheld cell phone use.

2.4. CONCLUSION

The review-type qualitative analysis carried out showed that handheld cell phone use has a negative impact and a detrimental effect on road safety. There is evidence to support that overcompensation occurs by certain driver categories (such as middle-aged and older drivers), but the overall effects of this risk factor are not negated and should thus be countered accordingly.

3. Supporting Document

3.1. IDENTIFYING RELEVANT STUDIES (CELL PHONE – HANDHELD)

Risk factor: handheld cell phone use

Database: Scopus **Date:** 28th of March 2016

search no.	search terms / operators / combined queries	hits
#1	("cellphone" OR "mobile" OR "handheld")	188,981
#2	(distraction)	3,435
#3	(„casualties" OR „fatalities" OR „traffic safety" OR „crash" OR „crash risk" OR „severity" OR „frequency" OR „collision" OR „incident" OR „accident")	22,319
#4	#1 AND #3	2,405
#5	#1 AND #2	683
#6	#1 AND #2 AND 3	469

Optional but recommended: Limitations/ Exclusions:

- Search field: TITLE-ABS-KEY (used for search #10)
- published: 1990 to current
- Document Type: "Review" and "Article"
- Language: "English"
- Source Type: "Journal"
- Exclusion of several countries (not used)
- Subject Area: "Engineering")

Results Literature Search

Database	Hits
Scopus (remaining papers after several limitations/exclusions)	469
Total number of studies to screen title/abstract	469

Screening

Total number of studies to screen title/ abstract	469
-De-duplication	0
-exclusion criteria A (not related to the topic/not relevant risk factor)	377
-exclusion criteria B (part of meta-analysis)	2
Remaining studies	90
Not clear (full-text is needed)	15
Studies to obtain full-texts	90

Eligibility

Total number of studies to screen full-text	90
Full-text could be obtained	90
Eligible papers after full text screening	30
Reference list examined Y/N	YES
Eligible papers after prioritizing	13

Prioritizing Coding

- Prioritizing Step A (accidents over other performance indicators)
- Prioritizing Step B (Journals over conferences and reports)
- Prioritizing Step C (Prestigious journals over other journals)
- Prioritizing Step D (More recent studies)

Comments: Four meta-analysis studies were found.

After full text screening, the most relevant papers for coding and the general scope of the project were prioritized, and thus the final 13 studies that were coded were obtained from the group of 30.

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Distraction – Cell Phones – Hands Free

Distraction of road users caused by using a cell phone with equipment enabling 'hands free' use (conversation, talking)

1. Summary

Ziakopoulos, A., Theofilatos, A., Papadimitriou, E., Yannis, G., September 2016

1.1. COLOUR CODE: RED

The effects of hands-free cell phone use for conversation have long related to accidents, with a large number of literature studies presenting findings to support that. Those studies have good levels of quality, and are overall consistent in their results. Finally, study results and professional practice indicate that hands-free cell phone use has a proven relation with accidents.

1.2. KEYWORDS

Cell phone; mobile phone; hands-free; crash risk; road safety; road accident; driver distraction

1.3. ABSTRACT

The use of hands-free cell phones induces a level of distraction to the person driving. This distraction translates to slower reaction times to events, increased percentages of time with eyes off the road, speeding, increased crashes and near misses, and also increased crash injury severities. Nine high quality studies regarding various hands-free cell phone topics were coded. On a basis of both study and effect numbers, it can be argued that hands-free cell phone use creates negative impacts on road safety, with most factors being statistically significant. There were cases, however, that reported no statistically significant impact to various road safety variables (including behavioural factors). The presence of meta-analyses makes the results generally transferable.

1.4. BACKGROUND

Definition of hands-free cell phone use

The presence of this risk factor exists when any vehicle driver is engaged in a conversation on a cellular (mobile) phone device that is operated in a hands-free manner, whether via a cable with headphones and a microphone connecting to the main phone device, or a wireless Bluetooth earpiece and speaker. In the context of road safety, this can mean searching for, dialling from and/or answering either the main device or its auxiliary, or simply conversing with them (for instance by being passed on by another passenger). As a variable, it is usually of binary nature (e.g. driver using or not using hands-free phones, being exposed or non-exposed to hands-free cell phone conversations, etc.).

How does hands-free cell phone use affect road safety?

It is generally understood that the use of cell phones with hands-free devices (i.e. not held by one of the user's hands close to their face) induces a level of distraction to the person driving, which is a major risk factor in road safety. The extra amount of mental workload and cognitive functions that drivers have to undertake reduces their reflexes and slows reaction times to events (both the time to mentally register the effect and the time to physically react to it), as supported by several studies.

Another study found an increase effect for percentages of time with eyes off the road. This risk factor can also lead to accidents and near misses, and other critical safety events such as striking pedestrians, ignoring stop sign, or exceeding the speed limits by a large margin and frequently, as a simulation study discovered. Lastly, distractions can result in acceleration and speed and position variations within the traffic flow which are proven causes of road accidents.

It is worth noting that cell phone use, hands-free or otherwise, is only one aspect of driver distraction. A driver can be under the influence of several other aspects, and therefore suffer under combined detrimental effects. Examples of distraction risk factors that can coincide with cell phone use are consumption of goods (e.g. smoking), sun glare or vehicle lights, watching objects outside the vehicle and others.

How is the effect of hands-free cell phone use on road safety studied?

The international literature has examined a variety of different approaches and ways to study the effect of hands-free cell phone use. Sometimes this particular risk factor is examined alongside other similar distraction factors such as handheld cell phone use and texting, and not solely by itself. Its examination or analysis may be adjusted to the models selected to capture the entire situation for the given case.

Given that it is unethical to conduct experiments on real circumstances (field experiments on the road) because it would compromise the safety of the participants, researchers have two alternative methods to use. They involve either examining databases of past accidents and analysing the effect of hands-free cell phone use on them (which sometimes leads to lack of data), or conducting simulation experiments, which are in a virtual environment where no hazard is present.

As for the analytic part, the binary approach mentioned above is the most common method, which categorizes drivers as exposed or not exposed to the risk factor that is hands-free cell phone use. There have been isolated studies that differentiate between shorter or longer (>5 min.) phone calls but that is usually not the case.

1.5. OVERVIEW OF RESULTS

A common notion in road safety is that hands-free devices are a means to improve the detrimental conditions imposed on the driver by conventional handheld cell phones, but very few research results seem to support this.

The effect of hands-free cell phone use on road safety is uniformly and collectively negative, unless the data in question did not lead to statistically significant results. Usually when hands-free cell phones are involved, the various study findings link them to increased accident absolute numbers and also frequencies.

There are also many behavioural variables examined, mainly in simulator studies where those environments allow for safe and detailed recording and examination of data. The most important are the event response times (which can be split to reaction times and movement times), which have increased statistical significance, along with speeding, tracking and lane-keeping (sometimes), and the percentage of time spent while driving with eyes off the road. On the other hand, headway and lateral positioning are not significantly affected by the risk factor. Other simulation events, such as running through stop signs or into pedestrians, appeared similarly significantly increased.

Transferability

Amongst the coded studies are three meta-analyses, which draw from several international studies and thus offer a rounded insight on the risk factor at hand. Furthermore, while the majority of studies are conducted in the USA, there are studies in the group from Australia, Norway and the United Kingdom. This is a good sample, although there is always room for representation of other areas of the globe.

Most studies concerned all motor vehicles for road accidents, combining cars, PTWs, LGVs, HGVs and buses without differentiating for different road users when examining past accidents. Simulation studies are conducted with devices resembling car interiors, therefore it can be said that there is a margin for representing different road users in the literature.

Notes on analysis methods

The methodology applied for capturing the impacts of hands-free cell phone use varies considerably among studies in regards to mainly the mathematical models utilised and secondly the outcomes evaluated as dependent variables.

What is more, hands-free cell phone use is sometimes not studied exclusively. This means that in some studies, the presence of other distraction factors is studied alongside this particular risk factor (e.g. consumption of goods). Consequently, the study designs might not always be completely tailored towards capturing the effect of hands-free cell phone use. There are studies that are focused exclusively on this risk factor solely, however.

There is some margin for investigating different road user categories and/or other geographical regions. All aforementioned factors make the findings for hands-free cell phone use generally transferable, though caution and care against oversimplification are always required.

2. Scientific overview

2.1. LITERATURE REVIEW

Analysis of study designs and methods

After appropriate use of various search tools and databases, nine high quality studies were selected and coded for the risk factor of hands-free cell phone use. Three of the studies investigated crash counts (Backer-Grøndahl & Sagberg, 2011; Hunton and Rose, 2005; Kass et al., 2007); the first was an observational examination of past real accident data and the two latter were simulation studies. The last study also investigated safety critical events equally important to collisions, such as striking pedestrians, driving through stop signs and exceeding speed limits. An additional meta-analysis study investigated accident risk (Elvik, 2011), as did an original study (Backer-Grøndahl and Sagberg, 2011).

There have been a number of studies investigating behavioural indicators, mainly by assessing driver performances. Reaction time when presented with a safety event is a quite popular variable for assessment (Caird et al., 2008, Consiglio et al., 2003, Horrey and Wickens, 2006). There were additional behavioural variables investigated in some of these studies, such as lateral positioning/ tracking (Caird et al., 2008, Horrey and Wickens, 2006), speed (Caird et al., 2008, Horberry et al., 2006, Kass et al., 2007) and headway (Caird et al., 2008). Lastly, Fitch et al. (2015) focused on examining the percentage of time that was spent by the drivers with eyes off the road.

In order to examine the relationship between the various hands-free cell phone uses and outcome indicators, the studies either deployed multivariate statistical models (quasi-induced exposure method, weighted and unweighted combined effect analysis etc.) or at least conducted non-model statistical analysis and compared differences or proportions with regard to statistical significance. Sometimes other independent variables were present as well, with some models controlling for them and others studying them independently.

A critical part of this synopsis is the findings of the three meta-analyses that were coded alongside the original studies, which by default encompass and analyse several studies from the international literature (Caird et al., 2008, Elvik, 2011, Horrey and Wickens, 2006). Though there is some minor overlap between the studies taken into consideration by the authors, it was decided that the findings were too important to exclude, therefore all meta-analysis are listed here. The meta-analyses have their own methods, such as the meta-analytic correlation analysis. It should be mentioned at this point that the meta-analysis of Elvik (2011) does not differentiate between hand-held and hands-free cell phone use, but the value of the results was prioritized and they are presented nonetheless.

All three of the studies which investigated crash counts (Backer-Grøndahl and Sagberg, 2011, Hunton and Rose, 2005, Kass et al., 2007) reported statistically significant increases in collisions by exposure to hands-free cell phone use (though for the first study the effect appears significant only when aggregating the data from both study years, 1997 and 2007 together). Kass et al. (2007) reported statistically significant increases for all risk factors they examined, which were striking pedestrians, driving through stop signs and exceeding speed limits. Elvik (2011) reported statistically significant accident risk increases for both adequately reported and poorly reported cell phone use during the accident.

With regards to driver behavioural variables, all studies generally agree that cell phone use is statistically significantly detrimental to event reaction time (Caird et al., 2008, Consiglio et al., 2003, Horrey and Wickens, 2006) and thus has a negative impact on road safety. The consensus appears to be uniform across studies.

Concerning speed, both Horberry et al. (2006) and Kass et al. (2007) found significant increases in mean speed, and in deviating from or exceeding the speed limit. In the third relevant study, which was a meta-analysis by Caird et al. (2008), they did not find any significant correlation with speed and hands-free cell phone use, nor with headway and lateral positioning. Lane keeping and tracking performance, however, was found to have a statistically significant correlation with hands-free cell phone use (Horrey and Wickens, 2006).

Lastly, Fitch et al. (2015) examined the impacts of both portable and integrated hands-free devices. For the integrated hands-free devices, the study found that beginning and ending a hands-free phone conversation device had a statistically significant negative effect on the percentage of time that was spent by the drivers with eyes off the road, when comparing with a baseline of unimpeded driving. For the conversation task the results were not statistically significant, which was also the case for the results of portable hands-free devices.

Limitations

A few limitations can arguably be found in the current literature for the effects of hands-free cell phone use on road safety. The first one lies in the design of the studies themselves: Either past data, along with their lack of detail, general limitations and underlying biases have to be relied upon to reach a conclusion, or the researchers must resort to simulators. Simulations are known to either underrepresent real world conditions, making them less believable environments which the drivers may not take entirely seriously, or sometimes cause dizziness or nausea on the participants, which are forms of discomfort. Both of these aspects might skew data from relevant experiments.

Secondly, there is a noticeable lack of studies that focus on the indirect effects of this particular risk factor. A common example of this is the case of a non-driver road user engaging in cell phone use, such as a passenger or pedestrian crossing the street, and the impacts of this activity in road safety.

An overview of the main features of the coded studies (sample, method, outcome and results) is illustrated on Table 1.

#	Author(s); Year; Country;	Sampling frame for hands-free cell phone conversation study	Method for hands-free cell phone conversation impact investigation	Outcome indicator	Main Result
1	Backer-Grøndahl, A., & Sagberg, F.; 2011; Norway	Accident risk was investigated in a sample of 4307 drivers who were involved in accidents in 2007. In addition, data from a	Quasi-induced exposure method	Crash count [Relative risk]	Data from both studies show that hands-free telephones impose a statistically significant increased relative risk of crash

#	Author(s); Year; Country;	Sampling frame for hands-free cell phone conversation study	Method for hands-free cell phone conversation impact investigation	Outcome indicator	Main Result
		similar survey from 1997 (N = 5007) were used in order to get more observations.			when combined with handheld phones only, and a non-significant relation when examined alone.
2	Caird, J. K., Willness, C. R., Steel, P., & Scialfa, C.; 2008; International	A meta-analysis of the effects of cell phones on driving performance was performed. A total of 33 studies collected through 2007 that met inclusion criteria yielded 94 effect size estimates, with a total sample size of approximately 2000 participants.	Meta-analytic correlation analysis [Meta-analysis]	Reaction time; Speed [Correlation coefficients: rc, weighted mean correlations corrected for reliability]	Slower reaction times occurred from conversing on the phone than in baseline conditions, especially in older driver groups. Speed was found elevated from the baseline for all drivers.
3	Consiglio, W., Driscoll, P., Witte, M., & Berg, W. P.; 2003; USA	Using a laboratory station which simulated the foot activity in driving, 22 research participants were requested to release the accelerator pedal and depress the brake pedal as quickly as possible following the activation of a red brake lamp.	Absolute difference comparison between exposed and non-exposed states	Reaction time in a breaking response (releasing throttle and pressing brake) in ms [Absolute difference in mean reaction]	Results indicated that conversation, whether conducted in-person or via a cellular phone caused reaction times to increase.
4	Elvik R.; 2011; Norway	13 studies were examined in two groups: 6 studies that reported the actual use of mobile phones at the time of an accident; 7 studies with less precise information about the use of mobile phones at the time of accident.	Random effects model combined with the trim-and-fill technique [Meta-analysis]	Accident risk [Odds Ratio]	There was a statistically significant increase in risk, which was almost three times the risk run when a mobile phone was not used.
5	Fitch, G. M., Bartholomew, P. R., Hanowski, R. J., & Perez, M. A.; 2015; USA	A naturalistic driving study recorded 204 drivers using video cameras and vehicle sensors for an average of 31 days. A total of 1564 cell phone calls made and 844 text messages sent while driving were sampled and underwent a video review.	Absolute proportion comparisons	Total eyes-off-road time (TEORT) % [Baseline/subtask mean comparisons]	With respect to HH cell phone use, locating the cell phone, dialling, browsing, text messaging, simultaneously browsing and conversing, and ending cell phone use were all found to significantly increase the percentage of time drivers took their eyes off road.
6	Horberry, T., Anderson, J., Regan, M. A., Triggs, T. J., & Brown, J.; 2006; Australia	31 participants were employed. Of these, 10 were younger drivers, 11 were mid-age drivers and 10 were older drivers. The research was designed to assess within-vehicle distraction through an auditory/vocal task: hands-free mobile phone conversation. Participants answered a series of general knowledge questions over the	Absolute difference comparison between exposed and non-exposed states. Analyses were performed using a mixed factorial ANOVA with	Mean speed, Deviation from the posted speed limit [Absolute difference]	Hands-free conversation was found to interfere with maintaining speed and preparedness to react to unexpected hazards (e.g. jaywalking). The main source of interference appeared to be the cognitive demand associated with answering the questions, as visual attention could still be focused on the road.

#	Author(s); Year; Country;	Sampling frame for hands-free cell phone conversation study	Method for hands-free cell phone conversation impact investigation	Outcome indicator	Main Result
		audio system.	repeated measures.		
7	Horrey, W. J., & Wickens, C. D.; 2006; International	The performance costs associated with cell phone use while driving were assessed meta-analytically using standardized measures of effect size along five dimensions. Twenty-three studies (contributing 47 analysis entries) met the appropriate conditions for the meta-analysis. The statistical results from each of these studies were converted into effect sizes and combined in the meta-analysis.	Unweighted and weighted combined effect sizes and corresponding tests of heterogeneity [Meta-analysis]	Response time (reaction time to effects); Tracking (lane keeping or tracking performance) ; Overall effect on safety (combination of the above) [Product moment correlation coefficient]	There are definite costs associated with cell phone use while driving; primarily in measures of response time to critical road hazards or stimuli. In contrast, the costs associated with lane-keeping or tracking performance are much smaller (and, for the unweighted means, nonsignificant).
8	Hunton, J., & Rose, J. M.; 2005; USA	Experimental participants consisted of licensed automobile drivers, some with aircraft pilot training and others without pilot training. There were a total of 55 nonpilots and 56 pilots in the sample (n = 111) and the mean (standard deviation (SD)) age was 23.07 (3.32) years. They completed a simulated driving course while involved in one of three conversation modes: no conversation, conversation with passenger, or conversation on a hands-free cellular telephone.	Absolute difference comparison between exposed and non-exposed states. Analyses were performed using a multiple analysis of covariance (MANCOVA) test.	Crashes [Absolute difference - main effect comparisons]	Hands-free cellular telephones interfere with driving, consume significant driver attention, and result in more crashes than having no conversations. The results also demonstrate that communication training may reduce the hazardous effects of cell phone conversations on driving performance.
9	Kass, S. J., Cole, K. S., & Stanny, C. J., 2007, USA	A simulation study was conducted differentiating between novice drivers ages 14–16 (n = 25) and experienced drivers ages 21–52 (n = 26). Participants were instructed to pay attention to environmental stimuli such as cross-traffic and pedestrians and to obey all traffic laws. They attempted to follow instructions to reach a destination.	Absolute difference comparison between exposed and non-exposed states	Collisions, Struck pedestrians, exceeding speed limit frequently, drove through stop signs [Absolute difference - MANOVA analysis]	Drivers using hands-free cell phones were involved in significantly more collisions with other vehicles, struck more pedestrians, exceeded the posted speed limits more frequently and drove through more stop signs. Cell phone use did not significantly impact the number of times drivers crossed the centreline, or the number of times they drove off the road.

Table 1: Description of coded studies

2.2. ANALYSIS METHODS AND RESULTS

The identified effects of hands-free cell phone use can be summarized as follows:

- 2 studies with a significant increase on collision/crash counts (one reported other safety-related critical events).
- 2 studies with a significant increase on accident/crash risk.
- 3 studies with a significant increase of reaction time to events, and non-significant effects on other behavioural factors (speeding/lateral positioning/tracking).
- 1 of those studies found a significant increase on speed and speed deviations.
- 1 study with a significant increase on the percentage of time that was spent by the drivers with eyes off the road for some tasks for integrated hands free-devices, and no significant effects for others.

After the results were reviewed together, the following points were observed:

a) There is an adequate number of studies, however;
b) Those studies have not used the same model for analysis but largely different ones.
c) There are different indicators, and even when they coincide they are not measured in the same way.
d) The sampling frames were quite different.
e) The presence of the meta-analyses carry increased weight
f) There is a slight overlap in studies in the three meta-analyses

2.3. DESCRIPTION OF ANALYSIS CARRIED OUT

Review type analysis

After considering the previous points it was decided that an all-encompassing meta-analysis could not be carried out in order to find the overall impact of hands-free cell phone use on road safety. The reasons for this is that the three existing meta-analyses that each have several studies carry different weight than the original studies. Despite the large amount of studies, the sampling frames, outcome variables and statistical analyses are all too different for the meta-analyses to be updated or unified, and the small overlap will induce double-counting bias in the end result. All of the considered meta-analyses have different strengths and focus on different detailed aspects for road safety, and they merit examination on their own by specialized researchers.

Taking all the above into consideration, it was decided that both the meta-analysis and the vote count analysis are inappropriate, and so the review type analysis was selected. Thus the effect of the hands-free cell phone use risk factor will be given via qualitative analysis.

The meta-analyses are the first to be examined as the most wide and critical studies in this group. All of them resulted in negative outcomes for road safety from the numerous studies they considered (Caird et al., 2008, Elvik, 2011, Horrey and Wickens, 2006). Furthermore, this also applies to the majority of original studies, regardless of their focus. This only leaves a small number of studies that had some inconclusive results (Backer-Grøndahl and Sagberg, 2011, Fitch et al., 2015).

When found to be statistically significant, all variables that were examined yielded negative effects for road safety. Accidents (collisions, crashes), in terms of counts, frequencies, or risks, were increased, as were similar safety-critical events such as striking pedestrians or running through the stop signs. Furthermore, response times were found to be slower, and there was an increase reported for the percentage of time with eyes off the road. Speeding was found to be increased with statistical significance in one of the studies, as was exceeding or deviating from the speed limit.

Other behavioural variables were found to be unaffected. The quantitative results of the coded studies alongside with their general effects on road safety are presented on Table 2.

Table 2: Quantitative results of coded studies and impacts on road safety. Key ↑ increased risk; - not significant; ↓ decreased risk

#	Author(s); Year; Country;	Outcome indicator	Quantitative Estimate	Effect on road safety
1	Backer-Grøndahl, A., & Sagberg, F.; 2011; Norway	Accident risk [Relative risk]	RR = 2.34, p>0.05, CI [95%] = [0.85, 6.44] (for 1997 data)	-
			RR = 1.98, p>0.05, CI [95%] = [0.63, 6.24] (for 2007 data)	-
			RR = 2.17, p<0.05, CI [95%] = [1.02, 4.65] (for combined data)	↑
2	Caird, J. K., Willness, C. R., Steel, P., & Scialfa, C.; 2008; International [Meta-analysis]	Reaction time; [Correlation coefficient: rc, weighted mean correlations corrected for reliability]	Reaction: rc=0.460, CI [95%] = [0.10, 0.82]	↑
		Lateral positioning; [Correlation coefficient: rc, weighted mean correlations corrected for reliability]	Lateral positioning: rc=-0.152, CI [95%] = [-0.98, 0.68]	-
		Headway; [Correlation coefficient: rc, weighted mean correlations corrected for reliability]	Headway: rc=0.1760, CI [95%] = [-0.39, 0.74]	-
		Speed; [Correlation coefficient: rc, weighted mean correlations corrected for reliability]	Speed: rc=0.230, CI [95%] = [-0.34, 0.80]	-
3	Consiglio, W., Driscoll, P., Witte, M., & Berg, W. P.; 2003; USA	Reaction time in a breaking response (releasing throttle and pressing brake) in ms [Absolute difference in mean reaction]	Reaction: Abs.Dif = 73 ms, p<0.0001	↑
4	Elvik R.; 2011; Norway	Accident risk for precise phone use data on the instance of the accident [Odds Ratio]	OR=2.86, CI [95%]=[1.72, 4.75], [Results for all phone use]	↑
		Accident risk for imprecise phone use data on the instance of the accident [Odds Ratio]	OR=1.28, CI [95%]=[1.12, 1.46], [Results for all phone use]	↑
5	Fitch, G. M., Bartholomew, P. R., Hanowski, R. J., & Perez, M. A.; 2015; USA	Portable hands-free devices: Total eyes-off-road time (TEORT) % [Baseline/subtask mean comparisons]	Proportions (PHF/baseline): Locate-put on: 0.2550 (S.E.=0.0380) / 0.1460 (S.E.=0.0880) [F-stat=n/a, p=n/a]	-
			Begin/answer: 0.2410 (S.E.=0.0120) / 0.1360 (S.E.=0.0180) [F-stat=0.90, p=0.3852]	-
			Talk/listen: 0.1600 (S.E.=0.0210) / 0.1640 (S.E.=0.0190) [F-stat=0.02, p=0.8776]	-
			End task: 0.2160 (S.E.=0.0910) / 0.1300 (S.E.=0.0530) [F-stat=0.44, p=0.5316]	-
		Integrated hands-free devices: Total eyes-off-road time (TEORT) % [Baseline/subtask mean comparisons]	Proportions (IHF/baseline): Begin/answer: 0.5270 (S.E.=0.0290) / 0.1170 (S.E.=0.0120) [F-stat=117.58, p<0.0001]	↑
			Talk-listen: 0.1560 (S.E.=0.0170) / 0.1240 (S.E.=0.010) [F-stat=1.32, p=0.2560]	-
			End task: 0.4540 (S.E.=0.0340) / 0.1480 (S.E.=0.0100) [F-stat=120.07, p<0.0001]	↑
6	Horrey, W. J.,	Response time (reaction time to effects)	Response time: CC=0.51, p<0.001, CI	↑

#	Author(s); Year; Country;	Outcome indicator	Quantitative Estimate	Effect on road safety
	& Wickens, C. D.; 2006; International [Meta-analysis]	[Product moment correlation coefficient]	[95%] = [0.13, 0.70]	
		Tracking (lane keeping or tracking performance) [Product moment correlation coefficient]	Tracking: CC=0.20, p=0.001, CI [95%] = [-0.04, 0.41]	↑
		Overall effect on safety (combination of the above) [Product moment correlation coefficient]	Overall Safety Level: CC=0.40, p<0.001, CI [95%] = [0.18, 0.58]	↑
7	Horberry, T., Anderson, J., Regan, M. A., Triggs, T. J., & Brown, J.; 2006; Australia	Mean speed (km/h) for each distraction condition [Absolute difference]	Abs.Dif = 0.46, p=0.0040, F-stat(2,22)=7.072	↑
		Deviation from the posted speed limit [Absolute difference]	Abs.Diff = n/a, p=0.0370, F-stat(2,21)=3.867	↑
8	Hunton, J., & Rose, J. M.; 2005; USA	Driving crash percentage for non-pilot participants [Absolute proportion]	Abs.Prop = 3.36, p=0.0500, R^2=0.461 [R^2(adj)=0.435]	↑
		Driving crash percentage for pilot participants [Absolute proportion]	Abs.Prop = 1.53, p=0.0500, R^2=0.461 [R^2(adj)=0.435]	↑
		Driving crash percentage for all participants [Absolute proportion]	Abs.Prop = 2.44, p=0.0500, R^2=0.461 [R^2(adj)=0.435]	↑
9	Kass, S. J., Cole, K. S., & Stanny, C. J., 2007, USA	Collisions [Absolute difference - MANOVA analysis]	Abs.Diff = 0.85, p<0.010, F(1,47)=10.39	↑
		Struck Pedestrians [Absolute difference - MANOVA analysis]	Abs.Diff = 0.78, p<0.010, F(1,47)=10.14	↑
		Exceeding speed limit frequently [Absolute difference - MANOVA analysis]	Abs.Diff = 2.05, p<0.010, F(1,47)=15.16	↑
		Drove through stop signs [Absolute difference - MANOVA analysis]	Abs.Diff = 0.47, p<0.050, F(1,47)=4.43	↑

Overall estimate for road safety

On a basis of both study and effect numbers, it can be argued that the risk factor of hands-free cell phone use has a uniformly negative effect on road safety. There are cases when its impact is inconclusive, but these are a minority. As mentioned before, these particular studies have good levels of quality, and are overall consistent in their results. This leads to the assignment of the red colour code for hands-free cell phone use.

2.4. CONCLUSION

The review-type qualitative analysis carried out showed that hands-free cell phone use has a negative impact and a detrimental effect on road safety. There is evidence to support that overcompensation occurs by certain driver categories (such as middle-aged and older drivers), but the overall effects of this risk factor are not negated and should thus be countered accordingly.

3. Supporting Document

3.1. IDENTIFYING RELEVANT STUDIES (CELL PHONE – HANDS-FREE)

Risk factor: hands-free cell phone use

Database: Scopus **Date:** 28th of March 2016

search no.	search terms / operators / combined queries	hits
#1	("cellphone" OR "mobile" OR "hands-free")	187,091
#2	(distraction)	3,435
#3	("casualties" OR "fatalities" OR "traffic safety" OR "crash" OR "crash risk" OR "severity" OR "frequency" OR "collision" OR "incident" OR "accident")	22,319
#4	#1 AND #3	2,406
#5	#1 AND #2	693

Optional but recommended: Limitations/ Exclusions:

- Search field: TITLE-ABS-KEY (used for search #10)
- published: 1990 to current
- Document Type: "Review" and "Article"
- Language: "English"
- Source Type: "Journal"
- Exclusion of several countries (not used)
- Subject Area: "Engineering"

Results Literature Search

Database	Hits
Scopus (remaining papers after several limitations/exclusions)	693
Total number of studies to screen title/ abstract	693

Screening

Total number of studies to screen title/ abstract	693
-De-duplication	0
-exclusion criteria A (not related to the topic/not relevant risk factor)	201
-exclusion criteria B (part of meta-analysis)	36
Remaining studies	456
Not clear (full-text is needed)	0
Studies to obtain full-texts	456
Studies after second abstract screening	68

Eligibility

Total number of studies to screen full-text	68
Full-text could be obtained	59
Reference list examined Y/N	YES
Eligible papers after prioritizing	9

After final determination of the most relevant papers, nine (9) studies were selected and prioritized for coding.

Prioritizing Coding

- Prioritizing Step A (accidents over other performance indicators)
- Prioritizing Step B (Journals over conferences and reports)
- Prioritizing Step C (Prestigious journals over other journals)
- Prioritizing Step D (More recent studies)

Comments: Three meta-analysis studies were found.

3.2. REFERENCES

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Distraction - Cell Phones – Texting

Distraction caused by using a cell phone to send or receive texts (reading, writing, browsing)

1. Summary

Ziakopoulos, A., Theofilatos, A., Papadimitriou, E., Yannis, G., NTUA, September 2016

1.1. COLOUR CODE: RED

The effects of texting have long been related to accidents, with a large number of literature studies presenting findings to support that. Those studies have good levels of quality, and are overall consistent in their results. Finally, study results and professional practice indicate that texting has a proven relation with accidents.

1.2. KEYWORDS

Cell phone; texting; crash risk; road safety; road accident; driver distraction

1.3. ABSTRACT

The use of cell phones for texting induces a level of distraction to the person driving. This distraction translates to an increase of; accidents and near misses, injury severities, reaction times to events, percentage of time with eyes off the road, speeding, and to inconsistencies in driving behaviour. Eight high quality studies regarding various texting topics were coded. On a basis of both study and effect numbers, it can be argued that texting via cell phones or other devices creates negative impacts on road safety, with most factors being statistically significant. There were cases, however, that reported no statistically significant relation of texting to various road safety variables (including behavioural factors). The presence of meta-analyses makes the results generally transferable.

1.4. BACKGROUND

Definition and effects of texting on road safety

Texting is essentially the use of cell phones or similar portable devices to write, read, send and receive text messages to other devices. This can mean that a driver spends time and effort searching for the device, typing on it or browsing on its screen.

In the context of road safety, texting induces a level of distraction to the person driving, which is a major risk factor in road safety. The extra amount of mental workload and cognitive functions that drivers have to undertake reduces their reflexes and slows reaction times to events (both the time to mentally register the effect and the time to physically react to it). The drivers spend time with their eyes fixed on the screen instead of the road, which can lead to accidents and near misses, and other critical safety events. Most of the times drivers are aware that they are not driving to the best of their abilities, and thus feel the need to balance this loss. However this usually leads to overcompensation via acceleration, speed, and position variations within the traffic flow, which are proven causes of road accidents.

It is worth noting that cell phone use, for texting or otherwise, is only one aspect of driver distraction. A driver can be under the influence of several other aspects, and therefore suffer under combined detrimental effects. Examples of distraction risk factors that can coincide with cell phone use are consumption of goods (e.g. smoking), sun glare or vehicle lights, watching objects outside the vehicle and others.

Which safety outcomes are affected by texting?

The reviewed studies focus on various outcomes. In some studies, the main focus is estimating the number of accidents, either absolutely or over time (accident frequency), that occur due to texting. In addition to this, various studies also investigate the amount of near misses, while one study investigates injury severity.

Some studies investigate the impact of texting on several behavioural factors, such as mean speed, speed variance, lateral positioning, headway (mean, minimum and variance) and total percentage of time with eyes off the road. Another critical safety outcome that was measured was reaction time to events, though it was more common in conversational cell phone analyses.

How is the effect of texting on road safety studied?

The literature has examined a variety of different approaches and ways to study the effect of texting on road safety. Sometimes this particular risk factor is examined alongside other similar distraction factors such as cell phone use for conversation (handheld or hands-free), and not solely by itself. Its examination or analysis may be adjusted to the models selected to capture the entire situation for the given case.

Given that it is unethical to conduct experiments on real circumstances (field experiments on the road) because it would compromise the safety of the participants, researchers have two possible alternatives. They involve either examining databases of past accidents and analysing the effect of texting on them (which sometimes leads to lack of data), or conducting simulation experiments which are in a virtual environment where no hazard is present.

As for the analytic part, the binary approach is the most common method, which categorizes drivers as exposed or not exposed to the texting risk factor. There have been studies that differentiate between reading and writing the messages as well.

1.5. OVERVIEW OF RESULTS

The effect of texting on road safety is collectively negative, except in cases where the data in question did not lead to statistically significant results. Usually when texting is involved, the various study findings link them to increased accident (or near miss) absolute numbers and frequencies.

There are also many behavioural variables examined. Those that were found to be statistically significant include reaction time, lateral positioning, speed (along with its variance) and headway (mean, minimum and variance), percentage of time with eyes off road, and lane excursions.

The previous results were reached by two meta-analyses that were coded, and are presented here to give an initial overview of the effects of texting. The meta-analyses have taken 34 unique papers from the international literature into consideration, and as such their findings have an increased weight and representation value. The remaining original studies also supported those trends.

Transferability

Amongst the coded studies there are two meta-analyses which draw from several international studies and thus offer a rounded insight on the risk factor at hand. The majority of the rest of the studies were conducted in the USA (and one in the UK), which leaves some room for representation of other countries in original studies.

Most studies concerned all motor vehicles for road accidents, combining cars, PTWs, LGVs, HGVs and buses without differentiating for different road users when examining past accidents. Simulation studies are conducted with devices resembling car interiors, therefore it can be said that there is a margin for representing different road users in the literature.

Notes on analysis methods

The methodology applied for capturing the impacts of texting varies considerably among studies in regards to mainly the mathematical models utilised and secondly the outcomes evaluated as dependent variables. What is more, texting is sometimes not studied exclusively. This means that in some studies, the presence of other distraction factors is studied alongside this particular risk factor (e.g. consumption of goods). Consequently, the study designs might not always be completely tailored towards capturing the effect of texting. There are studies that are focused exclusively on this risk factor, however.

There is some margin for investigating different road user categories and/or other geographical regions. All aforementioned factors make the findings for texting transferable with caution, and care against oversimplification is always required.

2. Scientific Overview

2.1. ANALYSIS OF METHODS AND RESULTS

Analysis of study methods and designs

After appropriate use of various search tools and databases, eight high quality studies were selected and coded for the risk factor of texting. Five of the studies investigated crash counts: Caird et al. (2014), Dingus (2016), Wang et al. (1996), Lansdown (2012), Simmons et al. (2016). The last two studies also examined near misses alongside collisions. Another study focused on injury severity from this risk factor (Donmez and Liu, 2015).

There have been a number of studies investigating several behavioural indicators, mainly by assessing driver performances. This is particularly found in simulator studies where virtual environments allow for safe and detailed recording and examination of data. Caird et al. (2014), examined a large number of these variables. Speed was examined as mean value and variance, along with headway (mean, minimum and variance), eye movements, detection and reaction time. Furthermore, Fitch et al. (2015) focused on examining the percentage of time was spent by the drivers with eyes off the road. Lastly, Rumschlag et al. (2015) focused their study on the lane excursion phenomenon, in three variations: its number, its percentage per subject and the times it took place while the driver was texting.

In order to examine the relationship between the various texting (exposure) and outcome indicators, the studies either deployed multivariate statistical models (ordered logit models, multiple regression analysis etc.) or at least conducted non-model statistical analysis and compared differences or proportions. Sometimes other independent variables were present as well, with some models controlling for them and others studying them independently.

A critical part of this synopsis is the findings of two meta-analyses that were coded alongside the original studies, which by default encompass and analyse many studies (34) from the international literature (Caird et al., 2014, Simmons et al., 2016). The meta-analyses have their own methods, such as the meta-analytic correlation analysis.

Three of the studies which investigated crash counts and performed relevant statistical analyses reported statistically significant increases on the number of collisions when engaging in texting (Caird et al., 2014, Dingus, 2016, Simmons et al., 2016), and also showed increases in near misses when they were examined (Simmons et al., 2016). Lansdown (2012) and Wang et al. (1996) reported only percentages / proportions which do not offer insights on statistical significance, though in the first study it is useful to note that writing and reading a text message had similar crash and near miss proportion frequencies. Of equal importance, accident injury was found to increase when texting across three study groups of different ages (young, middle-aged and old) (Donmez and Liu, 2015).

In regard to driver behavioural variables, all studies generally agree that cell phone use is statistically significantly detrimental to driver performance. Eye movements were found to be significantly increased and uncoordinated with driving both when reading and when writing a text (Caird et al., 2014, Fitch et al., 2015). Similarly most of the aforementioned behavioural variables were adversely affected, namely speed variance, headway (mean, minimum and variance) and reaction time. Mean speed and detection were unaffected (Caird et al., 2014).

Finally, Rumschlag et al. (2015) reached mostly non-significant results for the effect of texting on lane excursion. There were some exceptions though, the number of lane excursions performed by unskilled subjects and all subjects (skilled and unskilled grouped together) increased significantly when examined via text task duration (defined as starting at the time the subject received a text message, and ending at the time the subject sent a text reply).

All the aforementioned results are supported by previous scientific knowledge and professional practicing experience.

Limitations

A few limitations can be arguably found in the current literature for the effects of texting on road safety. The first one lies in the design of the studies themselves: Either past data, along with their lack of detail, general limitations and underlying biases have to be relied upon to reach a conclusion, or the researchers must resort to simulators. Simulations are known to either underrepresent real world conditions, making them less believable environments which the drivers may not take entirely seriously, or sometimes cause dizziness or nausea on the participants, which are forms of discomfort. Both of these aspects might skew data from relevant experiments.

Secondly, there might be times when this particular risk factor does not affect driving performance, such as a driver reading a text message while immobile at a red light. Databases of past accidents might not be detailed enough to account for such cases, and again may bias results in an undesired manner.

There is also a noticeable lack of studies that focus on the indirect effects of this particular risk factor. A common example of this is the case of a non-driver road user engaging in cell phone use, such as a pedestrian crossing the street while texting, and the impacts of this activity on road safety. An overview of the main features of the coded studies (sample, method, outcome and results) is illustrated in Table 2.

No.	Author(s); Year; Country;	Sampling frame for texting study	Method for texting impact investigation	Outcome indicator	Main Result
1	Caird J.K., Johnston K.A., Willness C.R, Asbridge M., Steele P., 2014, International [Meta-analysis]	Statistics were extracted from studies to compute effect sizes (rc). A total sample of 977 participants from 28 experimental studies yielded 234 effect size estimates of the relationships among independent and dependent variables.	Meta-analytic correlation analysis [Meta-analysis]	Eye movements; Detection; Reaction time; Collisions; Lateral positioning; Speed; Speed variance; Mean headway; Headway variance; Minimum headway	Typing and reading text messages while driving adversely affected eye movements, stimulus detection, reaction time, collisions, lane positioning, speed and headway.
2	Dingus T.A.; Guo F.; Lee S.; Antin J.F.; Perez M.; Buchanan-	The study used a US dataset comprising 905 injurious and property damage crash events. Crash events were gathered and analysed in detail through video	Mixed effect random logistic model (& 2-staged stratified random sampling	Accident risk [Odds Ratio]	Driver-related factors are present in almost 90% of crashes. Drivers are distracted more than 50% of the time

No.	Author(s); Year; Country;	Sampling frame for texting study	Method for texting impact investigation	Outcome indicator	Main Result
	King M.; Hankey J.; 2016; U.S.A.	observations and measurements of 3,542 drivers.	method)		while they are driving, resulting in a crash risk that is 2 times higher than model driving.
3	Donmez B., Liu Z.; 2015; USA	The study aimed to predict injury severity sustained by drivers using data from a specialised US database (2003 to 2008). The main focus was on the interaction of driver age and distraction type.	Ordered logit model	Injury severity - Categorical	Texting led to increased injury severities for each of the age categories examined in the study, young, middle-aged and old drivers.
4	Fitch, G. M., Bartholomew, P. R., Hanowski, R. J., & Perez, M. A.; 2015; USA	A naturalistic driving study recorded 204 participating drivers using video cameras and vehicle sensors for an average of 31 days. A total of 1564 cell phone calls made and 844 text messages sent while driving were sampled and underwent review.	Absolute proportion comparisons	Total eyes-off-road time (TEORT) %	With respect to texting, locating the cell phone, browsing/reading, text messaging, and ending the task were all found to significantly increase the percentage of time drivers took their eyes off road.
5	Lansdown, T.C.; 2015; United Kingdom	Survey data were collected using an anonymous online questionnaire. Four hundred eighty-two respondents contributed to the survey during a 2 month data collection period.	Absolute proportion comparisons	Crashes & Near misses	Drivers are frequently and repeatedly distracted while driving. While proportion results are lacking statistical analysis to back this, regression models later in the study support it.
6	Rumschlag, G., Palumbo, T., Martin, A., Head, D., George, R., & Commissaris, R. L.; 2015; USA	The present study examined the influence of driver age (18–59 years old) and other factors on the disruptive effects of texting on simulated driving behaviour. 50 subjects were categorised as skilled (27) or unskilled (23) in texting, and examined as groups together and separately.	Multiple Regression Analysis	Lane excursion number; Lane excursion subject percentage; Lane excursion texting time	In this study, texting dramatically increased lane excursions in the driving simulator.
7	Simmons S.M, Hicks A., Caird J.K.; 2016; USA [Meta-analysis]	6 of the studies identified from the literature were included. They use 7 sets of naturalistic driver data and assess the effects of distracting behaviours. 4 studies involved non-commercial drivers of light vehicles and 2 studies involved commercial drivers of trucks and buses.	Random-effects meta-analysis, stratified by distraction type, using reported (pre-calculated) odds ratios of SCE risk and their associated 95% confidence intervals. [Meta-analysis]	Crashes and near misses (Safety Critical Event Risk); some studies include all while others at-fault incidents only	Results show that tasks that require drivers to take their eyes off the road, such as texting, increase SCE risk to a greater extent than tasks that do not require eyes off the road such as talking.
8	Wang, J. S., Knipling, R. R., & Goodman, M. J.; 1996; USA	The Crashworthiness Data System (CDS) was employed to obtain more in-depth information on driver inattention related crash	Absolute proportion comparisons	Crash count	Judging by the percentages, inattention is a major factor on relevant crashes, followed by

No.	Author(s); Year; Country;	Sampling frame for texting study	Method for texting impact investigation	Outcome indicator	Main Result
		causes, including various distractions. This research paper reports the results of the 1995 CDS data collection on this issue.			fatigue and out-of-vehicle distractions. Texting plays such a role in this risk factor group.

Table 2: Description of coded studies

Conclusions

The identified effects of texting can be summarized as follows:

- 3 studies with a significant increase on collision/crash counts (one reported increased near misses as well). One of them is a meta-analysis and reports various increases of indicators that prove that texting is detrimental to driver behaviour quality, such as speed variance, headway (mean, minimum and variance), and reaction time. Detection and mean speed are not statistically significantly affected however.
- 2 studies with a descriptive result on collision/crash counts (one reported results for near misses as well).
- 1 study with a significant increase on accident or injury severity.
- 1 study with a significant increase on lane excursion numbers for many cases, while reporting non-significant results for lane excursion percentage per subject and the time lane excursion took place while the driver was texting.
- 1 study with a significant increase on the percentage of time that was spent by the drivers with eyes off the road for texting.

After the results were reviewed together, the following points were observed:

a) There is an adequate number of studies, however;
b) Those studies have not used the same model for analysis but largely different ones.
c) There are different indicators, and even when they coincide they are not measured in the same way.
d) The sampling frames were quite different.
e) The presence of the meta-analyses carry increased weight.

2.2. DESCRIPTION OF ANALYSIS CARRIED OUT

Review type analysis

After considering the previous points it was decided that an all-encompassing meta-analysis could not be carried out in order to find the overall impact of texting on road safety. The reasons for this is that the two existing meta-analyses that each have several studies carry different weight than the original studies. Despite the large amount of studies, the sampling frames, outcome variables and statistical analyses are all too different for the meta-analyses to be updated or unified. Both of the considered meta-analyses have different strengths and focus on different detailed aspects for road safety, and they merit examination on their own by specialized researchers.

Taking all the above into consideration, it was decided that both the meta-analysis and the vote count analysis are inappropriate, and thus the review type analysis was selected. Therefore the effect of the texting risk factor will be given via qualitative analysis.

The meta-analyses are the first to be examined as the most wide and critical studies in this group. Both of them resulted in negative outcomes for road safety from the numerous studies they considered (Caird et al., 2014, Simmons et al., 2016). Furthermore, this also applies to the majority of original studies, regardless of their focus. This only leaves a small number of studies that had some inconclusive results (Lansdown, 2012, Wang et al., 1996).

When found to be statistically significant, all variables that were examined yielded negative effects for road safety. Accidents (collisions, crashes), both in counts or frequencies, were increased, as were near misses which are similar safety-critical events. Injury severities from accidents appeared to be elevated as well.

Furthermore, response times were found to be increased, and the same result was reported for the percentage of time with eyes off the road. Speeding variance was found to be increased with statistical significance in one of the studies, as was minimum and mean headway and headway variance. Detection and mean speed appeared to remain unaffected. Lane excursions were significantly affected for many cases (skilled and all drivers), while non-significant results were reported for the corresponding percentage per subject and the time lane excursions took place while the driver was texting. The quantitative results of the coded studies along with their general effects on road safety are presented in Table 3.

Table 3: Quantitative results of coded studies and impacts on road safety. Key ↑ increased risk; - not significant; ↓ decreased risk

No.	Author(s); Year; Country;	Outcome indicator	Quantitative Estimate	Effect on road safety
1	Caird J.K., Johnston K.A., Willness C.R, Asbridge M., Steele P., 2014, International, [Meta-analysis]	Eye movements [Correlation coefficient: rc, weighted mean correlations corrected for reliability]	Reading: rc=0.600, CI [95%] = [0.35, 0.86]	↑
			Writing: rc=0.880, CI [95%] = [0.84, 0.92]	↑
			Reading & Writing: rc=0.740, CI [95%] = [0.41, 1.00]	↑
		Detection [rc]	Reading & Writing: rc=0.240, CI [95%] = [-0.09, 0.58]	-
		Reaction time [rc]	Reading: rc=0.470, CI [95%] = [0.29, 0.60]	↑
			Writing: rc=0.570, CI [95%] = [0.43, 0.71]	↑
			Reading & Writing: rc=0.590, CI [95%] = [0.42, 0.76]	↑
		Collisions [rc]	Reading: rc=0.320, CI [95%] = [0.03, 0.62]	↑
		Lateral positioning [rc]	Reading: rc=0.320, CI [95%] = [0.18, 0.52]	↑
			Writing: rc=0.500, CI [95%] = [0.39, 0.62]	↑
			Reading & Writing: rc=0.370, CI [95%] = [0.25, 0.50]	↑
		Speed [rc]	Reading & Writing: rc=0.590, CI [95%] = [0.42, 0.76]	↑
		Speed variance [rc]	Reading & Writing: rc=0.060, CI [95%] = [-0.12, 0.22]	-
		Mean headway [rc]	Reading & Writing: rc=0.530, CI [95%] = [0.36, 0.70]	↑
		Headway variance [rc]	Reading & Writing: rc=0.590, CI [95%] = [0.45, 0.73]	↑
		Minimum headway [rc]	Reading & Writing: rc=0.300, CI [95%] = [0.10, 0.48]	↑
2	Dingus T.A.; Guo F.; Lee S.; Antin J.F.; Perez M.;	Accident risk [Odds Ratio]	OR=6.1, CI [95%]=[4.50, 8.20], Baseline Prevalence=1.910%	↑

No.	Author(s); Year; Country;	Outcome indicator	Quantitative Estimate	Effect on road safety
	Buchanan-King M.; Hankey J.; 2016; U.S.A.			
3	Donmez B., Liu Z.; 2015; USA	Injury severity - Categorical [Odds ratio]	Young: OR=1.13, p<0.0001, CI [95%] = [1.09, 1.19]	↑
			Middle-aged: OR=1.53, p<0.0001, CI [95%] = [1.48, 1.58]	↑
			Old: OR=4.78, p<0.0001, CI [95%] = [3.46, 6.60]	↑
4	Fitch, G. M., Bartholomew, P. R., Hanowski, R. J., & Perez, M. A.; 2015; USA	Total eyes-off-road time (TEORT) % [Baseline/subtask mean comparisons]	Proportions (handheld/baseline): Locate: 0.3320 (S.E.=0.0160) / 0.1550 (S.E.=0.0090) [F-stat=28.42]	↑
			Browse-Read: 0.6290 (S.E.=0.0130) / 0.1600 (S.E.=0.0100) [F-stat=294.37]	↑
			Text: 0.6760 (S.E.=1.2000) / 0.1610 (S.E.=0.0130) [F-stat=263.32]	↑
			End task: 0.2960 (S.E.=0.0190) / 0.1580 (S.E.=0.0090) [F-stat=19.69]	↑
5	Lansdown, T.C.; 2015; United Kingdom	Crashes & Near misses [Absolute proportion frequency]	Reading: Accident frequency = 1.700, Near Miss frequency = 6.500	-
			Writing: Accident frequency = 1.500, Near Miss frequency = 6.700	-
6	Rumschlag, G., Palumbo, T., Martin, A., Head, D., George, R., & Commissaris, R. L.; 2015; USA	Lane excursion number [Slope (β coefficient)]	All subjects - For Texting duration: β=0.420, r=0.53 (overall), p=0.0040	↑
			Skilled subjects - For Texting duration: β=0.150, r=0.57 (overall), p=0.4300	-
			Unskilled subjects - For Texting duration: β=0.660, r=0.63 (overall), p=0.0040	↑
			All subjects - For Texts per week: β=-0.070, r=0.53 (overall), p=0.640	-
			Skilled subjects - For Texts per week: β=-0.190, r=0.57 (overall), p=0.3900	-
			Unskilled subjects - For Texts per week: β=-0.080, r=0.63 (overall), p=0.6800	-
		Lane excursion subject percentage [Slope (β coefficient)]	All subjects - For Texting duration: β=-0.110, r=0.47 (overall), p=0.4600	-
			Skilled subjects - For Texting duration: β=-0.050, r=0.61 (overall), p=0.8000	-
			Unskilled subjects - For Texting duration: β=-0.1100, r=0.11 (overall), p=0.6700	-
			All subjects - For Texts per week: β=-0.030, r=0.47 (overall), p=0.8200	-
			Skilled subjects - For Texts per week: β=0.1700, r=0.61 (overall), p=0.4200	-
			Unskilled subjects - For Texts per week: β=-0.1900, r=0.11 (overall), p=0.4100	-
		Lane excursion texting time [Slope (β coefficient)]	All subjects - For Texting duration: β=0.180, r=0.43 (overall), p=0.2400	-
			Skilled subjects - For Texting duration: β=0.150, r=0.55 (overall), p=0.4400	-
			Unskilled subjects - For Texting duration: β=0.210, r=0.14 (overall), p=0.4000	-
			All subjects - For Texts per week: β=-0.180, r=0.43 (overall), p=0.2400	-
			Skilled subjects - For Texts per week:	-

No.	Author(s); Year; Country;	Outcome indicator	Quantitative Estimate	Effect on road safety
			β=-0.190, r=0.55 (overall), p=0.3800	
			Unskilled subjects - For Texts per week: β=-0.1000, r=0.14 (overall), p=0.6800	-
7	Simmons S.M, Hicks A., Caird J.K.; 2016; USA [Meta-analysis]	Crashes and near misses (Safety Critical Event Risk); some studies include all while others at-fault incidents only [Odds ratio]	Texting: OR=10.30, p=0.0000, CI [95%] = [2.38, 44.67]	↑
8	Wang, J. S., Knipling, R. R., & Goodman, M. J.; 1996; USA	Crash count [Absolute proportion frequency]	Texting frequency=0.0005	-

Overall estimate for road safety

On a basis of both study and effect numbers, it can be argued that the risk factor of texting has a uniformly negative effect on road safety. However, there are cases when its impact is inconclusive. As mentioned before, the examined studies have good levels of quality, and are overall consistent in their results. This leads to the assignment of the red colour code for texting (cell phone use).

2.3. CONCLUSION

The review-type qualitative analysis carried out showed that texting has a negative impact and a detrimental effect on road safety. There is evidence to suggest that overcompensation occurs by certain driver categories (such as middle-aged and older drivers), but the overall effects of this risk factor are not negated and should thus be countered accordingly.

3. Supporting Document

3.1. IDENTIFYING RELEVANT STUDIES (CELL PHONE – TEXTING)

Risk factor: texting

Database: Scopus **Date:** 29th of March 2016

search no.	search terms / operators / combined queries	hits
#1	(„cell phone" OR "mobile phone" OR "cellphone" OR "phone") AND („text*")	567
#2	(„casualties" OR „fatalities" OR „traffic safety" OR „crash" OR „crash risk" OR „severity" OR „frequency" OR „collision" OR „incident" OR „accident" OR "behaviour" OR "behaviour" OR "performance" OR "distraction")	26,102
#3	#1 AND #2	271

Optional but recommended: Limitations/ Exclusions:
published: 1990 to current
Document Type: "Review" and "Article"
Language: "English"
Source Type: "Journal"
Subject Area: "Engineering and Social Sciences and Psychology for search #3", Engineering only for #1 and #2)"

Results Literature Search

Database	Hits
Scopus (remaining papers after several limitations/exclusions)	265
Total number of studies to screen title/ abstract	265

Screening

Total number of studies to screen title/ abstract	265
-De-duplication	0
-exclusion criteria A (not related to the topic/not relevant risk factor)	190
-exclusion criteria B (part of meta-analysis)	12
Remaining studies	68

Eligibility

Total number of studies to screen full-text	68
Full-text could be obtained	34
Reference list examined Y/N	Yes (+1 study)
Number of paper excluded (not-relevant)	24
Eligible papers	41

From the above 68 eligible papers:

- 8 studies on meta-analyses, crashes, incidents were given high priority
- 23 studies are related to other performance indicators (simulator studies, behaviour etc.) were given medium priority
- 11 studies are self-report, attitudes, perceptions were given low priority
- 24 studies were excluded or are uncertain

As a final selection, 8 studies were prioritized for coding. Two of them are meta-analyses.

Prioritizing Coding

- Prioritizing Step A (accidents over other performance indicators)
- Prioritizing Step B (Journals over conferences and reports)
- Prioritizing Step C (Prestigious journals over other journals)
- Prioritizing Step D (More recent studies)

3.2. REFERENCES

List of coded studies

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Distraction - Music & Entertainment Systems

Distraction caused by listening to music

1 Summary

Ziakopoulos, A., Theofilatos, A., Papadimitriou, E., Yannis, G., NTUA, September 2016

1.1 COLOUR CODE: GREY

The effects of listening to music while driving have been suspected to link to accidents, and thus many relevant scientific studies have been conducted to investigate the matter. The coded studies have good levels of quality, however they fail to settle to a common conclusion for the effects of this risk factor, or in some cases even reach opposite results. As there is a balance between positive and negative effects, and a lot of uncertainties, the overall impact of music is characterised as grey (unclear).

1.2 KEYWORDS

Music; entertainment systems; crash risk; road safety; road accident; driver distraction

1.3 ABSTRACT

The employment of music for entertainment while driving induces a level of distraction to the person driving. The specific impacts of these distractions vary, but in general music has an unclear impact on road safety. While in absolute numbers a lot of the effects of this risk factor are detrimental, there are many beneficial impacts as well, and a considerable number of variables remain statistically non-significant (not sufficiently related) to music. Driver behaviour variables such as speed and (lateral) positioning are affected. There is evidence to support that overcompensation occurs by certain drivers, but whether the overall, collective effects of this risk factor are negated is still unclear. The results of the analysis are generally transferable. The majority of the studies were quasi- or experimental studies with the capability to investigate various behavioural variables.

1.4 BACKGROUND

Definition and effects of music on road safety

Music is commonly used in vehicles everywhere to entertain the driver and/or passengers. It can originate from a number of sources, like a built-in vehicle radio (most common) or other portable music and sound devices that may or may not connect to the audio system of the vehicle.

In the context of road safety, listening to music and the engagement with various music devices induces a level of distraction to the person driving. Driver distraction is a major risk factor in road safety. The extra amount of mental workload and cognitive functions that drivers have to undertake reduces their reflexes and increases reaction times to events (both the time to mentally register the effect and the time to physically react to it). Music usually has an impact on driver mood, which plays a critical part in general driver behaviour as well. In the case of devices with screens present, drivers may spend time with their eyes fixed on the screen instead of the road, which can also lead to accidents and near misses, and other critical safety events.

Most of the time drivers are aware that they are not driving to the best of their abilities, and thus feel the need to balance this loss. However, this usually results in overcompensation via acceleration, speed and position variations within the traffic flow which are proven causes of road accidents.

It is worth noting that listening to music is only one aspect of driver distraction. A driver can be under the influence of several other aspects, and therefore suffer under combined detrimental effects. Examples of distraction risk factors that can coincide with this one are consumption of goods (e.g. smoking), sun glare or vehicle lights, watching objects outside the vehicle, cell phone use (studied separately) and others.

Which safety outcomes are affected by music on road safety?

The reviewed studies focus on various outcomes. In some studies, the main focus is estimating the number of accidents, either absolutely or over time (accident frequency), that occur due to music or device operation. In addition to collisions, other safety critical events are examined, such as the amount of near misses, running through red lights, or emergencies. One study also investigates accident injury severity.

There are several studies that investigate the impact of music on different behavioural factors, such as mean speed, speed variance, lateral positioning, vehicle control, maintaining space, visually searching in various vehicle directions, reaction time to events and a number of others.

How are the effects of music on road safety studied?

The international literature has examined a variety of different approaches and ways to study the effect of music on road safety. Sometimes these particular risk factors are examined alongside other similar distraction factors such as operating devices (IVIS, navigation etc.), or conversation with passengers and cell phone use, instead of separately, and their examination or analysis may be adjusted to the models selected to capture the entire situation for the given case.

Given that it is unethical to conduct experiments under real circumstances (field experiments on the street) because it would compromise the safety of the participants, researchers have two major solutions to resort to. They involve either examining databases of past accidents and analysing the effect of those risk factors on them (which sometimes leads to lack of data) or conducting simulation experiments, which are in a virtual environment where no hazard is present.

As for the analytical part, the binary approach is the most common method, which categorises drivers as exposed or not exposed to each risk factor. There have been studies that differentiate between interacting with the devices (e.g. adjusting the radio) and listening, as well as music type (driver-preferred or properly structured for driving).

1.5 OVERVIEW RESULTS

Judging by the studies taken into consideration, the effect of listening to music while driving is very unclear. There are as many positive effects compared to the size of the negative ones, and a lot of statistically non-significant results. When isolated effects are examined, music did seem to increase reaction times or collisions at times. An important behavioural finding is that music of a certain kind and structure was found to actually improve driver performance, perhaps by helping mentally order driver activities.

1.6 TRANSFERABILITY

The coded studies are based on data from several countries, such as Australia, Israel, the United Kingdom and the USA. This is a good sampling frame for general trends, though it leaves some room for representation of other countries.

Most studies concerned cars, which can be presumed to have been selected for their customisability. Simulation studies are conducted with devices resembling car interiors, therefore it can be said that there is a margin for representing different road users in the literature.

Notes on research and analysis method

The methodology applied for capturing the impacts of music varies considerably among studies in regards to mainly the mathematical models utilised and secondly the outcomes evaluated as dependent variables.

What is more, music is sometimes not studied exclusively. This means that in some studies, the presence or other distraction factors are studied alongside this particular risk factor (e.g. consumption of goods). Consequently, study designs might not always be completely tailored towards isolating those effects.

There is some margin for investigating different road user categories and/or other geographical regions. All aforementioned factors make the findings for music generally transferable with caution, though care against oversimplification is always required.

2 Scientific Details

2.1 ANALYSIS OF METHODS AND PRESENTATION OF RESULTS

Analysis of Study Methods and Designs

For the risk factor of music, and after appropriate use of various search tools and databases, seven high quality studies were selected and coded. The majority of the studies (Hatfield and Chamberlain, 2008, Horberry et al., 2006, Young et al., 2012) were simulator studies or a monitored instrumented vehicle study (Brodsky and Slor, 2013). As such, they had the capability to investigate behavioural variables such as vehicle control, attention, percentage of time spent with eyes off road, glances or searching outside the vehicle, speed (mean, adjusting, variability, exceedances), headway or maintaining space, interventions, lateral position (absolute and variability) and other variables – comprehensive tables follow later in the synopsis.

Some of the studies investigated accidents, either as collisions only (Hatfield and Chamberlain, 2008) or as crashes and near misses (Lansdown, 2012). As with related cell phone use research, a popular indicator was reaction time (Bellinger et al., 2009, Consiglio et al., 2003).

In order to examine the relationship between the various music (exposure) and outcome indicators, the studies either deployed forms of analysis of variance (ANOVA) statistical models or at least conducted non-model statistical analysis and compared differences or proportions. Sometimes other independent variables were present as well, with some models controlling for them and others studying them independently.

An overview of the main features of the coded studies for music (sample, method, outcome and results) is illustrated in Table 1. With regards to the behavioural variables, results vary greatly, as seen in Table 3 in the supporting document as well.

Vehicular control appears to be negatively affected by music, as would be expected, but in contrast driver fatigue appears to be reduced, perhaps due to the general uplifting effects of music on the mood of individuals. Many other variables such as attention, searching in the forward direction, speed adjustment and emergency incidents appeared to be adversely affected by the presence of driver-preferred music. When the music was created with the task of driving taken into account (or 'structurally designed to generate moderate levels of perceptual complexity', as the authors of the study reported) those indicators present reverse effects (Brodsky and Slor, 2013). It can thus be argued that the effect of music is dependent on its nature, and in that case merits further investigation.

The first of the simulator studies only found a statistically significant effect by exposure to an auditory radio sound for collisions with other vehicles, and all other variables were statistically non-significant (Hatfield and Chamberlain, 2008). Given that this applies to an audiovisual program exposure analysis, it can be assume that drivers overcompensate – they drive defensively and conservatively when distracted, which mitigates the risk factors.

Table 1: Description of coded studies

#	Author(s); Year; Country;	Sampling frame for music study	Method for music impact investigation	Outcome indicator	Main Result
1	Bellinger, D. B., Budde, B. M., Machida, M., Richardson, G. B., & Berg, W. P.; 2009; USA	27 licensed drivers aged 19-23 with some driving experience participated in a simulation study.	Absolute difference comparison between exposed and non-exposed states	Reaction time; Movement time; Response time [All in absolute difference]	Music did not influence the response time of participants, nor did the combination of cellular telephone conversation and different music volumes influence response time performance more than the cellular telephone conversation alone.
2	Brodsky, W., & Slor, Z.; 2013; Israel	85 young-novice drivers completed six trips in an instrumented Learners Vehicle. The on-road investigation compared three aural-background driving conditions: driver-preferred music, in-car music alternative, and no music.	Absolute difference comparison between exposed and non-exposed states. Difference of means of Young-novice driver deficiency rating scale - ANOVA.	Vehicle control; Traffic controls use; Attention; Driver fatigue; Search ahead; Search to the side; Search to the rear; Adjusting speed; Maintaining space; Signals; Emergencies; Interventions [Absolute difference]	Young drivers enjoy driving with music which contributes to the risk for distraction and aggressiveness. Music that is structurally designed to generate moderate levels of perceptual complexity improves vehicular performance leading to increased driver safety.
3	Consiglio, W., Driscoll, P., Witte, M., & Berg, W. P.; 2003; USA	Using a laboratory station which simulated the foot activity in driving, 22 research participants participated in a braking simulation study.	Absolute difference comparison between exposed and non-exposed states	Reaction time in a breaking response [Absolute difference in mean reaction]	Results indicated that listening to the radio did not cause reaction times to increase.
4	Hatfield, J., & Chamberlain, T.; 2008; Australia	In a driving simulator experiment, 27 participants completed drives under each of three conditions: without audio materials, with audio materials from a movie, and with audio materials from radio.	Absolute difference comparison between exposed and non-exposed states and ANOVA.	Lateral position; Lateral position variability; Main speed; Speed variability; Speed exceedances; Red lights ran; Collisions with vehicles; Collisions with pedestrians [Absolute difference]	There is a minimal impact of listening to both audio materials, on simulated driving. In the radio condition participants differed significantly from the baseline only by being more likely to collide with other vehicles.
5	Horberry, T., Anderson, J., Regan, M. A., Triggs, T. J., & Brown, J.; 2006; Australia	31 participants were employed, from 3 age categories. The research was designed to assess within-vehicle distraction through an auditory task. Participants answered a series of general knowledge questions over the audio system.	Absolute difference comparison between exposed and non-exposed states. Analyses were performed using a mixed factorial ANOVA with repeated measures.	Mean speed; Deviation from the posted speed limit [Absolute difference]	For the entertainment system the main distraction was a driver taking their eyes off the road (i.e. visual distraction), which made mean speed and deviations significantly different.
6	Lansdown, T.C.; 2015; United Kingdom	Survey data were collected using an anonymous online questionnaire. 482 respondents contributed to the survey during a 2 month data collection period.	Absolute proportion comparisons	Crashes & Near misses [Absolute proportion frequency]	Drivers are frequently and repeatedly conducting highly distracting tasks while driving. While proportion results are lacking statistical analysis to back this, regression models later in the study support it.

7	Young, K. L., Mitsopoulos -Rubens, E., Rudin-Brown, C. M., & Lenné, M. G.; 2012; Australia	A total of 37 drivers completed a PC-based distraction test while performing music selection tasks on a device. Drivers' eye glance behaviour was examined.	Absolute difference comparison between exposed and non-exposed states and repeated measures ANOVA.	Mean speed; Standard deviation of lane position; Mean number of lane excursions; Mean time headway; Mean percentage of time spent with eyes off road; Mean number of glances [Absolute difference]	Performing music search tasks while driving increased the amount of time that drivers spent with their eyes off the roadway and increased lane position and time headway variation. Drivers attempted to regulate their behaviour when distracted.

This is further supported by the findings of Horberry et al. (2006). While mean speed was significantly reduced, deviation from the posted speed limit was increased, which is an indication of distracted driving. On a dissimilar trend, Young et al. (2012) reported uniform increases in mean speed, standard deviation of lane position, mean number of lane excursions, mean percentage of time with eyes off the road and mean number of glances, all while searching on a music device (uniformly for long and short searches, with or without additional distractions). Mean time headway was the only variable not significantly affected.

Regarding reaction times, they appeared significantly elevated only in one of the relevant studies (Consiglio et al., 2003) and non-significant in the other (Bellinger et al., 2009). As for accidents (and near misses), apart from the aforementioned effect, no other significant finding appeared in general. Again, those findings can be supported by assuming drivers function more conservatively and cautiously when distracted (which of course is by no means a measure in itself). The effects of listening to music while driving along with their quantitative estimates appear in Table 3 in the supporting document.

Limitations for Music

A few limitations can be arguably found in the current literature for the effects of music on road safety. The first one lies in the nature of the design of the studies themselves. Either past data, along with their lack of detail, general limitations and underlying biases have to be relied upon to reach a conclusion, or the researchers must resort to simulators. Simulations are known to either underrepresent real world conditions, making them less believable environments which the drivers may not take entirely seriously, or sometimes cause dizziness or nausea on the participants, which are forms of added discomfort. Both of these aspects might skew data from relevant experiments.

Secondly, there might be times when this particular risk factor does not affect driving performance, such as a driver listening to music while immobile at a red light. Databases of past accidents might not be detailed enough to account for such cases, and again alter results in an undesired manner.

There is also a noticeable lack of studies that focus on the indirect effects of this particular risk factor. A common example of this is the case of a non-driver road user, such a pedestrian crossing the street while listening to music through headphones, and the impacts of this activity in road safety. Finally, sometimes studies do not differentiate between listening to music or interacting with the audio devices, which is a different type of distraction (includes visual distraction).

Conclusions for Music

The effects of listening to music while driving can be summarized as follows:

- 1 study with statistically significant increases (negative results for road safety) in several behavioural factors.
- 2 studies with statistically significant increases and decreases (mixed results for road safety) – the first on several behavioural factors and the second on speed alone.

- 1 study with statistically non-significant results in several behavioural factors.
- 1 study with statistically significant increases in driver reaction time.
- 1 study with statistically non-significant increases in driver reaction time.
- 1 study with a descriptive result on collisions and near misses.

After the results were reviewed together, the following points were observed:

1. There is an adequate number of studies;
2. However, those studies have not used the same model for analysis but largely different ones;
3. There are different indicators, and even when they coincide they are not measured in the same way;
4. The sampling frames were quite different (e.g. field testing or simulated driving).

2.2 DESCRIPTION OF ANALYSIS CARRIED OUT FOR MUSIC

Vote-Count Analysis for the Effect of Listening to Music While Driving

After considering the previous points, it was decided that a meta-analysis could not be carried out in order to find the overall estimated effect of music while driving. Therefore the vote-count analysis was resorted to. In vote-count analyses, each study (or each effect) is considered to give a vote for or against the risk-factor. Some variables have been grouped to make the vote-count analysis more meaningful and comprehensive. The results are summarised on Table 2.

Table 2: Vote-count analysis results for music

Outcome definition	Tested in # of studies	Result (# of studies)			Result (% of studies)			Result (# of effects)			Result (% of effects)		
		↑	-	↓	↑	-	↓	↑	-	↓	↑	-	↓
Reaction (or response) time	2	1	1	-	50.0%	50.0%	-	1	4	-	20.0%	80.0%	-
Vehicle control	1	1	-	-	100.0%	-	-	2	-	-	100.0%	-	-
Traffic controls use	1	-	-	1	-	-	100.0%	-	-	2	-	-	100.0%
Attention	1	-	-	-	-	-	-	1	-	1	50.0%	-	50.0%
Driver fatigue	1	-	-	1	-	-	100.0%	-	1	1	-	50.0%	50.0%
Search outside car	1	-	1	-	-	100.0%	-	1	4	1	16.7%	66.7%	16.7%
Adjusting speed	1	-	1	-	-	100.0%	-	1	-	1	50.0%	-	50.0%
Maintaining space	1	-	1	-	-	100.0%	-	-	2	-	-	100.0%	-
Signals	1	-	1	-	-	100.0%	-	-	2	-	-	100.0%	-
Emergencies	1	-	1	-	-	100.0%	-	1	-	1	50.0%	-	50.0%
Interventions	1	-	1	-	-	100.0%	-	-	2	-	-	100.0%	-
Lateral position	1	-	1	-	-	100.0%	-	-	4	-	-	100.0%	-
Lateral position variability	2	1	1	-	50.0%	50.0%	-	4	4	-	50.0%	50.0%	-
Mean speed	3	1	1	1	33.3%	33.3%	33.3%	4	2	1	57.1%	28.6%	14.3%
Speed variability	2	1	1	-	50.0%	50.0%	-	1	2	-	33.3%	66.7%	-

Outcome definition	Tested in # of studies	Result (# of studies)			Result (% of studies)			Result (# of effects)			Result (% of effects)		
		↑	-	↓	↑	-	↓	↑	-	↓	↑	-	↓
Speed exceedances	1	-	1	-	-	100.0%	-	-	2	-	-	100.0%	-
Red lights ran through	1	-	1	-	-	100.0%	-	-	2	-	-	100.0%	-
Collisions with vehicles	2	1	1	-	50.0%	50.0%	-	1	2	-	33.3%	66.7%	-
Collisions with pedestrians	1	-	1	-	-	100.0%	-	-	2	-	-	100.0%	-
Mean number of lane excursions	1	1	-	-	100.0%	-	-	4	-	-	100.0%	-	-
Mean time headway	1	-	1	-	-	100.0%	-	-	4	-	-	100.0%	-
Mean number of glances	1	1	-	-	100.0%	-	-	4	-	-	100.0%	-	-
Mean percentage of time spent with eyes off road	1	1	-	-	100.0%	-	-	4	-	-	100.0%	-	-

Key: ↑ Increased risk; - Not significant; ↓ Decreased risk

Overall Estimate of Music for Road Safety

On a basis of both study and effect numbers, it can be argued that the risk factor of listening to music while driving has an unclear effect on road safety. The coded studies have good levels of quality, however they fail to settle to a common conclusion for the effects of these risk factors, or in some cases even reach opposing results.

2.3 CONCLUSION FOR MUSIC

The analyses that were carried out in the coded studies showed that music has an unclear impact on road safety. While in absolute numbers, many of the effects of this risk factor are detrimental, there are many beneficial impacts as well, and a considerable number of variables remain statistically non-significant (i.e. not sufficiently related) to music.

There is evidence to support that overcompensation occurs by certain drivers, but whether the overall, collective effects of this risk factor are negated is still unclear. In conclusion, the overall impact of music is characterised as grey (unclear).

3 Supporting Documents

3.1 LITERATURE SEARCH STRATEGY

A systematic literature search was carried out using the available databases and online tools of scientific practice and knowledge. The results are summarized in the following tables.

Database: Scopus **Date:** 28th of March 2016

#	Search terms/logical operators/combined queries	hits
1	("music")	28,747
2	("distraction")	3,395
3	#1 AND #2	116

Limitations/ Exclusions:

- Published: 1990 to current
- Document Type: "Review" and "Article"
- Language: "English"
- Source Type: "Journal"
- Subject Area: "Engineering"

Results literature search

Database	hits
Scopus (remaining papers after several limitations/exclusions)	116
Total number of studies to screen title/abstract	116

Screening

Total number of studies to screen title/ abstract	116
-De-duplication	0
-exclusion criteria A (not related to the topic/not relevant risk factor)	95
-exclusion criteria B (part of meta-analysis)	0
Remaining studies	21
Not clear (full-text is needed)	0
Studies to obtain full-texts	**21**

Eligibility

Total number of studies to screen full-text	**21**
Full-text could be obtained	21
Reference list examined Y/N	No
Number of paper excluded (not-relevant)	14
Eligible papers	**7**

Prioritising Coding

- Prioritizing Step A (accidents over other performance indicators)
- Prioritizing Step B (Journals over conferences and reports)

No meta-analyses were found.

3.2 RESULTS OF THE CODED STUDIES

Table 3 presents the quantitative estimates of the 7 eligible papers, which were also used for the vote-count analysis of the effects of music on driving behaviour.

Table 3: Quantitative results of coded studies for music and impacts on road safety

Author, Year, Country	Outcome Indicator	Quantitative Estimate for Exposure to Music	Effect on Road Safety
Bellinger, D. B., Budde, B. M., Machida, M., Richardson, G. B., & Berg, W. P.; 2009; USA	Reaction time [Absolute difference]	Reaction - Abs.Dif: $F(2,156)=0.102$, $p>0.05$	-
	Movement time [Absolute difference]	Movement - Abs.Dif: $F(2,156)=1.421$, $p>0.05$	-
	Response time [Absolute difference]	Response - Abs.Dif: $F(2,156)=0.57$, $p>0.05$	-
Brodsky, W., & Slor, Z.; 2013; Israel	Driver preferred music vs. No music deficiency indicators [Absolute difference]	Vehicle control - Abs.Dif= 1.610, $p<0.05$	↑
		Traffic controls use - Abs.Dif= -0.680, $p<0.05$	↓
		Attention - Abs.Dif= 1.510, $p<0.001$	↑
		Driver fatigue - Abs.Dif= -0.280, $p<0.05$	↓
		Search ahead - Abs.Dif= 1.490, $p<0.05$	↑
		Search to the side - Abs.Dif= -0.410, $p>0.05$	-
		Search to the rear - Abs.Dif= -0.100, $p>0.05$	-
		Adjusting speed - Abs.Dif= 0.910, $p<0.01$	↑
		Maintaining space - Abs.Dif= -0.290, $p>0.05$	-
		Signals - Abs.Dif=-0.090, $p>0.05$	-
		Emergencies - Abs.Dif= 0.870, $p<0.01$	↑
		Interventions - Abs.Dif= -1.840, $p=0.06$	-
	In-car music alternative background vs. No music deficiency indicators [Absolute difference]	Vehicle control - Abs.Dif= 0.450, $p<0.05$	↑
		Traffic controls use - Abs.Dif= -2.090, $p<0.05$	↓
		Attention - Abs.Dif= -1.210, $p<0.001$	↓
		Driver fatigue - Abs.Dif= 0.210, $p>0.05$	-
		Search ahead - Abs.Dif= -0.580, $p<0.05$	↓
		Search to the side - Abs.Dif= -0.310, $p>0.05$	-
		Search to the rear - Abs.Dif= -0.380, $p>0.05$	-
		Adjusting speed - Abs.Dif= -0.950, $p<0.01$	↓
		Maintaining space - Abs.Dif= -0.600, $p>0.05$	-
		Signals - Abs.Dif=-0.530, $p>0.05$	-
		Emergencies - Abs.Dif= -0.240, $p<0.01$	↓

		Interventions - Abs.Dif= -4.470, p=0.06	-
Consiglio, W., Driscoll, P., Witte, M., & Berg, W. P.; 2003; USA	Reaction time [Absolute difference in mean reaction]	Reaction: Abs.Dif=16 ms, p<0.0001	↑
Hatfield, J., & Chamberlain, T.; 2008; Australia	Indicators from audiovisual program exposure [Absolute difference]	Lateral position (total drive): Abs.Dif=0.150, F=1.94, p=0.1760	-
		Lateral position (curves only): Abs.Dif=-0.050, F=0.85, p=0.3650	-
		Lateral position variability (total drive): Abs.Dif=-0.010, F=0.00, p=0.9310	-
		Lateral position variability (curves only): Abs.Dif=0.010, F=0.22, p=0.6470	-
		Mean speed: Abs.Dif=0.710, F=0.23, p=0.6370	-
		Speed variability: Abs.Dif=-0.390, F=0.03, p=0.8590	-
		Speed exceedances: Abs.Dif=0.410, F=0.97, p=0.3350	-
		Red lights ran: Abs.Dif=-0.0250, χ^2=0.10, p=0.7500	-
		Collisions with vehicles: Abs.Dif=0.0190, χ^2=1.01, p=0.3150	-
		Collisions with pedestrians: Abs.Dif=0.0740, χ^2=0.32, p=0.7500	-
	Indicators from radio function exposure [Absolute difference]	Lateral position (total drive): Abs.Dif=0.080, F=0.38, p=0.5450	-
		Lateral position (curves only): Abs.Dif=-0.090, F=3.60, p=0.0690	-
		Lateral position variability (total drive): Abs.Dif=-0.040, F=0.32, p=0.5780	-
		Lateral position variability (curves only): Abs.Dif=0.000, F=0.00, p=0.9360	-
		Mean speed: Abs.Dif=0.620, F=0.18, p=0.6760	-
		Speed variability: Abs.Dif=-2.390, F=1.90, p=0.1810	-
		Speed exceedances: Abs.Dif=0.070, F=0.02, p=0.8770	-
		Red lights ran: Abs.Dif=0.0370, χ^2=0.22, p=0.6360	-
		Collisions with vehicles: Abs.Dif=0.0120, χ^2=6.35, p=0.0120	↑
		Collisions with pedestrians: Abs.Dif=-0.1480, χ^2=0.32, p=0.2140	-
Horberry, T., Anderson, J., Regan, M. A., Triggs, T. J., & Brown, J.; 2006; Australia	Mean speed (km/h) [Absolute difference]	Abs.Dif = -4.150, p=0.0040, F-stat(2,22)=7.072	↓
	Deviation from the posted speed limit [Absolute difference]	Abs.Dif = n/a, p=0.0370, F-stat(2,21)=3.867	↑
Lansdown, T.C.; 2015; United Kingdom	Crashes & Near misses [Absolute proportion frequency]	Entertainment system use: Accident frequency = 1.300, Near Miss frequency = 5.700	-
Young, K. L., Mitsopoulos-Rubens, E., Rudin-Brown, C. M., & Lenné, M. G.; 2012; Australia	Indicators from short music search with interruption vs. baseline [Absolute difference]	Mean speed: Abs. dif.= -2.250, F(4,140)=5.67, p<0.03	↑
		Standard deviation of lane position: Abs. dif.= 0.080, F(4,136)=14.58, p<0.001	↑
		Mean number of lane excursions: Abs. dif.= 3.570, F(4,144)=11.46, p<0.001	↑
		Mean time headway: Abs. dif.= 0.850, F(4,128)=1.75, p=n/a	-
		Mean percentage of time spent with eyes off road: Abs. dif.= 20.040, F(4,120)=39.04, p<0.001	↑
		Mean number of glances: Abs. dif.= 15.920, F(3,93)=14.52, p<0.001	↑
	Indicators from long music search with interruption vs. baseline [Absolute difference]	Mean speed: Abs. dif.= -0.890, F(4,140)=5.67, p<0.03	↑
		Standard deviation of lane position: Abs. dif.= 0.080, F(4,136)=14.58, p<0.001	↑
		Mean number of lane excursions: Abs. dif.= 2.950, F(4,144)=11.46, p<0.001	↑
		Mean time headway: Abs. dif.= 0.540, F(4,128)=1.75, p=n/a	-
		Mean percentage of time spent with eyes off road: Abs. dif.= 20.980, F(4,120)=39.04, p<0.001	↑
		Mean number of glances: Abs. dif.= 21.690, F(3,93)=14.52, p<0.001	↑
	Indicators from short music search without interruption vs. baseline [Absolute difference]	Mean speed: Abs. dif.= -1.480, F(4,140)=5.67, p<0.03	↑
		Standard deviation of lane position: Abs. dif.= 0.110, F(4,136)=14.58, p<0.001	↑

		Mean number of lane excursions: Abs. dif.= 4.030, F(4,144)=11.46, p<0.001	↑
		Mean time headway: Abs. dif.= 0.570, F(4,128)=1.75, p=n/a	-
		Mean percentage of time spent with eyes off road: Abs. dif.= 18.530, F(4,120)=39.04, p<0.001	↑
		Mean number of glances: Abs. dif.= 12.290, F(3,93)=14.52, p<0.001	↑
	Indicators from long music search without interruption vs. baseline [Absolute difference]	Mean speed: Abs. dif.= -1.680, F(4,140)=5.67, p<0.03	↑
		Std. deviation of lane position: Abs. dif.= 0.070, F(4,136)=14.58, p<0.001	↑
		Mean number of lane excursions: Abs. dif.= 3.570, F(4,144)=11.46, p<0.001	↑
		Mean time headway: Abs. dif.= 0.620, F(4,128)=1.75, p=n/a	-
		Mean percentage of time spent with eyes off road: Abs. dif.= 21.500, F(4,120)=39.04, p<0.001	↑
		Mean number of glances: Abs. dif.= 19.810, F(3,93)=14.52, p<0.001	↑

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Distraction -Operating Devices

Distraction caused by using equipment within the vehicle that is not directly associated with the driving task e.g. In Vehicle Information Systems (IVIS), navigation devices

1 Summary

Ziakopoulos, A., Theofilatos, A., Papadimitriou, E., Yannis, G., September 2016

1.1 COLOUR CODE: GREY

The effects of operating devices while driving have been suspected to link to accidents, and thus many relevant scientific studies have been conducted to investigate the matter. The coded studies have good levels of quality, however they fail to settle to a common conclusion for the effects of these risk factors, or in some cases to even reach consistent and significant results. As there is a presence of several positive and negative effects, and a lot of uncertainties, the overall impact of operating devices is characterised as grey (unclear).

1.2 KEYWORDS

in vehicle information systems; navigation systems; operating driving devices; crash risk; road safety; road accident; driver distraction

1.3 ABSTRACT

The use or operation of various devices (generally IVIS) while driving induces many distractions to the person driving. The specific impacts of these distractions vary, but in general it can be assumed that driver behavioural variables are affected. Six high quality studies regarding various IVIS topics were coded. On a basis of both study and effect numbers, it can be argued that operating devices have an unclear impact on road safety, with most factors not being statistically significant. There were cases, however, that reported increased crash counts and reaction times to events (e.g. bicycle appearance) when distracted by IVIS. The results are moderately transferable.

1.4 BACKGROUND

Definition and effects of operating devices on road safety

Various devices that do not fall under a narrow category are being operated by drivers regularly. Those can be built-in auxiliary devices, such as air-conditioning or a car lighter, or information systems devices. The term in-vehicle information system (IVIS) encompasses most of the last category, which can be assistant devices such as GPS systems, traffic information systems, email, vehicle diagnostics, and, in some situations, warning systems and emergency help systems. A large number of professionals in the transport sector have come to adopt the use of such devices, and the variety of their uses is similar, for example location and position information, vehicle handling information, military applications etc.

In the context of road safety, the engagement with various devices induces a level of distraction to the person driving. Driver distraction is a major risk factor in road safety. The extra amount of mental workload and cognitive functions that drivers have to undertake reduces their reflexes and slows reaction times to events (both the time to mentally register the effect and the time to physically react to it). In the case of devices with screens present, drivers spend some time with their eyes fixed on the screen instead of the road, which can also lead to accidents and near misses, and other critical safety events.

Most of the time drivers are aware that they are not driving to the best of their abilities, and thus feel the need to balance this loss. However, this usually leads to overcompensation via acceleration, speed and position variations within the traffic flow which are proven causes of road accidents.

It is worth noting that operating vehicle devices is only a single aspect of driver distraction. A driver can be under the influence of several other aspects, and therefore suffer under combined detrimental effects. Examples of distraction risk factors that can coincide with these particular ones are consumption of goods (e.g. smoking), sun glare or vehicle lights, watching objects outside the vehicle, cell phone use (studied separately) and others.

Which safety outcomes are affected by operating devices on road safety?

The reviewed studies focus on various outcomes. In some studies, the main focus is estimating the number of accidents, either absolutely or over time (accident frequency), that occur due to device operation. In addition to collisions, other safety critical events are examined, such as the amount of near misses. A study also investigates accident injury severity.

There is also a study that investigates the impact of operating devices on several behavioural factors, such as accelerator reaction time, brake reaction time, event response time, sensitivity and others.

How are the effects of operating devices on road safety studied?

The international literature has examined a variety of different approaches and ways to study the effect of operating devices on road safety. Sometimes this risk factor is examined alongside other similar distraction factors such as conversation with passengers and cell phone use, and not separately. Its examination or analysis may be adjusted to the models selected to capture the entire situation for the given case.

Given that it is unethical to conduct experiments on real circumstances (field experiments on the road) because it would compromise the safety of the participants, researchers have two alternative methods to use. They involve either examining databases of past accidents and analysing the effect of those risk factors on them (which sometimes leads to lack of data), or conducting simulation experiments, which are in a virtual environment where no hazard is present.

As for the analytic part, the binary approach mentioned above is the most common method, which categorises drivers as exposed or not exposed to each risk factor. There have been more detailed approaches, such as studies that differentiate between interacting with the devices and browsing the screens.

1.5 OVERVIEW OF RESULTS

Judging by the studies taken into consideration, the effect of operating devices (IVIS, navigation etc.) while driving is unclear as well. Amongst the coded studies there are many statistically non-significant results. Some negative effects from a simulation study were reported, but this was a singular case. Moreover, operating devices were found to decrease accident injury severity, which translates into drivers adjusting their behaviour and compensating for the distraction they are engaging into.

A meta-analysis was conducted on operating devices, because some of the study designs, the sampling frame, the outcomes/indicators studied and the results produced are compatible and allow the process.

Transferability

The coded studies are based on data from several countries, such as Australia, the United Kingdom and the USA. This is a decent sampling frame for general trends in the developed countries, though it leaves some room for representation of other countries.

Most studies concerned cars, which can be presumed to have been selected for their customisability. Simulation studies are conducted with devices resembling car interiors, therefore it can be said that there is a margin for representing different road users in the literature. It is worth noting that there were no studies concerning professionals in heavier vehicles only.

1.6 NOTES ON RESEARCH AND ANALYSIS METHOD

The methodology applied for capturing the impacts of operating devices varies considerably among studies in regards to mainly the mathematical models utilised and secondly the outcomes evaluated as dependent variables.

What is more, those risk factors are sometimes not studied exclusively. This means that in some studies, the presence of other distraction factors are studied alongside this particular risk factor (e.g. consumption of goods). Consequently, study designs might not always be completely tailored towards isolating those effects.

There is some margin for investigating different road user categories and/or other geographical regions. All aforementioned factors make the findings for operating devices moderately transferable, though caution and care against oversimplification are always required.

2 Scientific Details

2.1 DESCRIPTION OF CODED STUDIES

Analysis of Study Methods and Designs for Operating Devices

For the risk factor of operating devices, and after appropriate use of various search tools and databases, six high quality studies were selected and coded. The majority of the studies are observational using real world data, with only one simulation.

Several studies investigated accidents, either as collisions (Dingus, 2016, McEvoy et al., 2007, Wang et al., 1996) or as crashes and near misses (Lansdown, 2012). Finally, a single study explored the effects of operating devices on accident injury severity (Neyens and Boyle, 2008).

Furthermore, the sole simulation study had the capability to investigate behavioural variables such as accelerator reaction time, brake reaction time, response to the appearance of a bicyclist, driver sensitivity, fixation duration and response bias (Reyes and Lee, 2008).

In order to examine the relationship between the various device engagement (exposure) and outcome indicators, the studies either deployed models (such as the ordered logit model) or forms of analysis of variance (ANOVA) statistical models. If those were not employed, researchers conducted basic statistical non-model analyses and compared differences or proportions. Sometimes other independent variables were present as well, with some models controlling for them and others studying them independently.

An overview of the main features of the coded studies for operating devices (sample, method, outcome and results) is provided in Table 1.

For operating devices results appear slightly uniform, with only a single positive event being reported. This appeared in the injury severity variable (Neyens and Boyle, 2008), meaning that injury severity was reported lower when drivers operated devices (such as IVIS, navigation, air conditioning, etc.). This has two explanations, that may apply independently of each other: Firstly, there is the well-known effect of overcompensation: Drivers adjust their behaviour and operate more conservatively to counter the negative effects of the distraction they are engaging with. Secondly, the fact that a slight injury is more likely than a severe or a fatal one when a driver crashes while operating devices means that non-serious accidents are far more numerous than the serious ones, thus resulting in such possibilities. Under no circumstances does this result imply that the road environment becomes somehow safer on its own while the driver is distracted by using various devices.

Three of the studies which investigated accidents reached inconclusive results (statistically non-significant) from past data due to exposure to the distraction from manipulating and interacting with devices (Lansdown, 2012, McEvoy et al., 2007, Wang et al., 1996), while the fourth one reached detrimental results for road safety, with increased crash occurrences reported (Dingus, 2016).

Concerning the behavioural variables, only response time to a certain event on a simulation (e.g. a bicyclist appearing) along with response bias were found to be statistically significant by the relevant study (Reyes and Lee, 2008). Accelerator reaction time, brake reaction time, driver sensitivity and fixation duration did not appear to have a statistically significant relation to device operation. The effects of operating devices while driving, along with their quantitative estimates, appear in Table 3 in the supporting document.

Table 1: Description of coded studies for operating devices

#	Author(s); Year; Country;	Sampling frame for operating devices study	Method for operating devices impact investigation	Outcome indicator	Main Result
1	Dingus T.A.; Guo F.; Lee S.; Antin J.F.; Perez M.; Buchanan-King M.; Hankey J.; 2016; U.S.A.	The study used a US dataset comprising 905 injurious and property damage crash events. Crash events were gathered and analysed in detail through video observations and measurements of 3,542 drivers.	Mixed effect random logistics model (& 2-staged stratified random sampling method)	Accident risk [Odds Ratio]	Driver-related factors (i.e., error, impairment, fatigue, and distraction) are present in almost 90% of crashes. Drivers are distracted more than 50% of the time while they are driving, resulting in a crash risk that is 2 times higher than model driving.
2	Lansdown, T.C.; 2015; United Kingdom	Survey data were collected using an anonymous online questionnaire. 482 respondents contributed to the survey during a 2 month data collection period.	Absolute proportion comparisons	Crashes & Near misses [Absolute proportion frequency]	Drivers are repeatedly conducting highly distracting tasks while driving. While proportion results are lacking statistical analysis to back this, regression models later in the study support it.
3	McEvoy, S. P., Stevenson, M. R., & Woodward, M.; 2007; Australia	1367 drivers who attended hospital following a crash were interviewed. A questionnaire was administered to each driver and additional data were collected from ambulance and medical records.	Absolute proportion comparisons	Crash count [Absolute proportion frequency]	Judging by the percentages, adjusting in-vehicle equipment is a minor factor on relevant crashes, being one of the rarest.
4	Neyens, D. M., & Boyle, L. N.; 2008; USA	A US database with crash data was used for the analysis. It included only teenage (16–19 years old) drivers and all of their passengers. It was also limited to crashes occurring in passenger vehicles.	Ordered logit model	Injury severity [Categorical - slope]	When teenage drivers use in-vehicle devices, the likelihood of serious injuries for the teenage driver and their passengers were significantly lower due to overcompensation.
5	Reyes, M. L., & Lee, J. D.; 2008; USA	12 participants drove in a simulator while intermittently performing an IVIS interaction that varied in duration from 1 to 4 min. There were three IVIS conditions: interacting with the IVIS, non-IVIS periods between IVIS interactions, and baseline driving without the IVIS task.	Absolute difference comparison between exposed and non-exposed states	Accelerator reaction time; Brake r.t; Bike r.t.; Sensitivity; Response bias; Fixation duration [Absolute difference – l.sq.means difference]	Driver responses remained uniform across IVIS conditions. IVIS interaction decreased bicyclist detection and increased reaction time and influenced eye movements.
6	Wang, J. S., Knipling, R. R., & Goodman, M. J.; 1996; USA	The Crashworthiness Data System was employed to obtain more in-depth information on driver inattention related crash causes, including various distractions. This research paper reports the results of the 1995 CDS data collection on this issue.	Absolute proportion comparisons	Crash count [Absolute proportion frequency]	Judging by the percentages, inattention is a major factor on relevant crashes, followed by fatigue and out-of-vehicle distractions.

Limitations for operating devices

A few limitations can arguably be found in the current literature for the effects of operating devices on road safety. The first one lies in the nature of the design of the studies themselves: Either past data, along with their lack of detail, general limitations and underlying biases have to be relied upon to reach a conclusion, or the researchers must resort to simulators. Simulations are known to either underrepresent real world conditions, making them less believable environments which the drivers may not take entirely seriously, or sometimes cause dizziness or nausea on the participants, which are forms of added discomfort. Both of these aspects might skew data from relevant experiments.

Secondly, there might be times when this particular risk factor does not affect driving performance, such as a driver browsing a GPS while immobile at a red light. Databases of past accidents might not be detailed enough to account for such cases, and may alter results in an undesired manner.

There is also a noticeable lack of studies that focus on the indirect effects of this particular risk factor. A common example of this is the case of a non-driver road user, such as a pedestrian crossing the street while using a GPS, and the impacts of this activity on road safety. Finally, there is a lack of studies that would examine the impact of device operation on professional drivers (e.g. GPS on truck drivers), which is a group that probably has the most interaction with such technology.

Conclusions for operating devices

The effects of listening to operating devices while driving can be summarized as follows:

- 3 studies with statistically non-significant results on accident (and near miss) counts.
- 1 study with statistically significant increases (negative effect for road safety) on accident counts.
- 1 study with statistically significant decreases (positive effect for road safety) on accident injury severity.
- 1 study with statistically significant increases to an event (bicyclist appearance) and response bias, and statistically non-significant results on other behavioural factors.

After the results were reviewed together, the following points were observed for the outcome indicator of the absolute proportion of total accidents that happen due to IVIS use while driving:

1. A minimum required number of studies is achieved (3).
2. Studies used the same methodology (absolute proportion of accidents) were identified.
3. The sampling frames were similar.

It was therefore concluded that a meta-analysis is possible and could be conducted.

2.2 DESCRIPTION OF ANALYSIS CARRIED OUT FOR OPERATING DEVICES

Meta-analysis introduction

It was attempted to apply a random effects meta-analysis for the effect of operating devices while driving on accident numbers. More specifically, the overall estimate of the raw proportion of accidents due to operating device use was investigated. To do so, the number of accidents due to operating devices (x_i) as well the total number of accidents (n_i) had to be defined for each study.

Then the estimate (y) and the variance v_i of raw proportion (x_i /n_i) was calculated for each study following Viechtbauer (2010). The results showed a statistically significant effect at a 95% level (p-value = 0.0186). The overall estimate for the raw absolute proportions of accidents was found to be 0.0107, as shown in Figure 1.

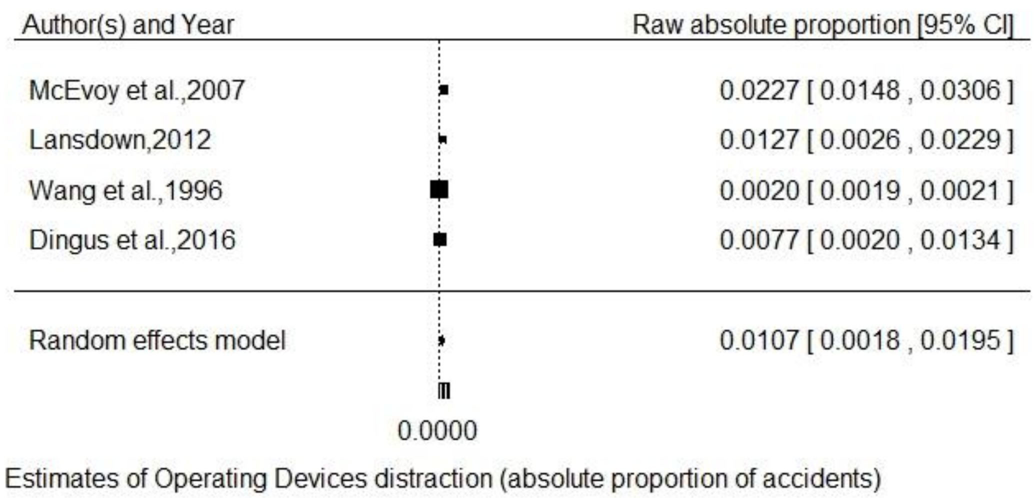

Figure 1: Forest plot for absolute proportion of total accidents that happen due to IVIS use while driving.

Overall estimate on the absolute proportion of accidents

A random effects meta-analysis was carried out. The overall estimate of the meta-analysis showed a statistically significant overall effect (estimate=0.0118, p-value=0.0581). Table 2 illustrates the main estimates of the random effects meta-analysis.

Table 2: Random effects meta-analysis for absolute proportion of total accidents due to operating devices (IVIS, navigation systems use)

Variable	Estimate	Std. Error	p-value	95% CI
Proportion of accidents due to IVIS use	0.0107	0.0045	0.0186	(0.0018, 0.0195)

Heterogeneity

The I^2 value indicates that 91.06% of the total variability in the effect size estimates can be attributed to heterogeneity among the true effects. The Q test is significant ($Q_{[df=3]}$=34.5634, p-value < 0.0001) suggesting considerable heterogeneity among the true effects. Therefore, the random effects meta-analysis that was carried out is preferred and there is no need to perform fixed effects meta-analysis.

Publication Bias

A funnel plot was firstly produced in order to detect potential publication bias. The visual examination of the funnel plot shows that it is symmetric suggesting that there no strong evidence for publication bias. Another method for testing for publication bias is to test whether the observed outcomes are related to their corresponding standard errors. The results showed that almost no publication bias exists (p-value = 0.0981).

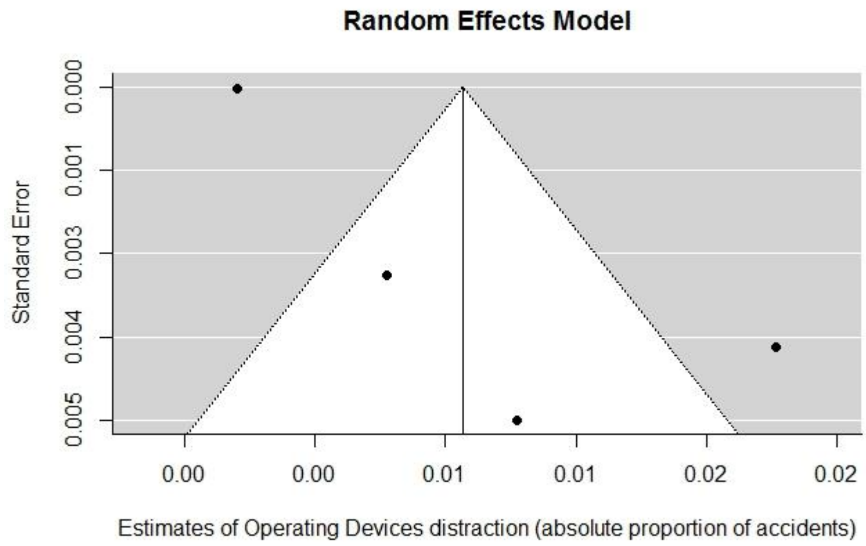

Figure 2: Funnel Plot for estimates of absolute proportion of accidents due to operating devices

Overall estimate of operating devices for road safety

On a basis of both study and effect numbers, it can be argued that the risk factor of operating devices has an unclear effect on road safety, though it can be described as more negative than positive. The coded studies have good levels of quality, however they fail to settle to a solid conclusion for the effects of these risk factors. The meta-analysis is statistically significant, and the raw absolute proportion is therefore a good indicator estimate, though the proportion of accidents is small.

2.3 CONCLUSION FOR OPERATING DEVICES FOR ROAD SAFETY

The previous analyses that were carried out showed that operating devices have an unclear impact on road safety. While in absolute numbers a lot of the effects of these risk factors are detrimental, there are beneficial impacts as well, and a considerable number of variables remain statistically non-significant (not sufficiently related) to operating devices. The results of the meta-analysis border on statistical significance. For these reasons, it can be argued that the impacts of operating devices are unclear but towards the risk side.

There is evidence to support that overcompensation occurs by certain drivers, but whether the overall, collective effects of this risk factor are negated is still unclear. In conclusion, the overall impact of operating devices is characterised as grey (unclear).

3 Supporting Documents

3.1 IDENTIFYING RELEVANT STUDIES (OPERATING DEVICES)

A systematic literature search was carried out using the available databases and online tools of scientific practice and knowledge. The results are summarized in the following tables.

Database: Scopus **Date:** 29th of March 2016

#	Search terms/logical operators/combined queries	hits
1	("vehicle" AND "device")	26,087
2	("distraction")	3,395
3	#1 AND #2	396

Limitations/ Exclusions:

- Published: 1990 to current
- Document Type: "Review" and "Article"
- Language: "English"
- Source Type: "Journal"
- Subject Area: "Engineering"

Results Literature Search

Database	hits
Scopus (remaining papers after several limitations / exclusions)	396
Total number of studies to screen title / abstract	**396**

Screening (Operating Devices)

Total number of studies to screen title / abstract	396
-De-duplication	0
-Exclusion criteria A (not related to the topic / not relevant risk factor)	344
-Exclusion criteria B (part of a meta-analysis)	0
Remaining studies	52
Not clear (full-text is needed)	8
Studies to obtain full-texts	**44**

Eligibility (Operating Devices)

Total number of studies to screen full-text	**44**
Full-text could be obtained	44
Reference list examined Y/N	Yes
Number of paper excluded (not-relevant)	21
Eligible papers	23

From the above 23 eligible papers:
- 6 studies on crashes, incidents were given high priority
- 6 studies are self-report, attitudes, perceptions were given low priority
- 11 studies were uncertain-improper for the coding template

Due to time constraints, the first 6 studies were selected and prioritized for coding based on their final fitness and reporting.

Prioritising Coding (Operating Devices)

- Prioritizing Step A (accidents over other performance indicators)
- Prioritizing Step B (journal over conference)
- Prioritizing Step C (journal quality)
- Prioritizing Step D (more recent studies)

No meta-analyses were found.

Below follows Table 3 which presents the quantitative estimates of the final six papers, which were also used for the meta-analysis of the effects of operating devices on accident proportions.

Table 3: Quantitative results of coded studies for operating devices and impacts on road safety

Author, Year, Country	**Outcome Indicator**	**Quantitative Estimate**	**Effect on Road Safety**
Dingus T.A.; Guo F.; Lee S.; Antin J.F.; Perez M.; Buchanan-King M.; Hankey J.; 2016; U.S.A.	Accident risk [Odds Ratio]	OR=2.5, CI [95%]=[1.80, 3.40], Baseline Prevalence=3.530%	↑
Lansdown, T.C.; 2015; United Kingdom	Crashes & Near misses [Absolute proportion frequency]	Use unfamiliar car displays: Accident frequency = 1.300, Near Miss frequency = 2.400	-
		Use unfamiliar car controls: Accident frequency = 1.500, Near Miss frequency = 2.600	-
		Entering navigator destination: Accident frequency = 2.000, Near Miss frequency = 2.800	-
		Following navigator route guidance: Accident frequency = 1.700, Near Miss frequency = 3.000	-
McEvoy, S. P., Stevenson, M. R., & Woodward, M.; 2007; Australia	Crash count [Absolute proportion frequency]	Adjusting in-vehicle equipment: Adjusting Proportion = 2.100	-
Neyens, D. M., & Boyle, L. N.; 2008; USA	Injury severity [Categorical - slope]	Slope (between injury categories): β=-0.14, s.e.=0.030, p<0.001	↓

Reyes, M. L., & Lee, J. D.; 2008; USA	IVIS indicators [Absolute difference]	Accelerator reaction time (IVIS/baseline): Abs. dif.= 0.070, s.e.=0.130, p=n/a	-
		Brake reaction time (IVIS/baseline): Abs. dif.= -0.020, s.e.=0.160, p=n/a	-
		Bike response time (IVIS/baseline): Abs. dif.= 0.290, s.e.=0.080, p<=0.05	↑
		Sensitivity (IVIS/baseline): Abs. dif.=-0.440, s.e.=0.130, p>0.05	-
		Fixation duration (IVIS/baseline): Abs. dif.=-0.013, s.e.=0.020, p=n/a	-
		Response bias (IVIS/baseline): Abs. dif.=-6.200, s.e.=0.820, p<=0.05	↑
	Non-IVIS indicators [Absolute difference]	Accelerator reaction time (non-IVIS/baseline): Abs. dif.= 0.120, s.e.=0.130, p=n/a	-
		Brake reaction time (non-IVIS/baseline): Abs. dif.= 0.030, s.e.=0.160, p=n/a	-
		Bike response time (non-IVIS/baseline): Abs. dif.= 0.020, s.e.=0.090, p<=0.05	↑
		Sensitivity (non-IVIS/baseline): Abs. dif.=-0.320, s.e.=0.130, p>0.05	-
		Fixation duration (non-IVIS/baseline): Abs. dif.=-0.008, s.e.=0.020, p=n/a	-
		Response bias (non-IVIS/baseline): Abs. dif.=-14.670, s.e.=0.820, p<=0.05	↑
Wang, J. S., Knipling, R. R., & Goodman, M. J.; 1996; USA	Crash count [Absolute proportion frequency]	Distracted while adjusting climate controls frequency=0.0020	-
		Distracted while adjusting radio, cassette, CD frequency=0.0180	-
		Distracted while using other device/object in vehicle frequency=0.0020	-

Key ↑ increased risk; - not significant; ↓ decreased risk

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Distraction- Cognitive overload, Inattention

Inattention caused by daydreaming and distraction through state of mind (e.g. pondering and cognitive overload)

1. Summary

Ziakopoulos, A., Theofilatos, A., Papadimitriou, E., Yannis, G., September 2016

1.1. COLOUR CODE: YELLOW

The effects of the risk factor of inattention (daydreaming and distraction through state of mind (pondering etc.)) and cognitive overload while driving have been suspected to link to accidents, and thus investigated accordingly. The coded studies have good levels of quality and decent consistency, though there are some unclear areas. As there are more detrimental effects than beneficial ones to road safety, the overall impact of inattention is characterised as yellow (probably risky).

1.2. KEYWORDS

inattention; pondering; crash risk; road safety; road accident; driver distraction; driver mind;

1.3. ABSTRACT

The inattention of drivers through loss of focus, daydreaming or state of mind induces a level of distraction to the person driving. On a basis of both study and effect numbers, it can be argued that the risk factor of inattention while driving has a likely detrimental effect on road safety. The specific impacts of these distractions vary, but they are negative and in general it can be assumed that driver behavioural variables such as perception and braking performance are affected. There are some positive results that show reduced injury severity or increased perception, but these occur mainly due to overcompensation and effects and are limited. The results of the analysis are generally transferable with caution. The majority of the studies were observational/case control studies which investigated past accident data.

1.4. BACKGROUND

Definition and effects of inattention on road safety

Inattention (daydreaming and distraction through state of mind (pondering etc.)) and cognitive overload (collectively referred to solely as 'inattention' in this synopsis) while driving is a common phenomenon. It can originate from the repetitive and automated tasks that driving a vehicle involves, the particular state of mind (mood) of the driver, or the cognitive overload (mental stress) from outside stimuli at any given time.

In the context of road safety, inattention in a certain way induces a level of distraction to the person driving, which is a major risk factor in road safety. The extra amount of mental workload and cognitive functions that drivers have to undertake if a need arises reduces their reflexes and slows reaction times to events (both the time to mentally register the effect and the time to physically react to it).

Driver state of mind or mood has been proven to influence behaviour on the road, making it more aggressive (increased speeding, speed variations and acceleration, reduced allowed spatial headways and generally more reckless driving) or defensive ("fear" of driving/other vehicles, speed variations, excessive braking reactions etc.).

In a few cases, as coded studies have shown as well, overcompensation effects from the driver are observed. Drivers are aware that they are not driving to the best of their abilities, and thus feel the need to balance the loss. However, this usually leads to acceleration, speed and position variations within the traffic flow which are proven causes of road accidents.

It is worth noting that inattention is only one aspect of driver distraction. A driver can be under the influence of several other aspects, and therefore suffer under combined detrimental effects. Examples of distraction risk factors that can coincide with this one are consumption of goods (e.g. eating), sun glare or vehicle lights, watching objects outside the vehicle, cell phone use, music and others.

Which safety outcomes are affected by inattention on road safety?

The reviewed studies focus on various outcomes. In some studies, the main focus is estimating the number of accidents, either absolutely or over time (accident frequency) that occur due to inattention. In addition to collisions, other safety critical events are examined, such as the amount of near misses, running through red lights or emergencies. One study also investigates accident injury severity.

There are several studies that investigate the impact of inattention on several behavioural factors. The most critical of those for inattention is perception (glances at directions around the vehicle, traffic lights, vehicular instruments, blink frequency and duration). Perception of added workload was also examined, along with braking performance and number of times ignoring traffic lights.

How are the effects of inattention on road safety studied?

The international literature has examined a variety of different approaches and ways to study the effect of inattention on road safety. Sometimes, especially in studies for state of mind, these particular risk factors are examined alongside other similar distraction factors such as operating devices (IVIS, navigation etc.), or conversation with passengers and cell phone use, and not separately. Its examination or analysis may be adjusted to the models selected to capture the entire situation for the given case.

Given that it is unethical to conduct experiments on real circumstances (field experiments on the road) because it would compromise the safety of the participants, researchers have two alternative methods to use. They involve either examining databases of past accidents and analysing the effect of those risk factors on them (which sometimes leads to lack of data), or conducting simulation experiments, which are in a virtual environment where no hazard is present.

As for the analytic part, the binary approach is the most common method, which categorizes drivers as exposed or not exposed to inattention or improper state of mind whilst driving.

1.5. OVERVIEW OF RESULTS

Judging by the studies taken into consideration, the effect of driver inattention is detrimental and negative. There are as some positive effects, albeit not comparable to the volume of the negative ones, and various statistically non-significant results. When isolated effects are examined, inattention did seem to increase safety risks by affecting behavioural variables such as perception (searching, glances), braking performance and mental workload.

Transferability

The coded studies are based on data from several countries, namely Australia, Canada, France and the USA. This is a decent sampling frame for general trends in developed countries, though there is always some room for representation of other countries.

Most studies concerned cars, which can be presumed to have been selected as the most common motor vehicles, whilst other studies grouped all vehicles together for analysis. Simulation studies are conducted with devices resembling car interiors, therefore it can be said that there is a margin for representing different road users in the literature.

Notes on analysis methods

The methodology applied for capturing the impacts of inattention varies considerably among studies in regards to mainly the mathematical models utilised and secondly the outcomes evaluated as dependent variables.

What is more, inattention is sometimes not studied exclusively. This means that in some studies, the presence of other distraction factors are studied alongside this particular risk factor (e.g. conversation with passenger). Consequently, study designs might not always be completely tailored towards isolating the effects of this risk factor.

There is some margin for investigating different road user categories and/or other geographical regions. All aforementioned factors make the findings for inattention generally transferable with caution, though care against oversimplification is always required.

2. Scientific Overview

2.1. ANALYSIS OF METHODS AND PRESENTATION OF RESULTS

Analysis of study methods and designs

For the risk factor of inattention and distraction through state of mind, and after appropriate use of various search tools and databases, nine high quality studies were selected and coded.

Several studies investigated accidents, either the numbers of accidents (McEvoy et al., 2007, Wang et al., 1996) or accident injury severity (Donmez and Liu, 2015, Neyens and Boyle, 2008). There were also more unconventional methods, such as comparisons between different violation types (e.g. signalling versus speeding violations) while drivers were inattentive (Fu et al., 2011).

Other studies focussed on analysing various behavioural factors to capture the effect of inattention, such as driver attention to environment, (Berthié et al., 2015), blinking variables, (Faure et al., 2016), safety-critical variables (such as ignoring traffic lights) and perception (Harbluk et al., 2007).

In order to examine the relationship between the various inattention (exposure) and outcome indicators, the studies either deployed multivariate statistical analysis models (such as the ordered logit and the multinomial logistic regression model) or utilized forms of analyses of variance (ANOVA) statistical models, or at least conducted non-model statistical analysis and compared differences or proportions. Sometimes other independent variables were present as well, with some models controlling for them and others studying them independently.

Crash counts are reported through descriptive statistics, with no direct statistical analysis to determine whether inattention is a variable significant enough to relate to accident causes (McEvoy et al., 2007, Wang et al., 1996). The findings for injury severity are somewhat ambiguous as well. One study found increased accident injury severity for two of the age groups participating, namely young and middle-aged drivers, but non-significant results for older drivers (Donmez and Liu, 2015). In contrast, another relevant study discovered a positive impact of inattention on accident injury severity (Neyens and Boyle, 2008). The last two findings can be explained by overcompensation on the part of the drivers, with conservative behaviour which dramatically reduces the chance of serious or fatal injury.

When comparing the violation types caused by inattention, there was a clear trend of inattentive drivers committing more speeding violations when compared to turning-signalling-yielding and sign-related violations (Fu et al., 2011). While this provides significant insights into the crashes that inattentive drivers are involved in, it does not illuminate the direct impacts on the usual road safety indicators (crashes, injuries) because no type of violation is inherently and collectively worse than the other.

Regarding the rest of the behavioural variables, inattention (or ‘mind wondering’, as the relevant study called it), was reported to change driving behaviour by significant portions of drivers as they were not paying attention to their driving environment (Berthié et al., 2015).

As for other perception variables, in a simulation study the mean eye blink frequency and duration were both affected in various environments. There were three different environments tested (motorway, rural and urban roads), and the experiment presented mixed results. For blinking frequency, all results were detrimental apart from one positive one for driving while performing a mental arithmetic task on a rural road. On the other hand, for blink duration, driving while performing a mental arithmetic task on an urban road and both tasks in a motorway environment were found to have a beneficial effect, and the rest of variables were found to be detrimental (Faure et al., 2016). Once again, those discrepancies can be explained by overcompensation effects.

The last study found negative impacts to all of its variables (some outward views, inspection of objects, braking performance, perception of workload and safety reduction and others) except for inspections of the central area (Harbluk et al., 2007).

An overview of the main features of the coded studies for inattention (sample, method, outcome and results) is illustrated on Table 1. Apart from their numbers, the studies are marked with either [In] or [Cg] to denote whether they originally belonged to the inattention or distraction through state of mind and cognitive overload coded study groups. With regards to variable outcomes, results may vary, as seen in Table 3 in the supporting document as well.

No.	Author(s); Year; Country;	Sampling frame for inattention study	Method for inattention impact investigation	Outcome indicator	Main Result
1 [In]	Donmez B., Liu Z.; 2015; USA	115,796 samples were used, from a probability sample selected through police reported traffic crashes from the years 2003-2008. The main focus was on the interaction of driver age and distraction type.	Ordered logit model	Injury severity - Categorical [Odds ratio]	Inattention led to increased injury severities for two of the age categories examined in the study, young, and middle-aged drivers.
2 [In & Cg]	Fu, C., Pei, Y., Wu, Y., & Qi, W.; 2013; USA	Data employed for this study is a probability sample selected through three stages of police reported traffic crashes from the year 2011. A total of 5679 violations were investigated.	Multinomial Logistic Regression Model	Inattention comparison between 3 violation types [Slope]	Inattentive drivers committed more speeding violations when compared to turning-signalling-yielding and sign-related violations.
3 [In]	McEvoy, S. P., Stevenson, M. R., & Woodward, M.; 2007; Australia	1367 drivers who attended hospital following a crash were interviewed. A questionnaire was administered to each driver and additional data were collected from hospital records.	Absolute proportion comparisons	Crash count [Absolute proportion frequency]	Judging by the percentages, lack of concentration while driving is a major factor on relevant crashes, being one quite common.
4 [In]	Neyens, D. M., & Boyle, L. N.; 2008; USA	A US database with crash data was used for the analysis. It included only teenage (16–19 years old) drivers and all of their passengers. It was also limited to crashes occurring	Ordered logit model	Injury severity [Categorical - slope]	When teenage drivers are inattentive, the likelihood of serious injuries for the teenage driver and their passengers was significantly lower due to overcompensation.

No.	Author(s); Year; Country;	Sampling frame for inattention study	Method for inattention impact investigation	Outcome indicator	Main Result
		in passenger vehicles.			
5 [In]	Wang, J. S., Knipling, R. R., & Goodman, M. J.; 1996; USA	This research paper reports the results of the 1995 CDS data collection on distraction while driving.	Absolute proportion comparisons	Crash count [Absolute proportion frequency]	Judging by the percentages, inattention is a major factor on relevant crashes, and the most important singular cause, at the top of the list of the risk inducing factors.
6 [Cg]	Berthié, G., Lemercier, C., Paubel, P. V., Cour, M., Fort, A., Galéra, C., Lagarde, E., Gabaude, G., & Maury, B.; 2015; France	Using a questionnaire, information was collected from 128 drivers about recent trips in 2012.	Absolute proportion comparisons	Impact of Mind-wandering episodes on driving behaviour; [Absolute proportion frequency]	The percentage that perceived significant changes on driving behaviour during MW was 21.4%. The percentage that reported to not pay attention to their driving environment in the same way during MW was 69%.
7 [Cg]	Faure, V., Lobjois, R., & Benguigui, N.; 2016; France	24 experienced drivers participated in a simulation study with three driving environments and with three dual task conditions.	Absolute difference comparison, repeated-measures ANOVA	Mean eye blink frequency; Mean blink duration [Absolute difference]	Eye blink frequency was a sensitive measure to elicit increased mental workload level coming from the driving context. Blink rate increased with the introduction of a cognitive secondary task but the median blink duration was not affected.
8 [Cg]	Harbluk, J. L., Noy, Y. I., Trbovich, P. L., & Eizenman, M.; 2007; Canada	Drivers performed demanding cognitive tasks while driving in actual city traffic. Task interactions were carried out in hands-free mode so that the 21 drivers were not required to take their visual attention away from the road.	Absolute difference comparison, repeated-measures ANOVA	Outward view –Central/ Peripheral Area; Instrument /Mirror inspection; Glances at/Times ignoring traffic lights; Braking performance; Perception of workload /safety reduction/distraction [Absolute difference]	Driver allocation of time for glances, visual behaviour and driving behaviour are all detrimentally affected (more details in the study).

Table 1: Description of coded studies for inattention

Limitations for inattention

A few limitations can be arguably found in the current literature for the effects of inattention and cognitive distractions on road safety. The first one lies in the nature of the design of the studies themselves: Either past data, along with their lack of detail, general limitations and underlying biases have to be relied upon to reach a conclusion, or the researchers must resort to simulators.

Simulations are known to either underrepresent real world conditions, making them less believable environments which the drivers may not take entirely seriously, or sometimes cause dizziness or nausea on the participants, which are forms of added discomfort. Both of these aspects might skew data from relevant experiments.

Secondly, there might be times when this particular risk factor does not affect driving performance, such as a driver being absentminded while immobile at a red light, and then falsely reporting this to the authorities after a crash. Databases of past accidents might not be detailed enough to account for such cases, and again alter results in an undesired manner.

There is also a noticeable lack of studies that focus on the indirect effects of this particular risk factor. A common example of this is the case of a non-driver road user, such as a pedestrian crossing the street while inattentive, and the impacts of this activity on road safety. Finally, as the human brain is extremely complex and, as of yet, highly uncharted scientifically, sometimes it might be hard to draw the line on when a driver is inattentive or distracted through state of mind or cognitive overload. There is also the possibility that some people are better at multitasking than others, and therefore the tests created to approximate cognitive overload (e.g. simultaneous driving and mental calculations) might not be completely objective.

Conclusions for inattention

The effects of inattention while driving can be summarized as follows:

- 2 studies with a descriptive result on crash counts
- 1 study with statistically significant increases (negative results for road safety) on accident injury severity
- 1 study with statistically significant decreases (positive results for road safety) on accident injury severity
- 1 study with statistically significant increases (negative results for road safety) on impacts of mind-wandering in driving behaviour and driver attention to environment
- 2 studies with statistically significant increases and decreases (mixed results for road safety) on impacts of inattention on several behavioural variables such as perception
- 1 study with statistically significant comparisons between violation types performed whilst being inattentive

After the results were reviewed together, the following points were observed:

a) There is an adequate number of studies, however;
b) Those studies have not used the same model for analysis but largely different ones.
c) There are different indicators, and even when they coincide they are not measured in the same way.
d) The sampling frames were quite different (e.g. field testing or simulated driving).

2.2. DESCRIPTION OF ANALYSIS CARRIED OUT FOR INATTENTION

Vote-count analysis for the effect of inattention while driving

After considering the previous points it was decided that a meta-analysis could not be carried out in order to find the overall effect of inattention while driving. Therefore the vote-count analysis was chosen. In vote-count analyses, each study (or each effect) is considered to give a vote for or against the risk-factor. Some variables have been grouped to make the vote-count analysis more meaningful and comprehensive. The results are summarized in Table 2.

Overall estimate of inattention for road safety

On a basis of both study and effect numbers, it can be argued that the risk factor of inattention while driving has a likely detrimental effect on road safety. The coded studies have good levels of quality, and the common conclusion that can be drawn for inattention is that either drivers are forced to compensate for its effects or suffer increased accident risks.

2.3. CONCLUSION FOR INATTENTION

The previous analysis that was carried out showed that inattention has a mostly negative impact on road safety. In absolute numbers a lot of the effects of this risk factor are detrimental, although there are some beneficial impacts as well, as well as a considerable number of variables that remain statistically non-significant (not sufficiently related) to inattention.

There is evidence to support that overcompensation occurs by certain drivers, but whether the overall, collective effects of this risk factor are negated is still unclear. In conclusion, the overall impact of inattention is characterised as yellow (probably risky).

Table 2: Vote-count analysis results for inattention. Key ↑ increased risk; ↓ decreased risk; - not significant

Outcome definition	Tested in number of studies	Result (number of studies)			Result (% of studies)			Result (number of effects)			Result (% of effects)		
		↑	-	↓	↑	-	↓	↑	-	↓	↑	-	↓
Crash count	2	-	2	-	-	100.0%	-	-	2	-	-	100.0%	-
Injury severity	2	1	-	1	50.0%	-	50.0%	8	4	4	50.0%	25.0%	25.0%
Eye blink frequency	1	1	-	-	100.0%	-	-	5	-	1	83.3%	-	16.7%
Blink duration	1	-	1	-	-	100.0%	-	3	-	3	50.0%	-	50.0%
Perception of distraction/ driving behaviour change	2	2	-	-	100.0%	-	-	3	-	-	100.0%	-	-
Attention to environment	1	1	-	-	100.0%	-	-	1	-	-	100.0%	-	-
Outward view - Central Area	1	-	1	-	-	100.0%	-	-	1	1	-	50.0%	50.0%
Outward view - Peripheral Area	1	1	-	-	100.0%	-	-	1	1	-	50.0%	50.0%	-
Instrument inspection	1	1	-	-	100.0%	-	-	1	1	-	50.0%	50.0%	-
Mirror inspection	1	1	-	-	100.0%	-	-	2	-	-	100.0%	-	-
Glances at traffic lights	1	1	-	-	100.0%	-	-	1	1	-	50.0%	50.0%	-
Times ignoring traffic lights	1	1	-	-	100.0%	-	-	1	1	-	50.0%	50.0%	-
Braking performance	1	1	-	-	100.0%	-	-	2	-	-	100.0%	-	-
Perception of workload	1	1	-	-	100.0%	-	-	2	1	-	66.7%	33.3%	-
Perception of safety reduction	1	1	-	-	100.0%	-	-	2	1	-	66.7%	33.3%	-

3. Supporting Document

3.1. QUANTITATIVE ESTIMATES FOR THE SYNOPSIS

Below follows Table 3 which presents the quantitative estimates of the eligible papers for the combined risk factor of inattention and distraction through state of mind and cognitive overload, which were also used for the vote-count analysis of the effects of inattention on driving behaviour.

No.	Author(s); Year; Country;	Outcome indicator	Quantitative estimate	Effect on road safety risk
1 [In]	Donmez B., Liu Z.; 2015; USA	Injury severity - Categorical [Odds ratio]	Young: OR=0.960, p<0.0001, CI [95%] = [0.95, 0.96]	↑
			Middle-aged: OR=0.86, p<0.0001, CI [95%] = [0.86, 0.87]	↑
			Old: OR=1.00, p=0.6900, CI [95%] = [0.99, 1.02]	-
2 [In+Cg]	Fu, C., Pei, Y., Wu, Y., & Qi, W.; 2013; USA	Inattention comparison between 3 violation types [Slope]	TSS vs SR violations: β=-1.360, s.e.=0.280, p<0.0001	-
			TYS vs SR violations: β=-1.090, s.e.=0.230, p<0.0001	-
			TYS vs TSS violations: β=0.260, s.e.=0.240, p>0.050	-
		Cognitive distraction comparison between 3 violation types [Slope]	TSS vs SR violations: β=0.240, s.e.=0.240, p>0.050	-
			TYS vs SR violations: β=0.760, s.e.=0.210, p=0.0010	-
			TYS vs TSS violations: β=0.530, s.e.=0.160, p=0.0010	-
3 [In]	McEvoy, S. P., Stevenson, M. R., & Woodward, M.; 2007; Australia	Crash count [Absolute proportion frequency]	Lack of concentration: Crash proportion: 0.1120	-
4 [In]	Neyens, D. M., & Boyle, L. N.; 2008; USA	Injury severity [Categorical - slope]	Slope (between injury categories) β=-0.58, s.e.=0.010, p<0.001	↓
5 [In]	Wang, J. S., Knipling, R. R., & Goodman, M. J.; 1996; USA	Crash count [Absolute proportion frequency]	Looked but did not see: frequency=0.089	-
6 [Cg]	Berthié, G., Lemercier, C., Paubel, P. V., Cour, M., Fort, A., Galéra, C., Lagarde, E., Gabaude, G., & Maury, B.; 2015; France	Impact of MW episodes on driving behaviour [Absolute proportion frequency]	Driver proportion: 0.2140, p<0.010	↑
		Attention to environment during MW [Absolute proportion frequency]	Driver proportion: 0.6900, p<0.010	↑
7 [Cg]	Faure, V., Lobjois, R., & Benguigui, N.; 2016; France	Mean eye blink frequency [Absolute difference]	Motorway: Dual-task low vs. Single task: Abs.dif.=1.100, p<0.010	↑
			Motorway: Dual-task high vs. Single task: Abs.dif.=5.600, p<0.010	↑
			Urban Road: Dual-task low vs. Single task: Abs.dif.=0.300, p<0.010	↑

No.	Author(s); Year; Country;	Outcome indicator	Quantitative estimate	Effect on road safety risk
			Urban Road: Dual-task high vs. Single task: Abs.dif.=5.400, p<0.010	↑
			Rural Road: Dual-task low vs. Single task: Abs.dif.=-1.300, p<0.010	↓
			Rural Road: Dual-task high vs. Single task: Abs.dif.=3.200, p<0.010	↑
7 [Cg]	Faure, V., Lobjois, R., & Benguigui, N.; 2016; France	Mean blink duration [One-way ANOVA]	Motorway: Dual-task low vs. Single task: Abs.dif.=-6.000, p<0.010	↓
			Motorway: Dual-task high vs. Single task: Abs.dif.=-6.000, p<0.010	↓
			Urban Road: Dual-task low vs. Single task: Abs.dif.=-3.000, p<0.010	↓
			Urban Road: Dual-task high vs. Single task: Abs.dif.=5.000, p<0.010	↑
			Rural Road: Dual-task low vs. Single task: Abs.dif.=4.000, p<0.010	↑
			Rural Road: Dual-task high vs. Single task: Abs.dif.=18.000, p<0.010	↑
8 [Cg]	Harbluk, J. L., Noy, Y. I., Trbovich, P. L., & Eizenman, M.; 2007; Canada	Outward view - Central Area [Absolute difference]	Difficult task vs. No task: Abs.dif.=0.0405, t-test(20)=2.20, p<0.05	↓
			Easy task vs. No task: Abs.dif.=0.0221, t-test(20)=1.52, p>0.05	-
		Outward view - Peripheral Area [Absolute difference]	Difficult task vs. No task: Abs.dif.=-0.0071, t-test(20)=2.18, p<0.05	↑
			Easy task vs. No task: Abs.dif.=0.0002, t-test(20)=0.97, p>0.05	-
		Instrument inspection [Absolute difference]	Difficult task vs. No task: Abs.dif.=-0.0085, χ^2-test(2)=16.38, p<0.001	↑
			Easy task vs. No task: Abs.dif.=-0.0030, χ^2-test(2)=16.38, p<0.001	-
		Mirror inspection [Absolute difference]	Difficult task vs. No task: Abs.dif.=-0.0075, χ^2-test(2)=7.25, p<0.05	↑
			Easy task vs. No task: Abs.dif.=-0.0019, χ^2-test(2)=7.25, p<0.05	↑
		Glances at traffic lights [Absolute difference]	Difficult task vs. No task: Abs.dif.=-0.9300, p<0.001	↑
			Easy task vs. No task: n/a	-
		Times ignoring traffic lights [Absolute difference]	Difficult task vs. No task: Abs.dif.=0.1410, χ^2-test(1)=8.07, p<0.01	↑
			Easy task vs. No task: n/a	-
		Braking performance [Absolute difference]	Difficult task vs. No task: Abs.dif.=1.820, p=0.05	↑
			Easy task vs. No task: Abs.dif.=1.250, p=0.05	↑
		Perception of workload [Absolute difference]	Difficult task vs. No task: Abs.dif.=3.790, χ^2-test(2)=32.67, p<0.0001	↑
			Easy task vs. No task: Abs.dif.=1.610, χ^2-test(2)=32.67, p<0.0001	↑
		Perception of safety reduction [Absolute difference]	Difficult task vs. No task: Abs.dif.=2.960, χ^2-test(2)=27.07, p<0.0001	↑
			Easy task vs. No task: Abs.dif.=1.760, χ^2-test(2)=27.07, p<0.0001	↑
		Perception of distraction [Absolute	Difficult task vs. No task: Abs.dif.=5.290, χ^2-test(2)=34.05, p<0.0001	↑

No.	Author(s); Year; Country;	Outcome indicator	Quantitative estimate	Effect on road safety risk
		difference]	Easy task vs. No task: Abs.dif.=3.340, χ^2-test(2)=34.05, p<0.0001	↑

Table 3: Quantitative results of coded studies for inattention and impacts on road safety

3.2. IDENTIFYING RELEVANT STUDIES FOR INATTENTION

A systematic literature search was carried out using the available databases and online tools of scientific practice and knowledge. The results are summarized in the following tables, separately for inattention – daydreaming and for distraction through state of mind and cognitive overload.

Risk factor: Inattention

Database: Scopus **Date:** 22nd of April 2016

search no.	search terms / operators / combined queries	Hits
#1	(„inattention")	633
#2	(„casualties" OR „fatalities" OR „traffic safety" OR „crash" OR „crash risk" OR „severity" OR „frequency" OR „collision" OR „incident" OR „accident")	22,319
#3	(„daydreaming")	26
#4	#1 OR #3	650
#5	#4 AND #2	436

Limitations/ Exclusions:

- Published: 1990 to current
- Document Type: "Review" and "Article"
- Language: "English"
- Source Type: "Journal"
- Subject Area: "Engineering"

Results Literature Search

Database	Hits
Scopus (remaining papers after several limitations/exclusions)	436
Total number of studies to screen title/ abstract	436

Screening

Total number of studies to screen title/ abstract	436
-De-duplication	0
-exclusion criteria A (not related to the topic/not relevant risk factor)	413
-exclusion criteria B (part of meta-analysis)	0
Remaining studies	23
Not clear (full-text is needed)	0
Studies to obtain full-texts	23

Eligibility

Total number of studies to screen full-text	23
Full-text could be obtained	23

Reference list examined Y/N	Yes (+3 papers)
Eligible papers prioritized	5

Prioritizing Coding

- Prioritizing Step A (accidents over other performance indicators)
- Prioritizing Step B (Journals over conferences and reports)
- Prioritizing Step C (journal quality)
- Prioritizing Step D (more recent studies)

No meta-analyses were found.

3.3. REFERENCES FOR INATTENTION

List of studies remaining after step 3 'eligibility' for inattention

1. Donmez B., Liu Z. (2015). Associations of distraction involvement and age with driver injury severities. Journal of Safety Research 52, 23–28. doi: http://dx.doi.org/10.1016/j.jsr.2014.12.001.
2. Beanlanda V., Fitzharris M., Young K.L., Lenné M.G. (2013). Driver inattention and driver distraction in serious casualty crashes: Data from the Australian National Crash In-depth Study. Accident Analysis and Prevention 54, 99– 107. doi: http://dx.doi.org/10.1016/j.aap.2012.12.043.
3. Zhu X., Srinivasan S. (2011). Modeling occupant-level injury severity: An application to large-truck crashes. Accident Analysis and Prevention 43, 1427–1437. doi:10.1016/j.aap.2011.02.021.
4. Neyens D.M., Ng Boyle L. (2008). The influence of driver distraction on the severity of injuries sustained by teenage drivers and their passengers. Accident Analysis and Prevention 40 (2008) 254–259. doi:10.1016/j.aap.2007.06.005.
5. Kelley-Baker T., Romano E. (2010). Female involvement in U.S. nonfatal crashes under a three-level hierarchical crash model. Accident Analysis and Prevention 42, 2007–2012. doi:10.1016/j.aap.2010.06.010.
6. Wang J.-S., Knipling R.R., Goodman M.J. (1996). The role of driver inattention in crashes; new statistics from the 1995 crashworthiness data system. NHTSA report. http://www-nrd.nhtsa.dot.gov/departments/Human%20Factors/driver-distraction/PDF/oldWang.pdf.
7. Shankar V., Mannering F. (1996). An exploratory multinomial logit analysis of single-vehicle motorcycle accident severity. Journal of Safety Research, 27(3), 183–194.
8. Fu C., Pei Y., Yuqing Wu Y., Qi W. (2013). The Influence of Contributory Factors on Driving Violations at Intersections: An Exploratory Analysis. Hindawi Publishing Corporation, Advances in Mechanical Engineering, Article ID 905075, 8 pages. doi: http://dx.doi.org/10.1155/2013/905075.
9. Huemer A.K., Vollrath M. (2011). Driver secondary tasks in Germany: Using interviews to estimate prevalence. Accident Analysis and Prevention 43, 1703–1712. doi:10.1016/j.aap.2011.03.029.
10. Braitman K.A., Kirley B.B., McCartt A.T., Chaudhary N.K. (2008). Crashes of novice teenage drivers: Characteristics and contributing factors. Journal of Safety Research 39, 47–54. doi:10.1016/j.jsr.2007.12.002.
11. McEvoy S.P., Stevenson M.R., Woodward M. (2007). The prevalence of, and factors associated with, serious crashes involving a distracting activity. Accident Analysis and Prevention 39, 475–482. doi:10.1016/j.aap.2006.09.005.
12. Peng Y., Ng Boyle L., Hallmark S.L. (2013). Driver's lane keeping ability with eyes off road: Insights from a naturalistic study. Accident Analysis and Prevention 50, 628– 634. doi: http://dx.doi.org/10.1016/j.aap.2012.06.013.

13. Daly N., Brogan M., Kaneswaran D., Deegan C., Markham C., Commins S. (2014). An exploratory study of the role played by sustained attention along a rural Irish route using a video-playback system. Transportation Research Part F 26 (2014) 138–150. doi: http://dx.doi.org/10.1016/j.trf.2014.06.014.
14. Ledesma R.D., Montes S.A., Po F.M., Lpez-Ramn M.F. (2010) Individual Differences in Driver Inattention: The Attention-Related Driving Errors Scale, Traffic Injury Prevention, 11:2, 142-150, doi: 10.1080/15389580903497139.
15. Schmidt E.A., Schrauf M., Simona M, Fritzsche M., Buchner A., Kincses W.E. (2009). Drivers' misjudgement of vigilance state during prolonged monotonous daytime driving. Accident Analysis and Prevention 41, 1087–1093. doi:10.1016/j.aap.2009.06.007.
16. Lemercier C., Pêcher C., Berthié G., Valéry B., Vidal V., Paubel P.-V., Cour M., Fort A., Galéra C., Gabaude C., Lagarde E., Maury B. (2014). Inattention behind the wheel: How factual internal thoughts impact attentional control while driving. Safety Science 62 (2014) 279–285. doi: http://dx.doi.org/10.1016/j.ssci.2013.08.011.

List of coded studies for inattention

1. DONMEZ, B. & LIU, Z. 2015. Associations of distraction involvement and age with driver injury severities. *Journal of safety research,* 52**,** 23-28.
2. FU, R., GUO, Y., YUAN, W., FENG, H. & MA, Y. 2011. The correlation between gradients of descending roads and accident rates. *Safety science,* 49**,** 416-423.
3. MCEVOY, S. P., STEVENSON, M. R. & WOODWARD, M. 2007. The prevalence of, and factors associated with, serious crashes involving a distracting activity. *Accident Analysis & Prevention,* 39**,** 475-482.
4. NEYENS, D. M. & BOYLE, L. N. 2008. The influence of driver distraction on the severity of injuries sustained by teenage drivers and their passengers. *Accident Analysis & Prevention,* 40**,** 254-259.
5. WANG, J.-S., KNIPLING, R. R. & GOODMAN, M. J. The role of driver inattention in crashes: New statistics from the 1995 Crashworthiness Data System. 40th annual proceedings of the Association for the Advancement of Automotive Medicine, 1996. 392.

3.4. IDENTIFYING RELEVANT STUDIES FOR DISTRACTION THROUGH STATE OF MIND AND COGNITIVE OVERLOAD

Risk factor: distraction through state of mind and cognitive overload

Database: Scopus **Date:** 28th of March 2016

search no.	search terms / operators / combined queries	hits
#1	(„mind" OR „cognitive" OR "workload" OR „ponder*")	79,462
#2	(„distract*")	4,197
#3	(„casualties" OR „fatalities" OR „traffic safety" OR „crash" OR „crash risk" OR „severity" OR „frequency" OR „collision" OR „incident" OR „accident")	22,319
#4	#1 AND #3	3,439
#5	#2 AND #3	1,430
#6	#1 AND #2 AND #3	800

Limitations/ Exclusions:

- Published: 1990 to current
- Document Type: "Review" and "Article"
- Language: "English"
- Source Type: "Journal"
- Subject Area: "Engineering"

Results Literature Search

Database	Hits
Scopus (remaining papers after several limitations/exclusions)	800
Total number of studies to screen title/ abstract	800

Screening

Total number of studies to screen title/ abstract	800
-De-duplication	0
-exclusion criteria A (not related to the topic/not relevant risk factor)	106
-exclusion criteria B (part of meta-analysis)	0
Remaining studies	694
Not clear (full-text is needed)	0
Studies to obtain full-texts	694

Eligibility

Total number of studies to screen full-text	694
Full-text could be obtained	34
Reference list examined Y/N	No
Eligible papers prioritized	4

Prioritizing Coding

- Prioritizing Step A (accidents over other performance indicators)
- Prioritizing Step B (Journals over conferences and reports)
- Prioritizing Step C (journal quality)
- Prioritizing Step D (more recent studies)

No meta-analyses were found.

3.5. REFERENCES FOR DISTRACTION THROUGH STATE OF MIND AND COGNITIVE OVERLOAD

List of coded studies for distraction through state of mind and cognitive overload

1. BERTHIÉ, G., LEMERCIER, C., PAUBEL, P.-V., COUR, M., FORT, A., GALÉRA, C., LAGARDE, E., GABAUDE, C. & MAURY, B. 2015. The restless mind while driving: drivers' thoughts behind the wheel. *Accident Analysis & Prevention,* 76**,** 159-165.
2. FAURE, V., LOBJOIS, R. & BENGUIGUI, N. 2016. The effects of driving environment complexity and dual tasking on drivers' mental workload and eye blink behavior. *Transportation research part F: traffic psychology and behaviour,* 40**,** 78-90.
3. FU, R., GUO, Y., YUAN, W., FENG, H. & MA, Y. 2011. The correlation between gradients of descending roads and accident rates. *Safety science,* 49**,** 416-423.
4. HARBLUK, J. L., NOY, Y. I., TRBOVICH, P. L. & EIZENMAN, M. 2007. An on-road assessment of cognitive distraction: Impacts on drivers' visual behavior and braking performance. *Accident Analysis & Prevention,* 39**,** 372-379.

Distraction: Conversation with Passengers

Distraction cause by talking to others travelling in the same vehicle

1. Summary

Theofilatos, A., Ziakopoulos, A., Papadimitriou, E., Yannis, G., September 2016

1.1. COLOUR CODE: RED

The meta-analyses carried out showed that conversation with other passengers (both adults and children) corresponds to a significant proportion of road accidents. There is also evidence to support that this distraction activity slows reaction times and increases injury severity, but more studies are needed to further support this statement.

1.2. KEYWORDS

Conversation; passengers; crash risk; road safety; road accident; driver distraction

1.3. ABSTRACT

Conversation and other interactions with passengers induce a level of distraction to the person driving. This distraction translates to slower reaction times to events or to increased severity of driver injuries in accidents. On a basis of both study and effect numbers, it is observed that a consistent non-negligible proportion of road accidents are caused by driver conversation with other passengers in the vehicle. The results of the meta-analyses carried out confirmed this trend and showed that this proportion is significant. In general, findings for this risk factor are generally transferable, though caution and care against oversimplification are always required.

1.4. BACKGROUND

How does conversation with passengers affect road safety?

Conversation with passengers is an in-vehicle distraction and is generally considered as an important distraction activity. The extra amount of mental workload and cognitive functions that drivers have to undertake through conversation reduces their reflexes and slows reaction times to events (both the time to mentally register the effect and the time to physically react to it), as stated in the literature. Moreover, one study indicates that conversation is correlated with specific types of traffic violations. Lastly, similarly to other distractions, conversation can result in acceleration, speed and position variations, and lane changes which are proven causes of road accidents. For that reason, a couple of studies indicate association of conversation with passengers and severe accidents.

It is worth noting that conversation with passengers is only one aspect of driver distraction. A driver can be under the influence of several other distracting activities and therefore suffer under combined detrimental effects. Examples of distraction risk factors that can coincide with conversation with passengers could be consumption of goods (e.g. smoking), music, watching objects outside the vehicle, and others.

Definition of conversation with passengers

The presence of this risk factor exists when any vehicle driver is engaged in a conversation with other passengers. In the context of road safety, this can imply discussion, a small talk or even a fight. As a variable, it is usually of binary nature (e.g. conversation with passengers or not).

Which safety outcomes are affected by conversation with passengers?

The reviewed studies focus on various outcomes. In some studies, the main focus is reporting the absolute number or the percentage (absolute proportion) of accidents or near misses caused by various distractions, including conversation with passengers. On the other hand, one study was found to investigate the effect of conversation with passengers on reaction time. In addition to these, a couple of studies investigated injury severity. Other critical safety events apart from crashes are investigated, such as violation types.

How is the effect of conversation with passengers on road safety studied?

The international literature has examined a variety of different approaches and ways to study the effect of conversation with passengers. Sometimes this particular risk factor is examined alongside other similar distraction factors such as handheld cell phone use, texting, consumption of goods, and not solely by itself. Its examination or analysis may be adjusted to the models selected to capture the entire situation for the given case. Given the fact that it is unethical to conduct experiments on real circumstances (field experiments on the road) because it would compromise the safety of the participants, researchers have two alternative methods. These involve either examining databases of past accidents and analysing the effect of conversation with passengers (which sometimes leads to lack of data), or conducting simulation experiments which are in a virtual environment where no hazard is present. As far as the analytic part is concerned, the binary approach mentioned above is the most common method, which categorizes drivers as exposed or not exposed to the risk factor that is engagement in conversation with passengers.

1.5. OVERVIEW OF RESULTS

Usually the literature indicates that driver conversation with passengers has a generally negative effect on road safety. In general, studies utilising past accident data argued that a non-negligible percentage of accidents are caused due to conversation with passengers. Indeed, the first meta-analysis that was carried out has showed a significant effect at a 95% level, when drivers talk with adult or teen passengers. On the other hand, the second meta-analysis showed a significant effect at a 90% level when interaction with children in the car is also considered. Furthermore, a couple of studies investigated the effect of driver conversation with passengers and found that more severe accidents tend to occur under these conditions. Another study found that under conversation with other passengers, some violation types are more likely to occur (e.g. speed-related).

There are also some simulator studies where those environments allow for safe and detailed recording and examination of data. The only dependent variable to be examined is the reaction time which is significantly slower when the driver is engaged in discussion.

Notes on analysis methods

The methodology applied for capturing the impacts of driver conversation with passengers varies considerably among studies in regards to mainly the mathematical models utilised, and secondly the outcomes evaluated as dependent variables. More specifically, studies relying on past accident data used straightforward methods, such as raw absolute proportion (percentage) of accidents caused by driver conversation with passengers, or percentage of drivers engaged in this distraction activity. On the other hand, studies focusing on injury severity utilised statistical models such as the ordered logit model.

It is noted that driver conversation with passengers is sometimes not exclusively studied. This means that in some studies, the presence or other distraction factors is studied alongside this particular risk factor (e.g. consumption of goods). Consequently, the study designs might not always be completely tailored towards capturing the effect of conversation with passengers. There are studies that are focused exclusively on this risk factor solely, however. There is still room for investigating other geographical regions. All aforementioned factors make the findings for this risk factor generally transferable, though caution and care against oversimplification are always required.

2. Scientific Overview

2.1. LITERATURE REVIEW

Analysis of study designs and methods

After appropriate use of various search tools and databases, eight quality studies were selected and coded for the risk factor of driver conversation with passengers in the vehicle. Two of the studies investigated crash injury severity (Domnez and Liu, 2015; Neyens and Boyle, 2008), four studies investigated the proportion of accidents due to conversation with passengers (Dingus et al., 2016; Lansdown, 2015; McEvoy et al., 2007; Wang et al., 1996), and one study examined the violation types in regard with this distraction activity (Fu et al., 2015). Only one relevant study was found to be carried out by using a simulator experiment (Consiglio et al., 2003) and examined the effect on reaction time.

A first important remark is that most of the studies relied on past accident data and less on driving simulators. It is thus observed that this distracting activity is under-represented in simulator studies, since simulator experiments focus on other distractions (e.g. mobile phone use). However, Dingus et al. (2016) carried out a 3-year naturalistic experiment.

In general, it is widely argued that conversation with passengers is detrimental for road safety as all road safety indicators deteriorate. A first examination of studies using past accident data and examining the accident causes (Lansdown, 2015; McEvoy et al., 2007; Wang et al., 1996) shows that a consistent number of accidents and near-misses happen due to conversation with passengers.

On the other hand, Domnez and Liu, (2015), as well as Neyens and Boyle (2008), applied ordered logit models to investigate the effect of conversation with passengers on accident injury severity. Domnez and Liu (2015) considered different age groups (e.g. young, middle, old), whilst Neyens and Boyle (2008) considered only teenage drivers (16-19 years old) involved in accidents only with passenger vehicles. However, both studies report that this distraction activity is associated with more severe injuries regardless of the age group.

The last study in this synopsis to have used past accident data is that of Fu et al. (2015). This study uses data from the USA which has been derived from the National Automotive Sampling System (NASS) General Estimates System (GES) from the year 2011. Authors have applied a multinomial logit model in order to compare violation types (traffic sign and signals violations vs turning-yielding-signalling violation vs speeding related violations). It was found that the most common violations due to conversation with passengers were the speeding related violations.

Regarding behavioural variables, Consiglio (2003) carried out an experiment in a laboratory station which simulated the foot activity in driving. 22 research participants were requested to release the accelerator pedal and depress the brake pedal following the activation of a red brake light. It is suggested that conversation with passengers slowed the reaction time in a breaking response (releasing throttle and pressing brake).

Lastly, one more study was decided to be coded and included even though its outcome indicator is not straightforward (Sullman, 2012). The reason for this decision was that it showed the distribution in distracting activities and thus was informative for this synopsis. More specifically, this study carried out observations that took place on randomly selected roads at three different time periods during two consecutive Tuesdays. The study found that that 14.4% of the 7,168 drivers observed were found to be engaged in a distracting activity. Conversation with passengers was the most common distraction activity.

An overview of the main features of the coded studies (sample, method, outcome and results) is illustrated on Table 1.

Table 1: Description of coded studies

No.	Author(s); Year; Country;	Sampling frame	Method	Outcome indicator	Main Result
1	Consiglio et al.; 2003; USA	Laboratory station which simulated the foot activity in driving. 22 research participants were requested to release the accelerator pedal and depress the brake pedal following the activation of a red brake lamp.	Absolute mean difference	Reaction time in a breaking response (releasing throttle and pressing brake)	Conversation with passengers increased reaction times.
2	Domnez and Liu; 2015; USA	Two-vehicle crashes, due to the existence and type of distraction as well as driver's age. Data used from the U.S. National Automotive Sampling System's General Estimates System (2003 to 2008).	Ordered logit model	Injury severity*	Conversation with passengers causes more severe accidents for every age group (<25, 26-64, >65).
3	Fu et al.; 2015; USA	Accident data used from the National Automotive Sampling System (NASS) General Estimates System (GES) from the year 2011. The data is a probability sample selected through three stages of police reported traffic crashes for estimating the national crash tendency by weighting.	Multinomial logit model (comparison between violation types)	Violation types**	SR violations are more likely to occur under conversation with passengers than TSS and TYS violations.
4	Lansdown; 2015; United Kingdom	Survey data were collected using an anonymous online questionnaire. Four hundred eighty-two respondents contributed to the survey during a 2 month data collection period.	Absolute proportion	Crashes and Near misses [Absolute proportion frequency]	Results suggest drivers are frequently, and repeatedly conducting highly distracting, and in many cases illegal tasks (in the United Kingdom) while driving. While proportion results are lacking statistical analysis to back this, regression models later in the study support it.
5	McEvoy et al.; 2007; Australia	Between April 2002 and July 2004, 1367 drivers involved in serious crashes in Perth, Western Australia were interviewed. They attended hospital following a crash. A structured questionnaire was administered to each driver and supplementary data were collected from ambulance and medical records.	Absolute proportion	Crashes	Distracting activities at the time of serious crashes are common and can cause crashes.
6	Neyens and Boyle; 2008; USA	Data from the year 2003 in the U.S. DOT–General Estimate System (GES), a national crash database, were used. The data included only	Ordered logit model	Injury severity*	Distraction caused by passengers increase severity of accidents.

No.	Author(s); Year; Country;	Sampling frame	Method	Outcome indicator	Main Result
		teenage (16–19 years old) drivers and all of their passengers. It was also limited to crashes occurring in passenger vehicles.			
7	Sullman; 2012; UK	The observations took place on randomly selected roads at three different time periods during two consecutive Tuesdays. The data revealed that 14.4% of the 7168 drivers observed were found to be engaged in a distracting activity.	Absolute proportion	Most common distraction activity	Conversation with passengers was the most common distraction activity.
8	Wang, J. S., Knipling, R. R., & Goodman, M. J.; 1996; USA	The Crashworthiness Data System (CDS) was employed to obtain more in-depth information on driver distraction related crash causes, including various distractions.	Absolute proportion	Crash count [Absolute proportion frequency]	Judging by the percentages, passenger distraction is a major factor on relevant distraction crashes.
9	Dingus et al.; 2016; U.S.A.	The study used a US dataset comprising 905 injurious and property damage crash events. Crash events were gathered and analysed in detail through video observations and measurements of 3,542 drivers.	Mixed effect random logistic model (& 2-staged stratified random sampling method)	Accident risk-probability of an accident [Odds Ratio]	Driver-related factors are present in almost 90% of crashes. Drivers are distracted more than 50% of the time while they are driving, resulting in a crash risk that is 2 times higher than model driving.

* 5-scale (No injuries, Possible Injuries, Non-incapacitating Injuries, Incapacitating Injuries, Fatal Injuries)
**Traffic sign and signals (TSS) violation, turning-yielding-signalling (TYS) violation, speeding related (SR)

2.2. ANALYSIS METHODS AND RESULTS

Introduction

The effects of conversation with passengers identified can be summarized as follows:

- 2 studies found a significant increase on injury severity due to conversation with passengers.
- 1 study found significant prevalence of specific violation types.
- 1 study found a significant increase on reaction times.
- 1 study showing that the major distracting activity is conversation with passengers.
- 2 studies stating that a non-negligible number of accidents were caused by conversation with passengers.

After the results were reviewed together, the following points were observed:

a) There is an adequate number of studies, however;
b) Those studies have not used the same analysis methods but largely different ones.
c) There are usually different outcome indicators
d) The sampling frames were quite different.
e) A meta-analysis on the raw absolute proportion of accidents due to conversation with passengers was decided to be carried out.
f) A vote count analysis could not be performed, because the results of a lot of studies cannot be interpreted as negative or positive effect of this risk factor (e.g. type of specific violation types due to conversation).

2.3. DESCRIPTION OF ANALYSIS CARRIED OUT

Introduction

It was decided to carry out 2 separate meta-analyses in order to find the overall estimate of the effect of conversation with passengers on road safety[1]. More specifically, it was attempted to investigate the overall estimate of the absolute proportion of accidents due to interaction (conversation) with a) adult passengers only and b) adult and child passengers. This was decided because the interaction with child passengers is not necessarily a conversation. However, it would be interesting to examine this effect as well.

The reasons for the meta-analysis decision are:

a) A minimum required number of effects is achieved (3).
b) The sampling frames were similar.
c) Outcome indicators of studies in each meta-analysis were the same (absolute proportion of accidents due to this distraction activity).
d) Studies were reporting standard errors.

The studies considered were the following:

1) McEvoy et al., 2007
2) Lansdown, 2012
3) Wang et al., 1996
4) Dingus et al., 2016

Meta-analysis (conversation with adult passengers only)

In this meta-analysis the overall estimate of the raw proportion of accidents due to conversation with adult passengers was investigated. To do so, the number of accidents due to conversation with adult passengers (xi) as well the total number of accidents (ni) had to be defined for each study. Then, the estimate (y) and the variance vi of raw proportion (xi/ni) was estimated for each study following Viechtbauer (2010). Results of the random-effects meta-analysis indicate that the overall estimate of the effect of conversation with adult passengers on absolute proportion of accidents is 0.0746, and the 95% confidence intervals are 0.075, and 0.1418 respectively (Table 2). The p-value (0.0294) indicates a significant effect at a 95% level.

Table 2 Summary of meta-analysis estimates of conversation with adult passengers on absolute proportion of accidents

Variable	Unit	Estimate	Std. Error	p-value	95% CI
Conversation with adult or teen passengers	Absolute proportion of accidents	0.0746	0.0343	0.0294	(0.075, 0.1418)

[1] It was not feasible to carry out a meta-analysis for Injury severity, because the sampling frames were not easily comparable.

Figure 1 illustrates the forest plot for absolute proportion of total accidents that happen due to conversation with adult passengers while driving.

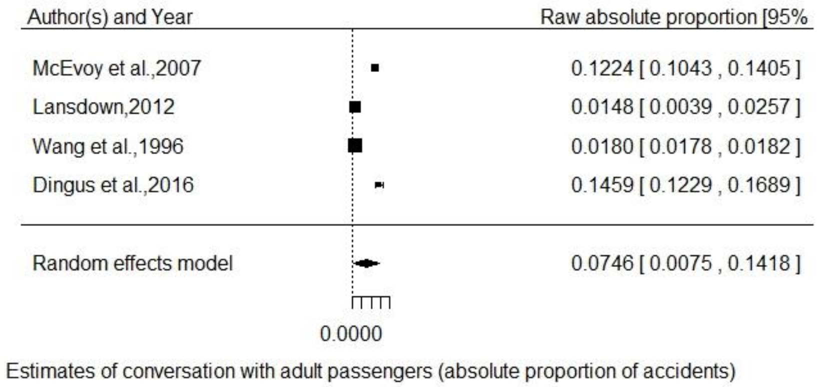

Figure 1 Forest plot for absolute proportion of total accidents that happen due to conversation with adult passengers while driving.

Heterogeneity

The Q test is significant ($Q = 246.7147$, p-value < 0.0001) suggesting considerable heterogeneity among the true effects. Therefore, the random effects meta-analysis that was carried out is preferred and there is no need to perform a fixed effects meta-analysis.

Publication Bias

A funnel plot was firstly produced in order to detect potential publication bias. No publication bias was found. The regression test for funnel plot asymmetry was not significant at a 95% level (p-value = 0.2031), suggesting no evidence for publication bias. Therefore, there is no need for correcting the estimates.

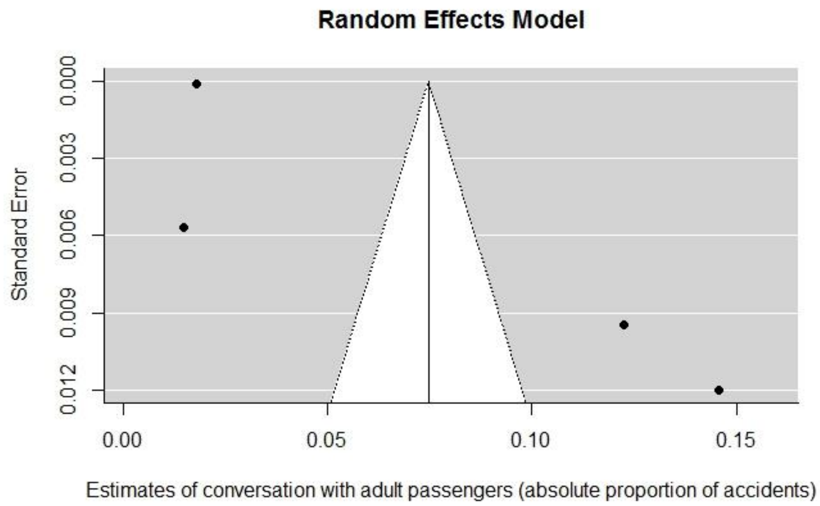

Figure 2 Funnel Plot for absolute proportion of total accidents that happen due to conversation with adult passengers while driving.

Meta-analysis (conversation with all passengers)

In this meta-analysis the following studies are included:

1) McEvoy et al., 2007
2) Lansdown, 2012
3) Wang et al., 1996
4) Dingus et al., 2016

The overall estimate of the raw proportion of accidents due to conversation with all passengers (adults and children) was investigated. The approach was the same as in the previous analysis. Results of the random-effects meta-analysis indicate that the overall estimate of the effect of conversation with all passengers on absolute proportion of accidents is 0.0437, and the 95% confidence intervals are -0.0069 and 0.0943 respectively (Table 3). The p-value (0.0907) indicates a significant effect but at a 90% level which is acceptable.

Table 3 Summary of meta-analysis estimates of conversation with adult passengers on absolute proportion of accidents

Variable	Unit	Estimate	Std. Error	p-value	95% CI
Conversation with all passengers	Absolute proportion of accidents	0.0437	0.0258	0.0907	(-0.0069, 0.0943)

Figure 3 illustrates the forest plot for absolute proportion of total accidents that happen due to conversation with all passengers while driving.

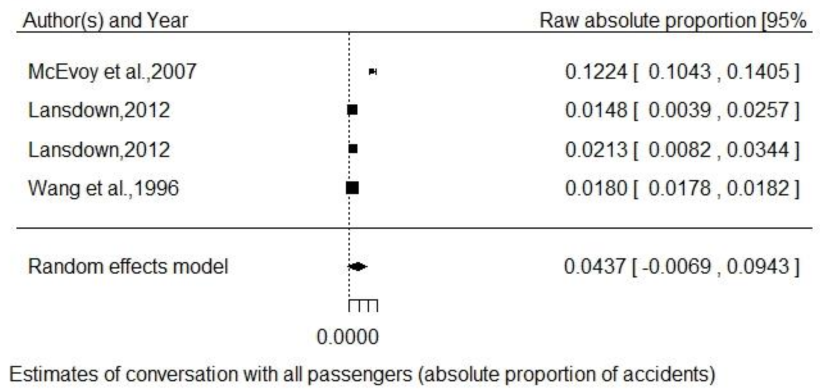

Figure 3 Forest plot for absolute proportion of total accidents that happen due to conversation with adult passengers while driving.

Heterogeneity

The Q test is significant (Q = 128.2325, p-value < 0.0001) suggesting considerable heterogeneity among the true effects. Therefore, the random effects meta-analysis that was carried out is preferred and there is no need to perform a fixed effects meta-analysis.

Publication Bias

A funnel plot was firstly produced in order to detect potential publication bias. No publication bias was found. The regression test for funnel plot asymmetry was not significant at a 95% level (p-value = 0.4257), suggesting no evidence for publication bias. Therefore, there is no need for correcting the estimates.

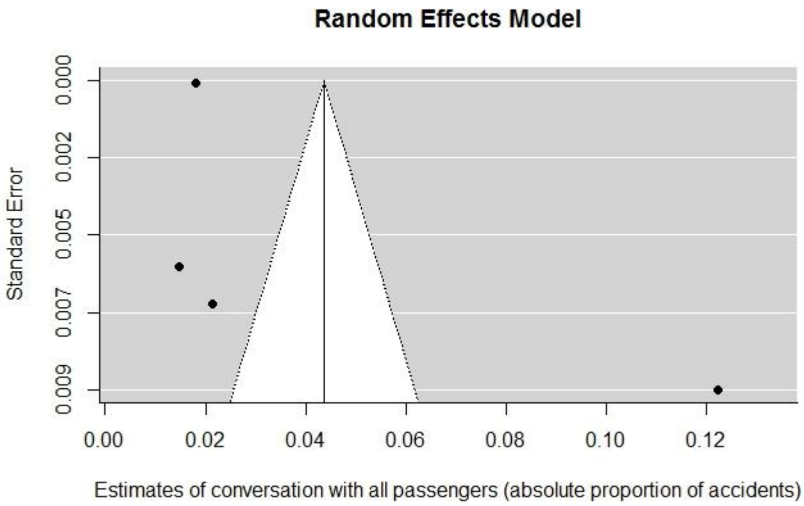

Figure 4 Funnel Plot for absolute proportion of total accidents that happen due to conversation with adult passengers while driving.

3. Supporting Document

3.1. IDENTIFYING RELEVANT STUDIES

Risk factor: Conversation with passengers

Database: Scopus **Date:** 28th of March 2016

search no.	search terms / operators / combined queries	hits
#1	(„passenger presence" OR „conversation")	1345
#2	(distraction)	3395
#3	#1 AND #2	171

Optional but recommended: Limitations/ Exclusions:

- Search field: TITLE-ABS-KEY (used for search #10)
- Published: 1990 to current
- Document Type: "Review" and "Article"
- Language: "English"
- Source Type: "Journal"
- Exclusion of several countries (not used)
- Subject Area: "Engineering"

Results Literature Search

Database	Hits
Scopus (remaining papers after several limitations/exclusions)	171
Total number of studies to screen title/ abstract	171

Screening

Total number of studies to screen title/ abstract	171
-De-duplication	0
-exclusion criteria A (not related to the topic/not relevant risk factor)	138
-exclusion criteria B (part of meta-analysis)	0
Remaining studies	33
Not clear (full-text is needed)	1
Studies to obtain full-texts	33
Studies after second abstract screening	33

Eligibility

Total number of studies to screen full-text	
Full-text could be obtained	33
Reference list examined Y/N	YES
Eligible papers	33

Due to time constraints, 9 studies out of 33 were selected and prioritized for coding.

Prioritizing Coding
- Prioritizing Step A (accidents over other performance indicators)
- Prioritizing Step B (Journals over conferences and reports)
- Prioritizing Step C (Prestigious journals over other journals)
- Prioritizing Step D (More recent studies)

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Distraction – Outside Vehicle Factors

Distraction caused by sources outside of the vehicle including:
Watching persons, situations;
Sun, other vehicles' lights;
Static objects (advertising signs, traffic management information, etc.)

1. Summary

Ziakopoulos, A., Theofilatos, A., Papadimitriou, E., Yannis, G., September 2016

1.1 COLOUR CODE: YELLOW

The effects of distraction outside the vehicle while driving have been suspected to link to accidents, and thus investigated accordingly. The coded studies encompass several topics and have good levels of quality and consistency, though there are some unclear areas. As all statistically significant effects are detrimental effects to road safety, the overall impact of outside factors is characterised as yellow (probably risky).

1.2 KEYWORDS

Outside distraction; roadside signs; sunlight; crash risk; road safety; road accident; driver distraction; human factor;

1.3 ABSTRACT

The engagement with various factors that can be present outside the vehicle induces a level of distraction to the person driving. The specific impacts of these distractions vary, but they are negative and in general it can be assumed that accident numbers and various driver behavioural variables such as lateral control and speeding are affected. Twelve high quality studies regarding various outside factors were coded. On a basis of both study and effect numbers, it can be argued that outside factors create mostly negative impacts on road safety, with all statistically significant effects being detrimental. There were cases, however, that reported no statistically significant relation of distraction outside of the vehicle to various road safety variables (including behavioural factors). The results seem generally transferable.

1.4 BACKGROUND

Definition and effects of outside factors on road safety

Distraction by individuals, objects or situations outside the vehicle while driving (referred hereby as 'outside factors') is a common phenomenon. It can originate from the surroundings, such as an extraordinary scenery or an unusual occurrence (e.g. a separate road accident). Environmental factors, such as intense sun glare (or fog) might hinder the driver as well. Moreover, static objects designed to capture the attention of the driver, such as road and/or advertising signs succeed in doing so, thus reducing drivers' engagement with the actual activity of operating the vehicle.

There are three main areas of distraction factors outside the vehicle that are examined in this synopsis. These are: the presence of static objects such as advertisements, traffic management information and others, watching persons and situations outside the vehicle, and the presence of sun glare or vehicle lights that might distract drivers.

In the context of road safety, outside factors increase the levels of distraction to the person driving, and driver distraction is a major risk factor in road safety. The extra amount of mental workload and cognitive functions that drivers have to undertake if a need arises reduces their reflexes and slows reaction times to events (both the time to mentally register the effect and the time to physically react to it).

In a few cases, as coded studies have shown as well, overcompensation effects from the driver are observed. Drivers are aware that they are not driving to the best of their abilities while distracted, and thus feel the need to balance the loss. However this is done to a higher degree than needed, and usually results in acceleration and speed and position variations within the traffic flow which are proven causes of road accidents.

It is worth noting that outside factors are only some aspects of driver distraction, both in general and for this particular synopsis. A driver can be under the influence of several other aspects, and therefore suffer under combined detrimental effects. Examples of distraction risk factors that can coincide with this one are consumption of goods (e.g. eating), conversation with passengers, cell phone use, music and others.

Which safety outcomes are affected by outside factors on road safety?

The reviewed studies focus on various outcomes. In some studies, the main focus is estimating the number of accidents, either absolutely or over time (accident frequency) that occur due to outside factors. In addition to collisions, other safety critical events are examined, such as the amount of near misses or recklessly crossing intersections. One study also investigates accident injury severity.

There are several studies that investigate the impact of outside factors on behavioural factors. The most critical of those factors is perception in various forms – pedestrian or object detection (such as signs or targets) and fixations in various directions. Other performance variables include speeding occurrences, time to change lanes and headway distance, braking performance, not signalling and number of times ignoring traffic lights.

Additionally, lateral positioning is investigated, mainly as instances drifting from the driving lane or time spent out of lane. Perception of added workload was also explored.

How are the effects of outside factors on road safety studied?

The literature has examined a variety of different approaches and ways to study the effect of outside factors on road safety. Sometimes, especially in studies for watching persons or situations outside the vehicle, these particular risk factors are examined alongside other similar distraction factors such as operating devices (IVIS, navigation etc.), or conversation with passengers, and not separately. Their examination or analysis may be adjusted to the models selected to capture the entire situation for the given case.

Given that it is unethical to conduct experiments on real circumstances (field experiments on the road) because it would compromise the safety of the participants, researchers have two main methods. They involve either examining databases of past accidents and analysing the effect of those risk factors on them (which sometimes leads to lack of data), or conducting simulation experiments, which are in a virtual environment where no hazard is present.

As for the analytic part, the binary approach is the most common method, which categorizes drivers as exposed or not exposed to a distraction risk factor outside the vehicle while driving.

1.5 OVERVIEW OF RESULTS

Judging by the studies taken into consideration, the collective effects of outside factors are detrimental and negative. There are no positive effects coded, though some papers mention them, but they are certainly not comparable to the volume of the negative ones, and various statistically non-significant results. When isolated effects are examined, outside factors did seem to increase safety risks by increasing accident occurrence probability and related injury severities, as well as decreasing driver performance.

Transferability

The coded studies are based on data from several countries, namely Australia, Greece, the Netherlands, New Zealand, Saudi Arabia, the United Kingdom and the USA. This is a very good sampling frame for general trends in developed countries, though there is always some room for representation of other countries.

Most studies concerned cars, which can be presumed to have been selected as the most common motor vehicles, whilst several other studies grouped all vehicles together for analysis. Simulation studies are conducted with devices resembling car interiors, therefore it can be said that there is room for representing different road users in the literature.

Notes on analysis methods

The methodology applied for capturing the impacts of outside factors varies considerably among studies in regards to mainly the mathematical models utilised, and secondly the outcomes evaluated as dependent variables.

What is more, the various aforementioned factors are sometimes not studied exclusively. This means that in some studies the presence or other distraction factors are studied alongside this particular risk factor (e.g. conversation with passenger). Consequently, study designs might not always be tailored towards isolating the effects of this risk factor.

There is some margin for investigating different road user categories and/or other geographical regions. All aforementioned factors make the findings for the previous outside factors generally transferable, though care against oversimplification is always required.

2. Scientific Overview

2.1 ANALYSIS OF METHODS AND PRESENTATION OF RESULTS

Analysis of study methods and designs

For the risk factor of factors outside the vehicle, and after appropriate use of various search tools and databases, twelve high quality studies were selected and coded. Several studies investigated accidents, either as numbers of accidents (McEvoy et al., 2007, Mitra, 2014, Mitra and Washington, 2012, Wang et al., 1996, Yannis et al., 2013) or crashes and near misses (Klauer et al., 2014). Furthermore, one study focussed on accident injury severity (Donmez and Liu, 2015).

Other studies focussed on analysing various behavioural factors to capture the effects of factors outside the vehicle, such as tailgating times and speeding occurrences (Bendak and Al-Saleh, 2010) or time to change lanes (Edquist et al., 2011). Headway and braking distance and braking reaction time were also investigated by Terry et al. (2008), while Young et al. (2009) examined time spent out of lane, lane excursions, times to contact and fixations. Finally, one study investigated lighting effects using speeding and detection distance measurements (Theeuwes et al., 2002).

In order to examine the relationship between the various outside factors (exposure) and outcome indicators, the studies would either deploy multivariate statistical analysis models (such as the ordered logit and the mixed effects logistic regression model), or utilized forms of analyses of variance (ANOVA) statistical models, or conducted non-model statistical analysis and compared differences or proportions. Sometimes other independent variables were present as well, with some models controlling for them and others studying them independently.

An overview of the main features of the coded studies for outside factors (sample, method, outcome and results) is illustrated in Table 1. Apart from their numbers, the studies are marked with [SO], [SVL] or [WP] to denote whether they originally belonged to the static object [SO] (advertisement and road signs), sunlight or vehicle light [SVL] or watching persons and situations [WP] coded study groups.

Table 1: Description of coded studies for risk factors outside the vehicle.

No.	Author(s); Year; Country;	Sampling frame for outside factor study	Method for impact investigation	Outcome indicator	Main Result
1 [SO]	Bendak, S., & Al-Saleh, K.; 2010; Saudi Arabia	12 volunteers participated in the driving simulation part of this study, while 160 drivers responded to a questionnaire.	Simple comparative statistics and cross-tabulations	Tailgating times; Overspeeding occurences; Drifting from lane; Not signalling; Recklessly crossing dangerous intersections [Absolute difference]	Drifting from lane and recklessly crossing intersections on a driving simulator are significantly affected by roadside advertising signs. Tailgating times, Overspeeding occurrences and Not signalling are not affected on a statistically significant level.
2	Edquist, J.,	This driving simulator	ANOVA -	Time to change	Billboards in the

No.	Author(s); Year; Country;	Sampling frame for outside factor study	Method for impact investigation	Outcome indicator	Main Result
[SO]	Horberry, T., Hosking, S., & Johnston, I.; 2011; Australia	experiment examines the effects of billboards on drivers, including older and inexperienced drivers. 48 drivers of three different age groups participated.	Correlation analysis	lanes [Correlation coefficient]	experiment distracted eye movements from the road ahead and delayed responses to road signs. They, like in-vehicle forms of distraction, should be considered as potentially harmful.
3 [SO]	Klauer, S. G., Guo, F., Simons-Morton, B. G., Ouimet, M. C., Lee, S. E., & Dingus, T. A.; 2014; U.S.A.	Two studies on the relationship between the performance of secondary tasks, and the risk of crashes and near-crashes were conducted. Instruments were installed in the vehicles of 42 newly licensed drivers and 109 adults with more driving experience	Mixed-effects logistic-regression analysis	Motor vehicle crash or Near crash [Odds ratio]	Among novice drivers only, looking at a roadside object, such as a vehicle in a previous crash, was associated with a significantly increased risk of a crash or near-crash.
4 [SO]	Terry, H. R., Charlton, S. G., & Perrone, J. A.; 2008; New Zealand	A sample of 78 participants were recruited to sense their ability to detect the deceleration of a preceding vehicle, once without distractions and once while a series of roadside signs were added to the simulation scenario.	Repeated measures MANOVA	Headway distance; Brake reaction time; Braking distance; Tau and optic expansion rate [Absolute difference]	A driver's detection of a looming vehicle is compromised in the presence of a sign-related distracting task.
5 [SO]	Yannis G., Papadimitriou E., Papantoniou P., Voulgari C.; 2011; Greece	Road accident data for the 'before' and 'after' periods on 9 test sites and control sites were extracted from the Hellenic Statistical database.	Function [$\theta i=(Xa/Xb)/(Ca/Cb)$]	Number of road accidents [Function]	The results showed that the placement of advertising signs showed no statistical significant difference in road accidents.
6 [SO]	Young, M. S., Mahfoud, J. M., Stanton, N. A., Salmon, P. M., Jenkins, D. P., & Walker, G. H.; 2009; United Kingdom	This simulator study involved 48 participants and quantified the effects of billboards on driver attention, mental workload and performance in Urban, Motorway and Rural environments.	Repeated measures ANOVA	Time spent out of lane; Number of lane excursions; Mean/Minimum time to contact; Number of fixations (left/middle/right), Subjective mental workload [Relative difference]	The results demonstrate that roadside advertising has clear adverse effects on lateral control and driver attention, in terms of mental workload.
7 [SVL]	Mitra, S.; 2014; U.S.A.	An empirical investigation was done to assess how sun glare affects intersection safety. It is performed by comparing and	Configural frequency analysis & ANOVA	Various Crashes (intersection-related) [Odds Ratio]	Examination of intersection crashes clearly demonstrates that sun glare (in general) affects intersection safety.

No.	Author(s); Year; Country;	Sampling frame for outside factor study	Method for impact investigation	Outcome indicator	Main Result
		contrasting crashes at 291 intersections that are possibly affected by sun-glare with those that are unaffected by glare.			
8 [SVL]	Mitra S., Washington S.; 2012; U.S.A.	This study examines the role of rarely-used variables in crash prediction. The model includes many spatial factors such as local influences of weather and sun glare. 291 signalized intersections in the city of Tucson, Arizona were considered.	Negative binomial model analysis	Number of accidents [Slope]	The results showed that sun glare on minor and major roads increases the number of accidents.
9 [SVL]	Theeuwes, J., Alferdinck, J. W., & Perel, M.; 2002; Netherlands	24 participants of the study drove at night in actual traffic along a track consisting of urban, rural, and highway stretches.	ANOVA - Relative difference analysis	Driving speed; Detection distance; Missed targets [Relative difference]	Low glare source caused a significant drop in detecting simulated pedestrians along the roadside and made participants drive significantly slower on dark and winding roads, and other effects. Road geometry also plays a role.
10 [WP]	Donmez B., Liu Z.; 2015; USA	The study aimed to predict injury severity sustained by drivers using data from the a specialised US database (2003 to 2008). The main focus was on the interaction of driver age and distraction type.	Ordered logit model	Injury severity - Categorical [Odds ratio]	Distraction from outside-the-vehicle sources led to increased injury severities for each of the age categories examined in the study, young, middle-aged and old drivers.
11 [WP]	McEvoy, S. P., Stevenson, M. R., & Woodward, M.; 2007; Australia	1367 drivers who attended hospital following a crash were interviewed. A questionnaire was administered to each driver and additional data were collected from ambulance and medical records.	Absolute proportion comparisons	Crash count [Absolute proportion frequency]	Judging by the percentages, outside-the-vehicle distractions while driving is one of the major factor on relevant crashes, being the third most common in the list.
12 [WP]	Wang, J. S., Knipling, R. R., & Goodman, M. J.; 1996; USA	The Crashworthiness Data System was employed to obtain more in-depth information on driver inattention related crash causes, including various distractions. This research paper reports the results of the 1995 CDS data collection on	Absolute proportion comparisons	Crash count [Absolute proportion frequency]	Judging by the percentages, outside-the-vehicle distractions are a minor factor on relevant crashes, being amongst the least important singular causes, towards the bottom of the list of the risk inducing factors.

No.	Author(s); Year; Country;	Sampling frame for outside factor study	Method for impact investigation	Outcome indicator	Main Result
		this issue.			

Limitations for outside factors

A few limitations can be arguably found in the current literature for the effects of the aforementioned outside factors on road safety. The first one lies in the nature of the design of the studies themselves. Studies used either past data, which along with their lack of detail, rely upon general limitations and underlying biases to reach a conclusion. Alternatively the researchers can use simulators. Simulations are known to either underrepresent real world conditions, making them less realistic environments which the drivers may not take entirely seriously, or sometimes cause dizziness or nausea on the participants, which are forms of added discomfort. Both of these aspects might skew data from relevant experiments.

Secondly, there might be times when some of those particular risk factors do not affect driving performance, for instance a driver being blinded by a vehicle lights while immobile at a red light, and then falsely reporting this to the authorities after an unrelated crash. Databases of past accidents might not be detailed enough to account for such cases, and again alter results in an undesired manner.

There is also a noticeable lack of studies that focus on the indirect effects of those particular risk factors. A common example of this is the case of a non-driver road user, such a pedestrian crossing the street while blinded by sun glare, and the impacts of this distraction in road safety.

Finally, as the human brain is extremely complex and, as of yet, highly uncharted scientifically, sometimes it might be hard to clearly identify when a driver is actually distracted by watching individuals or situations, instead of glancing at them and not registering them.

Conclusions for outside factors

The effects of outside factors while driving can be summarized as follows:

- 3 studies with a statistically significant increases on crash counts (or near misses as well)
- 1 study with a statistically non-significant relations on crash counts
- 2 studies with a descriptive result on crash counts
- 1 study with statistically significant increases (negative results for road safety) on accident injury severity
- 1 study with statistically significant increases (negative results for road safety) on drifting from lane and recklessly crossing dangerous intersection instances, as well as statistically non-significant effects for tailgating times, overspeeding occurrences and not signalling
- 1 study with statistically significant increases (negative results for road safety) on time to change lanes
- 1 study with statistically significant increases (negative results for road safety) braking reaction times, braking distances and tau and optic expansion rates, and with statistically non-significant effects for headway distance
- 1 study with statistically significant increases (negative results for road safety) in time spent out of lane, number of fixations and subjective mental workload
- 1 study with statistically significant increases (negative results for road safety) in detection distance and missed target numbers, and mixed results in speed changes

After the results were reviewed together, the following points were observed:

a) There is an adequate number of studies, however;
b) They are from different taxonomy topics/sections.
c) Those studies have not used the same model for analysis but largely different ones.
d) There are different indicators, and even when they coincide they are not measured in the same way.
e) The sampling frames were quite different (e.g. field testing or simulated driving).

2.2 DESCRIPTION OF ANALYSIS CARRIED OUT FOR OUTSIDE FACTORS

Review analysis for the effect of outside factors while driving

After considering the previous points it was decided that neither a meta-analysis nor a vote-count analysis could not be carried out in order to find the overall estimate of outside factors while driving. Therefore it was decided that a qualitative review-type analysis will be conducted for this synopsis. Crash counts are reported as elevated both by sun glare (Mitra, 2014, Mitra and Washington, 2012) and by advertising signs (Yannis et al., 2013, Klauer et al., 2014). In studies about watching outside persons and situations, however, these variables are reported through descriptive statistics, with no direct statistical analysis to determine whether outside factors is a variable significant enough to relate to accident causes. They appear to be elevated in one case and reduced in another (McEvoy et al., 2007, Wang et al., 1996).

The findings for injury severity are negative as well. A relevant study found increased accident injury severity across all three age groups participating, namely young, middle-aged and old drivers, when watching persons or situations outside the vehicle (Donmez and Liu, 2015).

When examining the aforementioned behavioural factors, advertising and road signs were found to have some detrimental effects. Studies reported increased drifting from lane instances, recklessly crossing dangerous intersections, time to change lanes or spent out of lane, braking distance and reaction time, fixations and other relevant variables (Bendak and Al-Saleh, 2010, Edquist et al., 2011, Terry et al., 2008, Young et al., 2009). Finally, Theeuwes et al. (2002) reported increased detection distance and more missed targets when the drivers are under the effect of glare from lights, and also claimed that the speeding variations they found are due to different road widths and not the effect of sun glare.

The quantitative results of the coded studies through their various effects are summarized in Table 2. The same notation of [SO], [SVL] and [WP] applies as before.

Overall estimate of outside factors for road safety

On a basis of both study and effect numbers, it can be argued that the risk factors that affect the driver from outside the vehicle have a likely detrimental effect on road safety. The coded studies have good levels of quality, and the common conclusion that can be drawn for those risk factors is that drivers suffer increased risks of several forms.

2.3 CONCLUSION FOR OUTSIDE FACTORS

The previous analysis that was carried out showed that outside factors have a mostly negative impact on road safety. In absolute numbers a lot of the effects of these risk factors are detrimental, although a considerable number of variables remain statistically non-significant (not sufficiently related) to sun glare or vehicle lights, watching persons or situations, and static objects.

There is little evidence to support the statement that overcompensation occurs with certain drivers, and in all likelihood the overall collective effects of this risk factor are not negated by this phenomenon. In conclusion, the overall impact of the aforementioned outside factors is characterised as yellow (probably risky).

Table 2: Quantitative results of coded studies and impacts on road safety for outside factors. Key ↑ increased risk; - not significant; ↓ decreased risk

No.	Author(s); Year; Country;	Outcome indicator	Quantitative estimate	Effect on road safety risk
1 [SO]	Bendak, S., & Al-Saleh, K.; 2010; Saudi Arabia	Tailgating times [Absolute difference]	Abs.dif.=0.250, p=0.140	-
		Overspeeding occurrences [Absolute difference]	Abs.dif.=0.250, p=0.190	-
		Drifting from lane [Absolute difference]	Abs.dif.=1.090, p=0.000	↑
		Not signalling [Absolute difference]	Abs.dif.=0.250, p=0.210	-
		Recklessly crossing dangerous intersections [Absolute difference]	Abs.dif.=0.580, p=0.000	↑
2 [SO]	Edquist, J., Horberry, T., Hosking, S., & Johnston, I.; 2011; Australia	Time to change lanes [Correlation coefficient]	Cor.coeff.=0.460, F-test=35.030, p=0.000	↑
3 [SO]	Klauer, S. G., Guo, F., Simons-Morton, B. G., Ouimet, M. C., Lee, S. E., & Dingus, T. A.; 2014; U.S.A.	Motor vehicle crash or Near crash [Odds ratio]	OR=3.900, CI [95%] = [1.720, 8.810]	↑
			OR=3.900, CI [95%] = [1.720, 8.810]	-
4 [SO]	Terry, H. R., Charlton, S. G., & Perrone, J. A.; 2008; New Zealand	Headway distance [Absolute difference]	Abs.dif.=n/a, p>0.050	-
		Brake reaction time [Absolute difference]	Abs.dif.=0.868, F-test(1,75)=11.39, p<0.001 (with outlying data) Abs.dif.=0.890, F-test(1,75)=9.31, p<0.001 (without outlying data)	↑
		Braking distance [Absolute difference]	Abs.dif.=0.832, F-test(1,75)=15.18, p<0.001	↑
		Tau and optic expansion rate [Absolute difference]	Abs.dif.=0.702, F-test(1,75)=31.87, p<0.001	↑
5 [SO]	Yannis G., Papadimitriou E., Papantoniou P., Voulgari C.; 2011; Greece	Crash count [Function]	Str#1: Function [θi=(Xa/Xb)/(Ca/Cb)] estimate=1.017	-
			Str#2: Function [θi=(Xa/Xb)/(Ca/Cb)]	-

No.	Author(s); Year; Country;	Outcome indicator	Quantitative estimate	Effect on road safety risk
			estimate=1.491	
			Str#3: Function [θi=(Xa/Xb)/(Ca/Cb)] estimate=1.165	-
			Str#4: Function [θi=(Xa/Xb)/(Ca/Cb)] estimate=0.988	-
			Overall: Function [θi=(Xa/Xb)/(Ca/Cb)] estimate=1.125	-
6 [SO]	Young, M. S., Mahfoud, J. M., Stanton, N. A., Salmon, P. M., Jenkins, D. P., & Walker, G. H.; 2009; United Kingdom	Time spent out of lane [Relative difference]	Rel.dif.: F-test(1, 47)=4.040, p=0.050	↑
		Number of lane excursions [Relative difference]	Rel.dif.: F-test(1, 47)=3.100, p<0.100	-
		Mean time to contact [Relative difference]	Rel.dif.: F-test(1, 47)=0.110, p=0.919	-
		Minimum time to contact [Relative difference]	Rel.dif.: F-test(1, 47)=9.888, p=0.325	-
		Number of fixations - left [Relative difference]	Rel.dif.: F-test(1, 19)=5.280, p<0.050	↑
		Number of fixations - middle [Relative difference]	Rel.dif.: F-test(1, 47)=6.050, p<0.050	↑
		Number of fixations - right [Relative difference]	Rel.dif.: F-test(1, 47)=6.330, p<0.050	↑
		Subjective mental workload [Relative difference]	Rel.dif.: F-test(1, 47)=4.840, p<0.050	↑
7 [SVL]	Mitra, S.; 2014; U.S.A.	Morning glare crashes (Direction: East) [Odds Ratio]	OR=1.100, CI [0.990, 1.200]	↑
		Evening glare crashes (Direction: West) [Odds Ratio]	OR=1.150, CI [1.080, 1.230]	↑
		Crashes not affected by glare (Direction: North) [Odds Ratio]	OR=0.930, CI [0.880, 0.990]	-
		Crashes not affected by glare (Direction: South) [Odds Ratio]	OR=0.940, CI [0.880, 0.990]	-
8 [SVL]	Mitra S., Washington S.; 2012; U.S.A.	Crash count [Slope]	β=2.202, t-test=7.842, p<0.0001 at 95% sig.lvl.	↑
9 [SVL]	Theeuwes, J., Alferdinck, J. W., & Perel, M.; 2002; Netherlands	Driving speed [Relative difference]	Rel.dif.: F-test(3, 63)=30.5, p<0.050	↑
		Detection distance [Relative difference]	Rel.dif.: F-test(3, 63)=9.4, p<0.010	↑
		Missed targets [Relative difference]	Rel.dif.: F-test(3, 63)=2.8, p<0.050	↑
10 [WP]	Donmez B., Liu Z.; 2015; USA	Injury severity - Categorical [Odds ratio]	Young: OR=0.840, p<0.0001, CI [95%] = [0.820, 0.860]	↑
			Middle-aged: OR=0.910, p<0.0001, CI [95%] = [0.900, 0.920]	↑
			Old: OR=0.710, p<0.0001, CI [95%] = [0.680, 0.750]	↑
11 [WP]	McEvoy, S. P., Stevenson, M.	Crash count [Absolute proportion frequency]	Outside person, object or event: Crash proportion:	-

No.	Author(s); Year; Country;	Outcome indicator	Quantitative estimate	Effect on road safety risk
	R., & Woodward, M.; 2007; Australia		0.095	
12 [WP]	Wang, J. S., Knipling, R. R., & Goodman, M. J.; 1996; USA	Crash count [Absolute proportion frequency]	Distracted by outside person, object or event: frequency=0.027	-

3. Supporting Document

In this chapter the literature searches that were carried out will be presented separately for the three different risk factors that were examined as outside vehicle distractions, sorted based on the final number of coded studies. They were handled separately until the writing of this synopsis, when it was decided that their merging would provide more comprehensive and coherent insights on their effects. The results are summarized in the relevant tables.

3.1 IDENTIFYING RELEVANT STUDIES FOR STATIC OBJECTS

Risk factor: static objects (advertising signs, traffic management information, etc.)

Database: Scopus **Date:** 28th of March 2016

search no.	search terms / operators / combined queries	hits
#1	(„advertis*" OR "sign" OR "object")	209,265
#2	(distract*)	4,197
#3	#1 AND #2	245

Limitations/ Exclusions:

- Published: 1990 to current
- Document Type: "Review" and "Article"
- Language: "English"
- Source Type: "Journal"
- Only Transport Journals were considered
- Subject Area: "Engineering"

Results Literature Search

Database	Hits
Scopus (remaining papers after several limitations/exclusions)	245
Total number of studies to screen title/ abstract	245

Screening

Total number of studies to screen title/ abstract	245
-De-duplication	0
-exclusion criteria A (not related to the topic/not relevant risk factor)	230
-exclusion criteria B (part of meta-analysis)	0
Remaining studies	15
Not clear (full-text is needed)	0
Studies to obtain full-texts	15

Eligibility

Total number of studies to screen full-text	15
Full-text could be obtained	15
Reference list examined Y/N	Yes (+7 papers)
Eligible papers prioritized	6

Prioritizing Coding

- Prioritizing Step A (accidents over other performance indicators)
- Prioritizing Step B (Journals over conferences and reports)
- Prioritizing Step C (journal quality)
- Prioritizing Step D (more recent studies)

No meta-analyses were found.

3.2 REFERENCES FOR STATIC OBJECTS

List of coded studies for static objects

1. BENDAK, S. & AL-SALEH, K. 2010. The role of roadside advertising signs in distracting drivers. *International Journal of Industrial Ergonomics,* 40**,** 233-236.
2. EDQUIST, J., HORBERRY, T., HOSKING, S. & JOHNSTON, I. 2011. Effects of advertising billboards during simulated driving. *Applied ergonomics,* 42**,** 619-626.
3. KLAUER, S. G., GUO, F., SIMONS-MORTON, B. G., OUIMET, M. C., LEE, S. E. & DINGUS, T. A. 2014. Distracted driving and risk of road crashes among novice and experienced drivers. *New England journal of medicine,* 370**,** 54-59.
4. TERRY, H. R., CHARLTON, S. G. & PERRONE, J. A. 2008. The role of looming and attention capture in drivers' braking responses. *Accident Analysis & Prevention,* 40**,** 1375-1382.
5. YANNIS, G., PAPADIMITRIOU, E., PAPANTONIOU, P. & VOULGARI, C. 2013. A statistical analysis of the impact of advertising signs on road safety. *International journal of injury control and safety promotion,* 20**,** 111-120.
6. YOUNG, M. S., MAHFOUD, J. M., STANTON, N. A., SALMON, P. M., JENKINS, D. P. & WALKER, G. H. 2009. Conflicts of interest: the implications of roadside advertising for driver attention. *Transportation research part F: traffic psychology and behaviour,* 12**,** 381-388.

List of studies remaining after step 3 'eligibility' for static objects

1. Yannis G., Papadimitriou E., Papantoniou P., Voulgari C. (2013) A statistical analysis of the impact of advertising signs on road safety, International Journal of Injury Control and Safety Promotion 20(2), 111-120, doi: 10.1080/17457300.2012.686042.
2. Belyusar D., Reimer B., Mehler B., Coughlin J.F. (2016). A field study on the effects of digital billboards on glance behaviour during highway driving. Accident Analysis and Prevention 88, 88–96. doi: http://dx.doi.org/10.1016/j.aap.2015.12.014.
3. Edquist J., Horberry T., Hosking S., Johnston I. (2011). Effects of advertising billboards during simulated driving. Applied Ergonomics 42, 619–626. doi:10.1016/j.apergo.2010.08.013.
4. Bendak S., Al-Saleh K. (2010). The role of roadside advertising signs in distracting drivers. International Journal of Industrial Ergonomics 40, 233–236. doi:10.1016/j.ergon.2009.12.001.
5. Klauer, S. G., Guo, F., Simons-Morton, B. G., Ouimet, M. C., Lee, S. E. & Dingus, T. A. 2014. Distracted driving and risk of road crashes among novice and experienced drivers. New England journal of medicine, 370, 54-59.

6. Divekar G., Pradhan A.K., Pollatsek A., Fisher D.L. (2013). Effect of external distractions behavior and vehicle control of novice and experienced drivers evaluated. Transportation Research Record 2321, 15-22. doi: 10.3141/2321-03.
7. Yea Z., Veneziano D., Lord D. (2011). Safety impact of Gateway Monuments. Accident Analysis and Prevention 43, 290–300. doi:10.1016/j.aap.2010.08.027.
8. Terry H.R, Charlton S.G., Perrone J.A. (2008). The role of looming and attention capture in drivers' braking responses. Accident Analysis and Prevention 40, 1375–1382. doi: 10.1016/j.aap.2008.02.009.
9. Young M.S., Mahfoud J.M., Stanton N.A., Salmon P.M., Jenkins D.P., Walker G.H. (2009). Conflicts of interest: The implications of roadside advertising for driver attention. Transportation Research Part F 12, 381–388. doi:10.1016/j.trf.2009.05.004.
10. Metz B., Hans-Peter Krüger H.-P. (2014). Do supplementary signs distract the driver? Transportation Research Part F 23 1–14. doi: http://dx.doi.org/10.1016/j.trf.2013.12.012.
11. Crundall D. Van Loon E., Underwood G. (2006). Attraction and distraction of attention with roadside advertisements. Accident Analysis and Prevention 38, 671–677.
12. Eyraud R., Zibetti E., Baccino T. (2015). Allocation of visual attention while driving with simulated augmented reality. Transportation Research Part F 32, 46–55. doi: http://dx.doi.org/10.1016/j.trf.2015.04.011.
13. Antonson H., Ahlströma C., Mårdha S., Blomqvista G., Wiklund M. (2014). Landscape heritage objects' effect on driving: A combined driving simulator and questionnaire study. Accident Analysis and Prevention 62, 168– 177. doi: http://dx.doi.org/10.1016/j.aap.2013.09.021.
14. Erke A., Sagberg F, Hagman R. (2007). Effects of route guidance variable message signs (VMS) on driver behaviour. Transportation Research Part F 10, 447–457. doi:10.1016/j.trf.2007.03.003.
15. Charlton S.G. (2006). Conspicuity, memorability, comprehension, and priming in road hazard warning signs. Accident Analysis and Prevention 38, 496–506. doi: 10.1016/j.aap.2005.11.007.

3.3 IDENTIFYING RELEVANT STUDIES FOR SUNLIGHT, OTHER VEHICLE'S LIGHTS

Risk factor: sun, other vehicles' lights

Database: Scopus **Date:** 28th of March 2016

search no.	search terms / operators / combined queries	hits
#1	(„sun" OR "light")	788,150
#2	(distraction)	3,435
#3	(„casualties" OR „fatalities" OR „traffic safety" OR „crash" OR „crash risk" OR „severity" OR „frequency" OR „collision" OR „incident" OR „accident")	22,319
#4	#1 AND #2	286

Limitations/ Exclusions:

- Published: 1990 to current
- Document Type: "Review" and "Article"
- Language: "English"
- Source Type: "Journal"
- Subject Area: "Engineering", "Psychology"

Results Literature Search

Database	Hits
Scopus (remaining papers after several limitations/exclusions)	286
Total number of studies to screen title/ abstract	286

Screening

Total number of studies to screen title/ abstract	286
-De-duplication	0
-exclusion criteria A (not related to the topic/not relevant risk factor)	285
-exclusion criteria B (part of meta-analysis)	0
Remaining studies	1
Not clear (full-text is needed)	0
Studies to obtain full-texts	1

Eligibility

Total number of studies to screen full-text	8
Full-text could be obtained	1
Reference list examined Y/N	Yes (+7 papers)
Eligible papers prioritized	4

Prioritizing Coding

- Prioritizing Step A (accidents over other performance indicators)
- Prioritizing Step B (Journals over conferences and reports)
- Prioritizing Step C (journal quality)
- Prioritizing Step D (more recent studies)

No meta-analyses were found.

3.4 REFERENCES FOR SUNLIGHT, OTHER VEHICLE'S LIGHTS

List of coded studies for sun, other vehicles' lights

1. MITRA, S. 2014. Sun glare and road safety: An empirical investigation of intersection crashes. Safety science, 70, 246-254.
2. MITRA, S. & WASHINGTON, S. 2012. On the significance of omitted variables in intersection crash modeling. Accident Analysis & Prevention, 49, 439-448.
3. THEEUWES, J., ALFERDINCK, J. W. & PEREL, M. 2002. Relation between glare and driving performance. Human Factors: The Journal of the Human Factors and Ergonomics Society, 44, 95-107.

List of studies remaining after step 3 'eligibility' for sun, other vehicles' lights

1. Sudeshna Mitra S. (2014). Sun glare and road safety: An empirical investigation of intersection crashes. Safety Science 70, 246–254. Doi: http://dx.doi.org/10.1016/j.ssci.2014.06.005.
2. Mitra S., Simon Washington S. (2012). On the significance of omitted variables in intersection crash modeling. Accident Analysis and Prevention 49, 439–448.

3. McIntyre S.E. (2008). Capturing attention to brake lamps. Accident Analysis and Prevention 40, 691–696. doi: doi:10.1016/j.aap.2007.09.020.
4. Theeuwes J. (2002). Relation Between Glare and Driving Performance. HUMAN FACTORS, 44(1), 95–107.
5. McGwin Jr G., Chapman V., Owsley C. (2000). Visual risk factors for driving difficulty among older drivers. Accident Analysis and Prevention 32, 735–744.
6. Zhang L., Colyar J., Pisano P., Holm P. (2005). Identifying and Assessing Key Weather-Related Parameters and Their Impacts on Traffic Operations Using Simulation. Transportation Research Board, 2005, Washington, DC.
7. Choi, E.H., Singh, S. Statistical Assessment of the Glare Issue-Human and Natural Elements. In: National Center for Statistics and Analysis. National Highway Traffic Safety Administration, Washington D.C. http://www.fcsm.gov/05papers/Choi_Singh_IVA.pdf.
8. Auffray B. (2007). Impact of adverse weather on traffic conditions on an American highway: Effect of the Sun Glare on Traffic Flow Quality. M.Sc Thesis.

3.5 IDENTIFYING RELEVANT STUDIES FOR WATCHING PERSONS-SITUATIONS

Risk factor: watching persons, situations

Database: Scopus **Date:** 28th of March 2016

search no.	search terms / operators / combined queries	Hits
#1	(„person" OR „situation" OR „people")	174,470
#2	(distract*)	4,197
#3	#1 AND #2	1,313

Limitations/ Exclusions:

- Published: 1990 to current
- Document Type: "Review" and "Article"
- Language: "English"
- Source Type: "Journal"
- Only Transport Journals were considered
- Subject Area: "Engineering"

Results Literature Search

Database	Hits
Scopus (remaining papers after several limitations/exclusions)	1,313
Total number of studies to screen title/ abstract	1,313

Screening

Total number of studies to screen title/ abstract	1,313
-De-duplication	0
-exclusion criteria A (not related to the topic/not relevant risk factor)	699
-exclusion criteria B (part of meta-analysis)	0
Remaining studies	614
Not clear (full-text is needed)	0
Studies to obtain full-texts	614

Eligibility

Total number of studies to screen full-text	614
Full-text could be obtained	64
Reference list examined Y/N	Yes (+2 papers)
Eligible papers	7
Eligible papers prioritized	3

Prioritizing Coding

During the previous steps 7 studies were detected that could be appropriate for the scope of this synopsis. However, since coding time was finite, there was a final selection process in order to determine the best studies for the analysis. The process was conducted via prioritizing, based on the following criteria:
- Prioritizing Step A (accidents over other performance indicators)
- Prioritizing Step B (Journals over conferences and reports)
- Prioritizing Step C (journal quality)
- Prioritizing Step D (more recent studies)
No meta-analyses were found.

3.6 REFERENCES FOR WATCHING PERSONS-SITUATIONS

List of coded studies for watching persons, situations

1. DONMEZ, B. & LIU, Z. 2015. Associations of distraction involvement and age with driver injury severities. *Journal of safety research,* 52**,** 23-28.
2. MCEVOY, S. P., STEVENSON, M. R. & WOODWARD, M. 2007. The prevalence of, and factors associated with, serious crashes involving a distracting activity. *Accident Analysis & Prevention,* 39**,** 475-482.
3. WANG, J.-S., KNIPLING, R. R. & GOODMAN, M. J. The role of driver inattention in crashes: New statistics from the 1995 Crashworthiness Data System. 40th annual proceedings of the Association for the Advancement of Automotive Medicine, 1996. 392.

List of studies remaining after step 3 'eligibility' for watching persons, situations

1. McEvoy S.P., Stevenson M.R., Woodward M. (2007). The prevalence of, and factors associated with, serious crashes involving a distracting activity. Accident Analysis and Prevention 39, 475–482. doi: 10.1016/j.aap.2006.09.005.
2. Wang J.-S., Knipling R.R., Goodman M.J. (1996). The role of driver inattention in crashes; new statistics from the 1995 crashworthiness data system. NHTSA report. http://www-nrd.nhtsa.dot.gov/departments/Human%20Factors/driver-distraction/PDF/oldWang.pdf.
3. Briggs G.F., Hole G.J., Land M.F. (2016). Imagery-inducing distraction leads to cognitive tunnelling and deteriorated driving performance. Transportation Research Part F 38, 106–117. doi: http://dx.doi.org/10.1016/j.trf.2016.01.007.
4. Kountouriotis G.K., Merat N. (2016). Leading to distraction: Driver distraction, lead car,and road environment. Accident Analysis and Prevention 89, 22–30. doi: http://dx.doi.org/10.1016/j.aap.2015.12.027.
5. Jones M.P., Chapman P., Bailey K. (2014). The influence of image valence on visual attention and perception of risk in drivers. Accident Analysis and Prevention 73, 296–304. doi: http://dx.doi.org/10.1016/j.aap.2014.09.019.

6. Terry H.R., Charlton S.G., Perrone J.A. (2008). The role of looming and attention capture in drivers' braking responses. Accident Analysis and Prevention 40, 1375–1382. doi:10.1016/j.aap.2008.02.009.
7. Donmez, B. & Liu, Z. 2015. Associations of distraction involvement and age with driver injury severities. *Journal of safety research*, 52**,** 23-28.

Fatigue – Not Enough Sleep/Driving While Tired

Experiencing sleepiness at the wheel due to sleep deprivation or other factors

1 Summary

Talbot, R. September 2016

1.1 COLOUR CODE: YELLOW

Although studies suggest that in general sleepiness/fatigue increases the risk of road traffic accidents, the wide range of methodologies used makes it difficult to compare results and findings are not always consistent across studies.

1.2 KEY WORDS

Fatigue, Sleep, Sleepiness, Not enough sleep, Sleep deprivation, daytime sleepiness, driving while tired, Epworth Sleepiness Scale, ESS

1.3 ABSTRACT

Fatigue is examined in terms of drivers who have not had enough sleep or more generally driving while feeling tired irrespective of how this was caused. Fatigue and road traffic accident risk is studied and measured in a variety of different ways in the scientific literature. This includes both directly observing fatigue symptoms and more commonly using self-report methodologies to capture information on sleep habits and sleepiness while driving. Both accidents and near miss events are focussed on and participants have been recruited directly following a road traffic accident or at a stop point during a journey. There appears to be relatively strong evidence for sleepiness at the wheel/not having enough sleep increasing the risk of professional drivers being involved in safety critical events. For car drivers, when participants report actually falling asleep at the wheel (or display drowsy behaviour), the risk of having a road traffic crash is substantially higher. However differences between sleepy and alert drivers are sometimes small or non-significant and the variation in methodologies make comparisons between studies problematic.

1.4 BACKGROUND

How are fatigue and Sleepiness defined?

Fatigue can be considered to refer to the tiredness experienced as a result of mental or physical effort (e.g. from driving for a long time) which could be overcome by ceasing the fatiguing activity. Whereas sleepiness can be considered as the physiological pressure to fall asleep (e.g. from poor sleep quality, reduced sleep duration or time of day effects) which can only be overcome by sleeping or physiologically influence such as with caffeine. Although the terms fatigue and sleepiness have differing meanings, they are often used interchangeably in the literature and the risk they pose to driving relate to the decrease in both mental and physical performance capacity that they cause.

Fatigue is examined here in terms of: (i)drivers who have not had enough sleep – 7-9 hours sleep is generally considered to be the amount of sleep required by the average adult – or (ii) more generally driving while feeling tired irrespective of how this was caused.

How is fatigue and sleepiness measured?

Fatigue is studied and measured in a variety of different ways in the scientific literature. Fatigue has been assessed through variables related to not enough sleep/sleep habits (sleep duration, quality of sleep, hours of wakefulness) and those that assess how sleepy a driver is while driving (subjective sleepiness, sleep events, observed sleepiness). Self-report methodologies are the primary tool for measuring fatigue either by direct questioning (e.g. how many hours did you sleep last night?), or employing an established tool. These can measure both state sleepiness (how sleepy you are at a particular point) and trait sleepiness (how sleepy you are in general). One of the most common tools for assessing trait sleepiness is the Epworth Sleepiness Scale (ESS) where participants are asked to rate the chance of them falling asleep in particular situations. Sleepiness at the wheel can be studied more objectively by observing physical sleepiness signs captured on video in naturalistic driving studies.

How many drivers suffer from fatigue/sleepiness?

It is very difficult to quantify how many drivers operate vehicles while feeling sleepy or how many road traffic accidents are linked to fatigue. Dingus et al (2016) identified that participants displayed signs of fatigue in 1.57% of 'normal' driving sampled. Self-report studies of driving while sleepy suggest that between 10-14% of participants had fallen asleep or had a micro sleep while driving which a much higher percentage (up to 60%) reporting that they sometimes drove while feeling tired (DaCoTA, 2012)

How is the relationship between fatigue/sleepiness and accidents studied?

There are a huge variety of different methodologies used to examine the relationship between fatigue and accidents. One way is to identify drivers who have been involved in a crash, either through attendance at a hospital or through a police registry and record information about their sleep habits and levels of sleepiness at the time of the crash. Another is to recruit drivers during a journey (e.g. at a police stop point), and question them about their sleep habits/levels of sleepiness and their experience of accidents or near miss events. Some studies apply a mixture of both these methodologies. A third is by observing drivers as they go about their everyday driving in naturalistic driving studies. Naturalistic driving studies involve observing real driving over a period of time through the instrumentation of vehicles, often that which the participant usually drives, and the installation of cameras which monitor driver behaviour. Statistical techniques are then employed to compare the proportion of the fatigued group that have experienced an accident with the corresponding proportion in the control group to generate an estimate of increased risk.

1.5 OVERVIEW OF RESULTS

A systematic literature review was undertaken to identify peer-reviewed journal papers that show a measurable relationship between fatigue/sleepiness and the risk of being involved in a road traffic accident. Studies using accident data were the primary focus and eight of the most recent studies have formed the basis of this synopsis.

The large range of methodologies used to examine the relationship between fatigue/sleepiness and accidents in the studies discussed here makes it difficult to form firm conclusions. There appears to be relatively strong evidence for sleepiness at the wheel/not having enough sleep increasing the risk of professional drivers being involved in safety critical events, although this might be by a relatively small amount (~1.7 times that of non-fatigued drivers) and it is not given that the risk of a safety critical event is the same as a crash risk. However for car drivers, when participants report actually falling asleep at the wheel (or display drowsy behaviour), the risk of having a road traffic crash appears to be substantially higher. Individual studies also indicate that fatigue is more associated with single as opposed to multiple vehicle accidents and hard shoulder verses main carriageway of the motorway accidents. In general having less sleep or driving while sleepy had an increased risk, but this is relatively small with different studies having different results.

Fatigue and sleepiness in relation to road traffic crashes has been relatively well researched over a long period of time. However the variety of methodologies employed can make comparisons between studies problematic. The studies included in this analysis were conducted in a number of European countries as well as the USA making it likely that the findings reported here could apply to a range of western countries. . It should be recognised that fatigue is a continuum, drivers may remain safe under some level of fatigue. However, a driver who is asleep at the wheel is without doubt at risk of crashing. There is currently insufficient research evidence to determine exactly what level of fatigue before the point that a person falls asleep, should be considered high risk.

2 Scientific Overview

2.1 INTRODUCTION

The definition of fatigue varies greatly in the literature with terms such as 'fatigue', 'sleepiness' and 'drowsiness' being used interchangeably. The dictionary definition of fatigue is 'extreme tiredness resulting from mental or physical exertion or illness'[1] whereas sleepiness can be defined as the neurobiological need for sleep (NHTSSA, 2001 cited in DaCoTA 2012). Sleepiness can be described as the drive for sleep whereas fatigue is a signal from the body that the current activity – either physical or psychological or just being awake – should end (DaCoTA 2012). Although sleepiness and fatigue have differing meanings, their effects are the same, namely a decrease in the capacity to perform psychological or physical tasks (DaCoTA 2012).

Fatigue is studied and measured in a variety of different ways in the scientific literature. The types of fatigue examined here can form two groups – fatigue variables related to sleep deprivation/sleep habits (sleep duration, quality of sleep, hours of wakefulness) and those that assess how sleepy a driver is while driving (subjective sleepiness, sleep events, observed sleepiness). Self-report methodologies are the primary tool for measuring fatigue either by direct questioning (e.g. how many hours did you sleep last night?), or employing an established tool. One of the most common tools for assessing trait sleepiness is the Epworth Sleepiness Scale (ESS) (Johns, 1991) where participants are asked to rate the chance of them falling asleep in particular situations. If a person's ESS score was 10-16, they would be classed as experiencing excessive daytime sleepiness and over 16 would be classed as dangerously sleepy. Another tool used in the studies mentioned here is the Basic Nordic Sleep Questionnaire (BNSQ) (Partinen and Gislason, 1995), which can be used to gather information on sleep habits and disorders though the use of a five point scale which indicates how often the sleep measure is experienced. Methods for assessing state sleepiness include a Visual Analog Scale (VAS) (e.g. Gould et al, 2001), which allows participants to rate their sleepiness level on, for example, a horizontal bar ranging from not sleepy to very sleepy. Naturalistic study designs allow for the direct observation of physical sleepiness signs through the use of video extracts associated, by vehicle instrumentation, with near miss or accident events.

2.2 METHODOLOGY

A systematic literature review was undertaken to identify peer-reviewed journal papers that show a measurable relationship between fatigue/sleepiness and the risk of being involved in a road traffic accident. Studies using accident data were the primary focus and eight of the most recent studies will be discussed here.

These studies use a variety of methodologies and focus on both professional and non-professional drivers. Included are a meta-analysis of 11 studies (Zhang et al, 2014), two naturalistic driving studies (Dingus et al, 2016; Chen et al, 2016) where cars and trucks respectively were fitted with monitoring instruments and cameras, four studies examining non-professional drivers who had been involved in a road traffic accident (Lucidi et al, 2013; Michalaki et al, 2015; Philip et al, 2014; Valent et al, 2010) and one study which employed interview techniques to collect data for car drivers travelling on a toll highway (Quera Salva et al, 2014). Table 1 gives an overview of the methodologies used in the eight studies discussed in this synopses.

[1] Oxford English Dictionary http://oxforddictionaries.com

Table 1: Overview of study methodologies – Fatigue/Sleepiness

Author(s), year, country	Study Methodology	Risk group/ Cases	Control group/ Controls	Effect measure
Zhang et al, 2014	Meta-analysis	Professional drivers with excessive daytime sleepiness (Epworth Sleepiness scale 11+)	Professional drivers without Excessive Daytime sleepiness	Odds Ratio
Dingus et al, 2016, USA	Naturalistic Driving, Case-control cohort. Random stratified sample of control driving windows	Car drivers who have had crash events: driving period directly before crash (20s)	Car drivers who have had crash events: Normal Driving periods the same duration as observed crash events	Odds Ratio
Chen et al, 2016, USA	Naturalistic Driving Observational, sample of 96 truck drivers driving 1397 shifts	Truck drivers where their driving shifts exhibited 'safety critical events'	Truck drivers where their driving shifts did not exhibit 'safety critical events'	Relative risk
Lucidi et al, 2013, Italy	Real world diurnal crash cases, Observational, case-controlled. Sample of 185 crashes	Car drivers involved in single vehicle crashes	Car drivers involved in multiple vehicle crashes	Odds Ratio
Michalaki et al, 2015, UK	Real world crash cases, Observational. Sample of 47,870 crashes	Drivers involved in injury/fatal crashes on the motorway where fatigue was recorded as a contributory factor	Drivers involved in injury/fatal crashes on the motorway where fatigue was not recorded as a contributory factor	Model correlation coefficient; Marginal effects
Philip et al, 2014, France	Real world crashes, observational, case-controlled, sample of 544 drivers	Car drivers admitted to hospital as a result of crash	Car drivers stopped at random police check points	Odds Ratio
Quera Salva et al, 2014, France	Interviews, Observational, Cross-sectional, sample of 3051 drivers	Car drivers who reported having near miss sleepy accidents	Car drivers who did not report having near miss sleepy accidents	Odds Ratio
Valent et al, 2010, Italy	Real world crashes, Observational, Case-crossover, matched pair, sample of 574 drivers involved in crashes	Drivers (all motorised vehicle types) who had a crash. Case window = 24h period leading up to crash	Drivers (all motorised vehicle types) who had a crash. Control window = period ~48-24h prior to crash – driving without crashing	Relative Risk

2.3 ANALYSIS AND RESULTS

Zhang et al's (2014) meta-analysis found that sleepiness, as measured by the Epworth Sleepiness Scale (score of at least 11), increases the risk of a safety related incident (road traffic accident, near miss or work place accident) among professional drivers (Odds ratio 1.72). Using very different methodologies, Chen et al (2016) examined the sleep patterns, measured by daily activity logs, of truck drivers and their association with safety critical events as identified by their instrumented trucks (verified via video extracts). A higher risk of having a critical event was associated with less sleep (6 hours) in the earlier stages of the non-work period (prior to driving shift) when compared to longer sleep durations (8-9 hours) during the middle or the majority of the non- work period (Relative risk 1.79 and 1.62 respectively).

Four studies focused upon non-professional car drivers, all using very different methodologies. Dingus et al (2016) analysed a database of road traffic accidents that were observed during a large scale naturalistic driving study. They compared video extracts of driver behaviour 20 seconds prior to crashes and a matched sample of other driving periods for the same driver that did not result in a crash. Fatigue was associated with an increased risk of road traffic crashes (odds ratio 3.4). Philip et al (2014) also used drivers who were known to have crashed (recruited at a hospital) and compared them to other drivers who had been travelling at the same time of day but had not crashed. A number of significant results were reported for fatigue variables that were assessed via self-report methods. Two relate to sleep habits (< 6 hours duration OR=1.69 /poor quality OR = 3.35) and the remaining two are associated with driving while sleepy (sleep episode prior to crash OR=9.97 /break during journey OR=4.04).

Quera Salva et al (2014) employed weaker methodologies by interviewing drivers stopped at a toll booth about their experience of near miss sleepy events (non-crashes), although established scales, namely the Basic Nordic Sleep Questionnaire (BNSQ) and a Visual Analog Scale(VAS) were used to assess their sleep habits and sleepiness respectively for their current journey. They found that a lack of restorative sleep (BNSQ; OR=1.9) and subjective sleepiness (VAS; OR 1.4) were associated with an increase in risk of having a near miss sleepy event during the current journey. Finally, Lucidi et al (2013) did not examine the fatigue related risk of being involved in a road traffic accident per se, rather they looked at the risk of being involved in a single vehicle verses a multiple vehicle accident as it is thought that single vehicle accidents are more likely to involve fatigue than multiple vehicle accidents. Poor sleep (< 6hours) and prolonged wakefulness (>18 hours) were associated with a greater risk of having a single vehicle accident (Odds ratios 12.28 and 46.2 respectively) as was daytime sleepiness (ESS > 10; OR = 12.5) and at least one of the 7 signs of sleepiness (OR = 7.16) used in the study (see footnote for table xx). A two hour change in sleep amount, nocturnal shift work and insomnia were not found to be significant.

The remaining two studies examined drivers of all motorised vehicles, without distinguishing between professional and non-professional drivers. Michalaki et al (2015) examined the relationship between fatigue and the severity of injury of motorway crashes that occurred on the main carriageway or hard shoulder of the motorway and were included in a road traffic accident database. They found that having a police recorded contributory factor of 'fatigue' increased the likelihood of having a serious or fatal crash on both the main carriageway and hard shoulder, with this effect being more pronounced on the hard shoulder, but the likelihood of having a slight (non-hospitalised) injury crash was decreased (see Table 2for marginal effects estimates). It should be noted however that it is difficult for police offices to identify fatigued drivers so numbers of crashes that have involved fatigue are often underreported (Radun et al, 2013). Valent et al (2010), similarly to Philip et al (2014) recruited drivers who had attended a hospital following a road traffic accident. They used case and control windows – the period prior to the accident and an equivalent period when the same driver was driving 24hours prior to the accident – to investigate the relationship between sleep habits/driving while sleepy and road traffic accidents. However unlike the other studies reported here, Valent et al failed to find any significant relationship between wakefulness, sleep duration and work hours with the exception of sleeping at least 11 hours. The later result reduced the likelihood of an accident (Relative risk = 0.44). These results may however have been influenced by the complexity of the study design.

Table 2 summarises the exposure (independent) variable, the outcome (dependent), variable, and the effect direction, measure and description for each of the eight studies.

Table 2: Summary of measures and results for studies examining fatigue/sleepiness

Author(s), Year, Country	Independent / Exposure variable	Dependant / outcome type	Effects on Road Safety		Main outcome - Description
Zhang and Chan, 2014	Excessive daytime sleepiness - scoring at least 11 on the Epworth Sleepiness scale	Incident (road traffic accident, near miss or work place accident)	↗	Odds ratio = 1.72 (CI 1.36-2.18)	Experiencing excessive daytime sleepiness leads to a significantly increased risk of having an incident (road traffic accident, near miss or work place accident) for professional drivers
Dingus et al 2016 USA	Observed fatigue (video analysis) from 20 seconds prior to crash or control window	Road traffic accident	↗	OR=3.4, CL=95%, CI=2.3-5.1) Baseline prevalence=1.57 %	Fatigue significantly increases the risk of car drivers having a road traffic accident
Chen et al, 2016, USA	Cluster 1: short duration (approx. 6 hour), moderate sleep % (50%); later in non-work period (cf cluster 2)	Safety Critical Events	—	RR=1.25, CL=95%, CI=0.9-1.73	Non-significant effect for cluster 1 truck drivers when compared to cluster 4: long sleep duration (8-9 hours); high sleep percentage (90%) (almost entire non work period)
	Cluster 2: short duration (approx. 6 hour), moderate sleep % (50% of non-work period); earlier in non-work period (cf cluster 1)	Safety Critical Events	↗	RR=1.62, CL=95%, CI=1.01-2.59	Cluster 2 truck drivers had an increased risk of having a safety critical event when compared to Cluster 4: long sleep duration (8-9 hours); high sleep percentage (90%) (almost entire non work period)
	Cluster 3: Long sleep duration (8-9 hours); high sleep percentage (70% of non-work period) (middle non work period)	Safety Critical Events	—	RR=0.91, CL=95%, CI=0.7-1.18	Non-significant effect for cluster 3 truck drivers when compared to cluster 4: long sleep duration (8-9 hours); high sleep percentage (90%) (almost entire non work period)
	Cluster 1: short duration (approx. 6 hour), moderate sleep % (50% of non-work period); later in non-work period (cf cluster 2)	Safety Critical Events	—	RR=1.38, CL=95%, CI=0.99-1.9	Non-significant effect for cluster 1 truck drivers compared to cluster 3: long sleep duration (8-9 hours); high sleep percentage (70% of non-work period) (middle non work period)
	Cluster 2: short duration (approx. 6 hour), moderate sleep % (50% of non-work period); earlier in non-work period (cf cluster 1)	Safety Critical Events	↗	RR=1.79, CL=95%, CI=1.12-2.84	Cluster 2 truck drivers had a significant increased risk of having a safety critical event when compared to cluster 3: long sleep duration (8-9 hours); high sleep percentage (70% of non-work period) (middle non work period)

	Cluster 1: short duration (approx. 6 hour), moderate sleep % (50% of non-work period); later in non-work period (cf cluster 2)	Safety Critical Events	—	RR=0.77, CL=95%, CI=0.47-1.27	Non-significant effect for cluster 1 truck drivers when compared to cluster 2: short duration (approx. 6 hour), moderate sleep % (50% of non-work period); later in non-work period (cf cluster 2)
Lucidi et al, 2013, Italy	Poor sleep (<6h)	Single vehicle (case) or multiple vehicle (control) accident	↗	OR=12.28, CL=95%, CI=1.96-76.79	Drivers with poor sleep were significantly more likely to be involved in a single vehicle rather than a multiple vehicle accident
	Change in sleep amount before crash (>2 hours)	Single vehicle (case) or multiple vehicle (control) accident	—	OR=4.89, CL=95%, CI=0.78-30.59	Non-significant effect
	Prolonged wakefulness (>18h)	Single vehicle (case) or multiple vehicle (control) accident	↗	OR=46.2, CL=95%, CI=5.19-412.4	Drivers with prolonged wakefulness were significantly more likely to be involved in a single vehicle rather than a multiple vehicle accident
	Self-reported daytime sleepiness (ESS score > 10)	Single vehicle (case) or multiple vehicle (control) accident	↗	OR=12.5, CL=95%, CI=1.98-78.6	Drivers self-reported daytime sleepiness were significantly more likely to be involved in a single vehicle rather than a multiple vehicle accident
	Nocturnal shift work	Single vehicle (case) or multiple vehicle (control) accident	—	OR=1.89, CL=95%, CI=0.28-1.92	Non-significant effect
	Insomnia	Single vehicle (case) or multiple vehicle (control) accident	—	OR=5.44, CL=95%, CI=0.87-34.14	Non-significant effect
	At least one of the 7 signs of sleepiness*	Single vehicle (case) or multiple vehicle (control) crash	↗	OR=7.16, CL=95%, CI=	Drivers with at least 1 of the 7 signs of sleepiness* were significantly more likely to be involved in a single vehicle rather than a multiple vehicle accident
Michalaki et al, 2015, UK	Fatigue as contributing factor (opinion of police)	Accident severity (slight cf serious & fatal; slight and serious cf fatal)	↗	Correlation coefficient = 0.3891 (main carriageway); 0.7928 (Hard shoulder) CI=90%	Having fatigue as a contributing factor to an accident is associated with a more severe crash on both the main carriageway and hard shoulder
		Fatal accident	↗	Marginal effects = 0.0054 (main carriageway); 0.0522 (Hard shoulder)	If fatigue is present then the likelihood of having a fatal crash is 0.54% higher on the main carriageway and 5.2% higher on the hard shoulder
		Serious accident	↗	Marginal effects = 0.0355 (main	If fatigue is present then the likelihood of having serious crash is

				carriageway); 0.1204 (Hard shoulder)	3.55% higher on the main carriageway and 12% higher on the hard shoulder
		Slight accident	↘	Marginal effects = -0.0409 (main carriageway); -0.1726 (Hard shoulder)	If fatigue is present then the likelihood of having a slight crash is 4% lower on the main carriageway and 17.26% higher on the hard shoulder
Philip et al, 2014, France	Sleep episode (immediately prior to accident/during journey) Nb small sample compared to other effects in study	Road traffic accident	↗	OR=9.97, CL=95%, CI=1.57-63.5	Drivers who have a sleep episode significantly increase the risk of a road traffic accident
	Sleep duration <6 hours (in previous 3 months)	Road traffic accident	↗	OR=1.69, CL=95%, CI=1.00-2.85	Having a sleep duration of <6 hours over the previous 3 months significantly increases the risk of a road traffic accident
	Quality of sleep - neither good nor bad	Road traffic accident	—	OR=1.69, CL=95%, CI=0.99-4.322	Non-significant effect when compared to reference of very/pretty good sleep
	Quality of sleep - pretty/very bad	Road traffic accident	↗	OR=3.35, CL=95%, CI=1.00-2.85	Drivers who have pretty/very bad quality of sleep have a significantly increased accident risk when compared to reference of very/pretty good sleep
	Break during journey	Road traffic accident	↗	OR=4.04, CL=95%, CI=2.00-8.18	Drivers who do not take a break during their journey have a significantly increased risk of a road traffic accident
Quera Salva et al, 2014, France	Restorative sleep (less than 3 nights per week in last 3 months)	Near miss sleepy event in current journey	↗	Odds ratio = 1.9, CL=95%, CI=1.00-3.60	Drivers who had had a lack of restorative sleep in previous 3 months were significantly more likely to have had a near miss sleep related event in their current journey.
	Subjective sleepiness (mean) (current journey)	Near miss sleepy event in current journey	↗	Odds ratio = 1.4, CL=95%, CI=1.2-1.6	Subjective sleepiness (current journey) was significantly associated with experiencing a near miss sleepy event in the same journey
	Near miss sleepy event in past year	Near miss sleepy event in current journey	↗	Odds ratio = 3.4, CL=95%, CI=1.7-6.4	Drivers who had experienced a near miss sleepy event in the previous year were significantly more likely to have experienced a near miss sleepy event in the current journey.
Valent et al, 2010, Italy	Sleep duration of ≥ 11h	Crash in case window; no crash in control window	↘	RR=0.44, CL=95%, CI=0.22-9.0	Significant decrease in risk of having a crash

	Wakefulness, work hours, sleep <11 hours (various)	Crash in case window; no crash in control window	—	Not significant

Key: ↗ = increase in accident risk; — = none significant result; ↘ decrease in accident risk

*Poor sleep (<6h); Prolonged wakefulness (>18h); Change in sleep amount before crash (>2 hours); Self-reported acute sleepiness (Karolinska Sleepiness Scale score > 6); Self-reported daytime sleepiness (Epworth Daytime Sleepiness score > 10); Nocturnal shift work and Insomnia.

2.4 CONCLUSIONS

The large range of methodologies used in the studies discussed here makes it difficult to form firm conclusions. There appears to be relatively strong evidence (Zhang et al, 2014; Chen et al, 2016) for sleepiness at the wheel/being sleep deprived increasing the risk of professional drivers being involved in safety critical events, although this might be by a relatively small amount (~1.7 times that of non-fatigued drivers) and it is not given that the risk of a safety critical event is the same as a crash risk. However for car drivers, when participants report actually falling asleep at the wheel (or display drowsy behaviour), the risk of having a road traffic crash appears to be substantially higher (Dingus et al 2016; Quera Salva et al 2014 – although the latter has a small sample size for sleep episode). Studies also indicate that fatigue is more associated with single as opposed to multiple vehicle accidents (Lucidi et al, 2013) and hard shoulder verses main carriageway of the motorway accidents (Michalaki et al, 2015). In general having less sleep or driving while sleepy had an increased risk but this is relatively small and for some measures non-significant.

Drivers who are actually asleep at the wheel clearly have an increased risk of crash however it is unclear at what point of sleepiness, without actually falling asleep, the risk of having a crash becomes significantly higher (than alert drivers). Measuring actual levels of fatigue is a challenge as the most accurate forms of measurement e.g. recording brain activity (EEG) are too intrusive or not possible to implement in a study design. It therefore is necessary to rely on self-report or the ability of the police to identify. This will inevitably introduce bias into the study design.

3 Supporting Documents

3.1 DESCRIPTION OF STUDIES

The following paragraphs give a more detailed overview of each paper included here with a summary of the relevant findings.

Zhang et al (2014) conducted a meta-analysis on studies that examined the risk of crashes that relate to sleepiness for professional drivers. A systematic literature review was undertaken to identify studies. Studies had to report findings for professional drivers (excluding non-professional) using one of the following measurements for sleepiness: sleep disorders, excessive daytime sleepiness, insomnia, sleepiness at wheel, sleep quality and quantity, work factors and snoring. Accident types, including near misses, accident severity and professional driver type definitions varied from paper to paper. A random effects meta-analysis was conducted on 11 studies. Tests for heterogeneity and publication bias were conducted and an adjustment made for publication bias. Excessive daytime sleepiness was found to significantly increase the risk of having a driving incident (accident or near miss) for professional drivers (Odds ratio = 1.72, 95% CI: 1.36-2.18).

In Dingus et. al 2016:Crash events were gathered and analysed in detail through video observations and measurements of 3,542 drivers recruited for the Second Strategic Highway Research Program Naturalistic Driving Study (SHRP 2 NDS) in the United States. Naturalistic driving (ND) data collected with multiple on-board video cameras and sensors is used to evaluate risk factors during the seconds leading up to a crash. The ND dataset comprised 905 injurious and property damage crash events, the magnitude of which allows a direct analysis of causal factors using crashes only. This approach assesses time-variant risk factors for crashes and controls by contrasting exposure information derived from short time windows—typically those that are seconds long—to maintain relative homogeneous exposure within the window. The controls are short, free of safety-critical events, and comprise normal driving episodes, thus representing the exposure of risk factors during normal driving conditions. The exposure for crashes (i.e., cases) was extracted from short time windows (6 s for distraction and 20 s for error or impairment) of video surrounding the onset of crashes. To estimate the exposure under the normal, non-crash driving condition, a two-staged stratified random sampling method was used to select 19,732 control driving segments greater than 5 mph. The control driving episode was the same length as the crash exposure reduced to ensure the consistency of exposure information. The first stage determined the number of baselines for each driver proportional to driving time. The second stage involved total random sampling within a driver. The results show that crash causation has shifted dramatically in recent years, with driver-related factors (i.e., error, impairment, fatigue, and distraction) present in almost 90% of crashes. Fatigue was found to significantly increase the risk of crashing (OR=3.4, 95% CI=2.3-5.1) and the baseline prevalence of fatigue was 1.57%.

Chen et al (2016) examined the sleep patterns of commercial truck drivers and the impacts of these on their driving performance and risk. Data was sourced from the Naturalistic Truck Driving study that recorded 735,000 miles of truck driving by 96 commercial truck drivers (75 long haul and 21 line-haul). K mean Cluster analysis was used to identify 4 groups of drivers according to their sleep patterns during the non-work period of a workday shift (non-work period followed by work period). Negative binomial regression was used to model the association between Safety Critical Events (SCE) and sleep patterns adjusted for driver demographics. Less sleep in the earlier stages of the non-work period (cluster 2) was found to have a higher SCE risk than longer duration sleep that lasted for the majority of the non-work period (clusters 3 and 4). Results also showed that shifts with more sleep time between1 a.m. and 5 a.m. (Cluster 1, 3, 4) were involved with a lower driving risk and better driving performance than shifts with less sleep time between 1 a.m. and 5 a.m. (Cluster 2).

Lucidi et al (2013) aimed to estimate the presence and number of sleep related risk factors in day time accidents and whether there were more likely to occur in single verses multiple vehicle crashes. The study also examined the relationship between these risk factors and young drivers and crashes occurring on non-urban roads (not reported here). 185 crashes were included in the study that were part of an on-the-scene crash investigation study. The inclusion criteria were crashes that occurred in the Marche region of Italy between 7am and 10pm that were reported to the regional Rescue Service and an ambulance was requested to attend. 68.6% of the crashes involved two vehicles; 22% were single vehicle crashes; and the remainder involved three or more vehicles. These crashes involved 253 drivers with 30 involved in single vehicle crashes and 223 involved in multiple vehicle crashes. They were interviewed at the crash scene (~53%), at a hospital (21.7%) or at home (19.7%). Driver's ages ranged between 18 and 95 years old and 66.1% were male. Drivers had held their licence for on average 21 years (Standard deviation = 14.69). Study participants took part in a 20 min structured interview aiming to collect information on sleep habits, level of sleepiness before the collision and daytime sleepiness (Italian version Epworth Sleepiness Scale). Drivers were assessed for the following 7 risk factors: Poor sleep (<6h); Prolonged wakefulness (>18h); Change in sleep amount before crash (>2 hours); Self-reported acute sleepiness (Karolinska Sleepiness Scale score > 6); Self-reported daytime sleepiness (Epworth Daytime Sleepiness score > 10); Nocturnal shift work and Insomnia. The odds of being involved in a single verses multiple vehicle crash were significant ($p<0.05$) for Poor sleep (12.28, 95%CI: 1.96–76.79); Prolonged wakefulness (46.2, 95%CI: 5.19–412.4), Self-reported daytime sleepiness (12.5, 95%CI: 1.98–78.6) and having at least 1 of the 7 risk factors (7.16, 95%CI: 3.0–17.06).

Michalaki et al (2015) examines the factors that affect the severity of crashes that occur on the hard shoulder (emergency lane) and main carriageway of motorways in Great Britain. An accident database (STATS19) was analysed containing all road traffic accidents involving a fatality or other severity of injury that were reported to the police. All motorway crashes were identified and a distinction was made between collisions that occurred on the hard shoulder and those that occurred on the main carriageway. The database includes ‘contributory factors’ which are aspects associated with the crash which the police have judged as having contributed to their occurrence. Fatigue is included as a contributory factor. The partially constrained generalised ordered logit model was used to estimate the marginal effects of fatigue. The output (dependent variable) was the severity of the crash: fatal (died within 30 days of accident), serious (admitted as in-patient to a hospital) and slight (all other forms of injury). This was included in the model at the accident level, meaning that if multiple injuries occurred in the accident, the maximum severity was assigned to the accident as a whole. The following marginal effects for the ‘contributory factor’ fatigue were reported: Slight injury on main carriageway (−0.0409) and hard shoulder (-0.1726); Serious injury on main carriageway (0.0355) and hard shoulder (0.1204); fatal injury on main carriageway (0.0054) and hard shoulder (0.0522). This shows that if fatigue is present, the likelihood of having a slight accident is lower and the likelihood of having a serious or fatal crash is higher when compared with accidents without fatigue as a contributory factor. This effect is more pronounced for the hard shoulder than the main carriageway.

Philip et al (2014) aimed to examine sleep related factors that are associated with road traffic accidents. 272 drivers who attended an emergency unit following a road traffic accident were interviewed within 24 hours of the accident occurring. 272 controls were recruited during routine random police checks and were matched by time of day. Chi Squared and t-tests were used to find significant differences ($p<.05$) between cases and controls and then multivariate logistic regression analyses were performed for all significant variables. Odds ratios adjusted for age group, gender, km driven per year, years of having licence, type of road and medication in previous 24 hours were reported for all significant associations with the reference value (factor thought to be at lowest risk of accidents). The factor with the most increased risk was found to be having a sleep episode at the wheel just before the accident (OR 9.97, CI 95%: 1.57–63.50, p,0.05). Significant negative effects were also found for 'Sleeping 6 hours or fewer in the last three months'; having pretty/very bad quality of sleep in the last three months, not taking a break during the journey, the age group 18-30, experiencing anxiety or nervousness on the previous day and taking 2 or more medications in the previous 24 hours.

Quera Salva et al (2014) examined sleepiness and sleep hygiene in relation to driving risk among highway drivers. 3051 participants were recruited at a toll booth in France on high volume travel days in July 2011 between 8am-8pm. Participants took part in a structured interview to complete a questionnaire asking about sleep variables and their experience of Near Miss Sleepy Accidents (NMSA) during their current journey and previous 3 months. Both univariate and multivariate logistic regression analyses were carried out with Sex, age, BMI and all significant variables (NMSA in past year; sleepiness related driving accident in last year; Restorative sleep, Snoring, Apneas, Nocturnal awakenings, from 'Basic Nordic Sleep Questionnaire', and 'Epworth Sleepiness Scale for last 3 months') from the univariate analyses being included in the logistic regression model. NMSA in past year, subjective sleepiness for current journey, Restorative sleep and Snoring were found to have a statistically significant negative impact on road safety in the multivariate analysis.

Valent et al (2010) conducted a study to examine the relationship between sleepiness, prolonged wakefulness and extended work hours on accident risk. Participants were recruited at the Emergency Room of a hospital in North-Eastern Italy who were attending for treatment of injuries following a road traffic crash. Participants took part in a semi-structured interview usually while still at the hospital and were asked about sleep and work patterns (for the 48hours prior to crash) and any modifications in the previous month. Analyses used a matched pair interval approach where events/exposure in a case window was compared with events/exposure in a control window. Two approaches were used: fixed and variable window. The fixed widow approach took the case window as the 24 hours prior to the crash was compared to the 24h prior to the time of the crash for the day before (control window). Participants were only included in this if they were driving the day before at the same time as the crash. The variable window approach took the case window as the 16h prior to the crash and the control window as the 16h prior to the most recent episode of driving from 16-32h before the crash. The fixed window was used to assess the effect of sleep deprivation, wakefulness duration and extended work hours. The variable window was used to assess only the effect of wakefulness duration. No significant relationship was found between the number of hours slept and crash risk other than sleep duration ≥ 11h. The latter was found to decrease the risk of a crash (Relative risk: 0.44 95% CI: 0.22-0.90). No significant relationship was found between the number of hours worked but the direction and magnitude of the relative risk suggest that working >12 hours could increase the risk of crash. No significant relationship was found between the number of hours awake and crash risk. Effect measures are only reported here for sleep duration ≥11 hours. All other results were none significant.

3.2 LITERATURE SEARCH

A systematic literature search was undertaken to identify papers that examined the risk of being involved in a road traffic accident when the driver is fatigued. This section describes the search terms, screening and eligibility selection processes that were used to identify relevant papers.

The following criteria were applied to a key word search in the database Scopus. See Table 3 for full results.:

- Search field: TITLE-ABS-KEY

- published: year > 1990
- Document Type: "Review" and "Article"
- Source Type "Journal"
- Language: "English"

Table 3: Scopus search terms and results

Database: Scopus **Date:** 3 May 2016

search no.	search terms / operators / combined queries	hits
#1	"fatigue*" OR "sleep*" OR "tired*" OR "drowsy" OR "drowsiness" OR "alert*" OR "monoton*" OR "time on task" OR "mental* fatigue*" OR "mental* tired*"	393,733
#2	"Sleep disorde*" OR "Narcolepsy" OR "Apneoa" OR "'Apnea" OR "Sleep disordered breathing" OR "OSA"	72,103
#3	"road safety" OR "traffic safety" OR "driv*" OR "road" OR "transport" OR "traffic" OR "Pedestrian" OR "Rider"	1,586,152
#4	"collision*" OR "crash*" OR "accident*" OR "incident*" OR "Road casualt*" OR "Road fatalit*" OR "injur*"	1,164,341
#5	"risk*" OR "severit*" OR "frequenc*"	3,472,721
#6	#1 OR #2	405,751
#7	#6 AND #3 AND #4 AND #5	1,682

Due to the large number of search results, the search was limited to papers originating in the following countries: Europe, Israel, North America, Australia, New Zealand and Japan and publication period: 1 Jan 2006- 3 May 2016. This reduced the number of papers to be screened to 997.

Screening

A two stage screening process then took place. Table 4 shows the first stage where titles and if necessary abstracts were quickly assessed to eliminate papers that were not relevant (to the focus on crash studies and measured effects) and Table 5 shows the results of a more detailed title and abstract screening of the Not enough sleep/Driving while tired papers to identify particular road user groups and papers that were not relent or could not be coded in the SafetyCube template (next step of methodology see D4.1 main text). This second stage was also used to identify meta-analysis papers.

Table 4: 1st Title and abstract screening for relevance

Total number of studies to screen title/ abstract – 1st screening	**997**
-De-duplication	5
-Exclusion: not relevant (not addressing risk of fatigue in relation to road safety)	832
Remaining studies	
Sleep Disorders	51

Not enough sleep/Driving while tired	96
Other fatigue papers	12
Total	159

Table 5: 2nd Title and abstract screening for relevance

Not enough sleep/Driving while tired – title / abstract - 2nd Screening	96
Exclusion: included in meta-analysis	3
Exclusion: not relevant (not addressing risk of fatigue in relation to road safety)	35
-exclusion:- not possible to code in template (review/commentary/no figures/no control group)	7
Remaining studies	51
General population	26
Professional drivers	8
Vulnerable road user	2
Young/teen drivers	5
Novis drivers	1
New parents	2
Shift workers/specific worker groups	7
Studies to obtain full-texts: General population and professional drivers	34

Eligibility

The final stage was to identify the papers for which a full text could be obtained based on paper availability. Simulator studies were excluded at this point as the focus was on studies examining real world crashes (see Table 6).

Table 6: Eligible papers

Total number of studies to screen full-text	34
Full-text could be obtained	30
Reference list examined: N	-
Exclusion: Simulator studies	6
Eligible papers	24

Prioritisation

Once the full papers had been obtained they were assessed as to their suitability to be included in this synopsis based on the following prioritisation criteria:

- Prioritizing Step A: Meta-analysis;
- Prioritizing Step B: Studies examining crash risk for truck drivers published after the meta analysis literature search date;
- Prioritizing Step C: Studies examining crash risk for general driving population;
- simulator studies = excluded.

For each prioritisation step, papers from Europe were coded before papers from USA, Japan, Australia, with the most recent papers being coded first. The full list of 24 papers and the reason why they were coded or not are shown in Table 7.

Table 7: Coding decisions

No.	Publication	Coded Y/N	Reason
1.	Zhang, T., & Chan, A. H. S. (2014). Sleepiness and the risk of road accidents for professional drivers: A systematic review and meta-analysis of retrospective studies. Safety Science, 70, 180–188. http://doi.org/10.1016/j.ssci.2014.05.022	Y	Priority step A
2.	Chen, G. X., Fang, Y., Guo, F., & Hanowski, R. J. (2016). The influence of daily sleep patterns of commercial truck drivers on driving performance. Accident Analysis & Prevention, 91, 55–63. http://doi.org/10.1016/j.aap.2016.02.027	Y	Priority step B
3.	Dingus, T. A., Guo, F., Lee, S., Antin, J. F., Perez, M., Buchanan-King, M., & Hankey, J. (2016). Driver crash risk factors and prevalence evaluation using naturalistic driving data. Proceedings of the National Academy of Sciences, 113(10), 201513271. http://doi.org/10.1073/pnas.1513271113	Y	Priority step C
4.	Michalaki, P., Quddus, M. A., Pitfield, D., & Huetson, A. (2015). Exploring the factors affecting motorway accident severity in England using the generalised ordered logistic regression model. Journal of Safety Research, 55, 89–97. http://doi.org/10.1016/j.jsr.2015.09.004	Y	Priority step C
5.	Gonçalves, M., Amici, R., Lucas, R., Åkerstedt, T., Cirignotta, F., Horne, J., … Grote, L. (2015). Sleepiness at the wheel across Europe: a survey of 19 countries. Journal of Sleep Research, 24(3), 242–53. http://doi.org/10.1111/jsr.12267	N	No information on crash risk
6.	Gonçalves, M., Peralta, A. R., Monteiro Ferreira, J., & Guilleminault, C. (2015). Sleepiness and Motor Vehicle Crashes in a Representative Sample of Portuguese Drivers: The Importance of Epidemiological Representative Surveys. Traffic Injury Prevention, 16(7), 677–83. http://doi.org/10.1080/15389588.2015.1013535	N	Prevalence figures only
7.	Chen, G. X., Sieber, W. K., Lincoln, J. E., Birdsey, J., Hitchcock, E. M., Nakata, A., … Sweeney, M. H. (2015). NIOSH national survey of long-haul truck drivers: Injury and safety. Accident; Analysis and Prevention, 85, 66–72. http://doi.org/10.1016/j.aap.2015.09.001	N	Not related to fatigue

8.	Philip, P., Chaufton, C., Orriols, L., Lagarde, E., Amoros, E., Laumon, B., … Sagaspe, P. (2014). Complaints of Poor Sleep and Risk of Traffic Accidents: A Population-Based Case-Control Study. PloS One, 9(12), e114102.	Y	Priority step C
9.	Quera Salva, M. A., Barbot, F., Hartley, S., Sauvagnac, R., Vaugier, I., Lofaso, F., & Philip, P. (2014). Sleep disorders, sleepiness, and near-miss accidents among long-distance highway drivers in the summertime. Sleep Medicine, 15(1), 23–6. http://doi.org/10.1016/j.sleep.2013.06.018	Y	Priority step C
10.	Lucidi, F., Mallia, L., Violani, C., Giustiniani, G., & Persia, L. (2013). The contributions of sleep-related risk factors to diurnal car accidents. Accident; Analysis and Prevention, 51, 135–40. http://doi.org/10.1016/j.aap.2012.11.015	Y	Priority step C
11.	ABE, T., KOMADA, Y., ASAOKA, S., OZAKI, A., & INOUE, Y. (2011). Questionnaire-based evidence of association between sleepiness while driving and motor vehicle crashes that are subjectively not caused by falling asleep. Sleep and Biological Rhythms, 9(3), 134–143. http://doi.org/10.1111/j.1479-8425.2011.00498.x	N	Lower priority – location Japan
12.	Sandberg, D., Anund, A., Fors, C., Kecklund, G., Karlsson, J. G., Wahde, M., & Åkerstedt, T. (2011). The characteristics of sleepiness during real driving at night--a study of driving performance, physiology and subjective experience. Sleep, 34(10), 1317–25. http://doi.org/10.5665/SLEEP.1270	N	No information on crash risk
13.	Valent, F., Di Bartolomeo, S., Marchetti, R., Sbrojavacca, R., & Barbone, F. (2010). A case-crossover study of sleep and work hours and the risk of road traffic accidents. Sleep, 33(3), 349–354. Retrieved from http://www.scopus.com/inward/record.url?eid=2-s2.0-77649306318&partnerID=tZOtx3y1	Y	Priority step C
14.	Sagaspe, P., Taillard, J., Bayon, V., Lagarde, E., Moore, N., Boussuge, J., … Philip, P. (2010). Sleepiness, near-misses and driving accidents among a representative population of French drivers. Journal of Sleep Research, 19(4), 578–84. http://doi.org/10.1111/j.1365-2869.2009.00818.x	N	Not examined
15.	Abe, T., Komada, Y., Nishida, Y., Hayashida, K., & Inoue, Y. (2010). Short sleep duration and long spells of driving are associated with the occurrence of Japanese drivers' rear-end collisions and single-car accidents. Journal of Sleep Research, 19(2), 310–6. http://doi.org/10.1111/j.1365-2869.2009.00806.x	N	Not examined
16.	Drake, C. L., Roehrs, T., Breslau, N., Johnson, E., Jefferson, C., Scofield, H., & Roth, T. (2010). The 10-year risk of verified motor vehicle crashes in relation to physiologic sleepiness. Sleep, 33(6), 745–752. Retrieved from http://www.scopus.com/inward/record.url?eid=2-s2.0-77953162404&partnerID=tZOtx3y1	N	Not examined
17.	Clarke, D. D., Ward, P., Bartle, C., & Truman, W. (2009). Work-related road traffic collisions in the UK. Accident; Analysis and Prevention, 41(2), 345–51. http://doi.org/10.1016/j.aap.2008.12.013	N	Not examined
18.	Heaton, K. (2009). Sleep and motor vehicle crash risk. Journal of Emergency Nursing: JEN : Official Publication of the Emergency Department Nurses Association, 35(4), 363–5. http://doi.org/10.1016/j.jen.2009.02.012	N	No possible to code – no effect figures

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Fatigue – Sleep disorders - Obstructive Sleep Apnea

Fatigue and sleepiness while driving caused by disturbed sleep due to the sleep disorder Obstructive Sleep Apnea

1 Summary

Talbot, R., Filtness, A., September 2016

1.1 COLOUR CODE: RED

Studies consistently show that untreated Obstructive Sleep Apnea is associated with increased risk for road traffic accidents.

1.2 KEY WORDS

Fatigue, Sleep, Sleepiness, Obstructive Sleep Apnea, Obstructive Sleep Apnea Syndrome, Apnoea, Sleep disorder, OSA, Apnea Hypopnoea Index, AHI, Epworth Sleepiness Scale, ESS

1.3 ABSTRACT

Obstructive Sleep Apnoea (OSA) is where the muscles and tissue in the airway collapse during sleep and cause the airway to be blocked. This can cause the sufferer to partially wake repeatedly through the night and therefore can result in sleep deprivation and feelings of sleepiness during the day. The severity of OSA is measured using the Apnea-Hypopnoea Index (AHI) which gives a score of the number of apnea (airway collapse) episodes that occur per hour. Studies usually include a group of participants with untreated OSA and a control group and the number of accidents experienced in each group, as measured by self-report or police registry, is compared. The studies examined here, in general, suggest that a driver is 2-3 times more likely to have been involved in an accident if suffering from untreated OSA with the risk of truck drivers with OSA being potentially higher. However, although the measure of OSA is often objective, self-report methodologies are commonly used to gather information on accidents which may lead to accident risk being under or over stated.

1.4 BACKGROUND

How are fatigue and Sleep Apnea defined?

Fatigue refers to the tiredness experienced as a result of mental or physical effort, whereas sleepiness is the physical and or mental need for sleep and often is associated with poor sleep quality or reduced duration. Although the terms fatigue and sleepiness have differing meanings, they are often used interchangeably in the literature and the risk they pose to driving relate to the decrease in mental and physical performance capacity that they cause.

Sleep disorders are clinical conditions that affect and or disrupt sleep patterns. Examples of sleep disorders include insomnia, narcolepsy and Obstructive Sleep Apnea (OSA). Obstructive Sleep Apnoea is where the muscles and tissue in the airway collapse during sleep and cause the airway to be blocked. Sufferers can experience episodes multiple times a night and in severe cases, they can occur every one to two minutes. Each episode can cause the sufferer to partially wake and therefore can result in sleep deprivation and feelings of sleepiness during the day. It is possible that an OSA sufferer may partially wake and immediately resume sleeping leaving them unaware that they have just woken.

How is Obstructive Sleep Apnea measured?

OSA is generally assessed, using objective methodologies , by monitoring breathing, heart rate, chest movements and oxygen during a night's sleep. This can take place at home using portable self-administered equipment or at an over-night stay at a sleep clinic, under the supervision of a physician, where more sophisticated polysomnography tests are administered. The severity of OSA is measured using the Apnea-Hypopnoea Index (AHI) which gives a score of the number of apnea episodes that occur per hour. The following criteria gives an indication of the severity of OSA (NHS, 2016):

- Not suffering from OSA – AHI score of < 5
- Mild – AHI score of 5-14
- Moderate – AHI score of 15 - 30
- Severe – AHI score of > 30

Subjective methods can also be used to assess OSA, including asking participants about their medical history, whether others have witnessed an apnea (pause in breathing) or assessing the risk of having OSA by using the Berlin Questionnaire. The Berlin Questionnaire is a questionnaire-based screening tool for OSA and participants are judged as being high risk of OSA if they if they are included in two of the three categories of 'snoring', 'sleepiness and fatigue' and 'hypertension or obesity (BMI≥30)'. However these methods of assessment would be considered weaker and less reliable than more objective techniques.

How many drivers suffer from Sleep Apnea?

Studies have estimated that between 3% to 7% of the general adult population suffer from OSA with certain population groups e.g. males having an increased chance of having OSA(Punjabi, 2008) and it has been estimated that a much larger proportion (26%-50%) of professional drivers have OSA (Smolensky et al. 2011).

How is the relationship between Sleep Apnea and accidents studied?

There are a variety of different methodologies used by researchers when examining the relationship between OSA and accident risk. Researchers often start by identifying a population of interest that are not being treated for OSA, e.g. those attending a sleep clinic for assessment, truck drivers or those that have been involved in an accident. Objective methodologies as described above are usually employed to gain an AHI score that can be used to divide participants into an OSA group and a control group. Participants are then asked about their accident or near miss history using self-report methodologies (interview/questionnaires). Police registries or notifications are used in some studies to identify drivers who have been involved in an accident and this would be considered a stronger methodology than self-report. Statistical techniques are then employed to compare the proportion of the OSA group that have experienced an accident with corresponding proportion in the control group to generate an estimate of increased risk.

An alternative methodology is the use of driving simulators to assess driving performance of those with OSA compared to a control group overall and over time. Common measures of performance include lane positioning and departure. As the links between driving performance and accident risk are not always clear, the focus here has been on studies that examine accident risk more directly.

1.5 OVERVIEW OF RESULTS

The studies examined here in general suggest that a driver is 2-3 times more likely to have been involved in an accident if suffering from untreated OSA with the risk of truck drivers with OSA being potentially higher. However, although the measure of OSA is often objective, self-report methodologies are often used to gather information on accidents which may lead to accident risk being under or over stated.

Fatigue and OSA are topic areas that have been relatively well researched over a long period of time, however the variety of methodologies employed can make comparisons between studies problematic. Also although generally accident risk is increased when suffering from OSA, it is more problematic to identify which specific individuals are at increased risk. The studies included in this analysis were conducted in a range of European countries as well as the USA and Australia, making it likely that the findings reported here could apply to a range of western countries.

2 Scientific Overview

2.1 INTRODUCTION

The definition of fatigue varies greatly in the literature with terms such as 'fatigue', 'sleepiness' and 'drowsiness' being used interchangeably. The dictionary definition of fatigue is 'extreme tiredness resulting from mental or physical exertion or illness'[1], whereas sleepiness can be defined as the neurobiological need for sleep (NHTSSA, 2001 cited in DaCoTA 2012). Sleepiness can be described as the drive for sleep whereas fatigue is a signal from the body that the current activity – either physical or psychological or just being awake – should end (DaCoTA 2012). Although sleepiness and fatigue have differing meanings their effects are the same, namely a decrease in the capacity to perform psychological or physical tasks (DaCoTA 2012).

Obstructive Sleep Apnea (OSA) is a sleep disorder characterised by reoccurring apneas (obstructions to the airway) caused by the relaxing and of muscles and tissue during sleep to the point of collapse in the respiratory tract, despite persistent respiratory effort on the part of the individual[2]. This results in frequent partial arousals during sleep can lead to sleep deprivation and daytime tiredness.

OSA is assessed by monitoring breathing, heart rate, chest movements and oxygen during a night's sleep. This can take place at home using portable self-administered equipment or at an overnight stay at a sleep clinic where more sophisticated polysomnography tests, usually under the supervision of a physician, are administered. The severity of OSA is measured using the Apnea-Hypopnoea index (AHI) which gives a score of the number of airway collapse episodes that occur per hour. The following criteria give an indication of the severity of OSA (NHS, 2016):

- Not suffering from OSA – AHI score of < 5
- Mild – AHI score of 5-14
- Moderate – AHI score of 15 - 30
- Severe – AHI score of > 30

2.2 METHODOLOGY

A systematic literature review was undertaken to identify peer-reviewed journal papers that show a measurable relationship between OSA and the risk of being involved in a road traffic accident. Studies using accident data were the primary focus, although simulator studies were also included in the search.

Six papers were identified. Two are meta-analyses (Garbarino et al. 2015; Tregear et al. 2009) that examined the accident risk of drivers with OSA compared to those who do not suffer from OSA. Three studies were included in both meta-analyses with an additional six examined in Garbarino et al and an additional seven examined in Tregear et al. A further two studies assessed the relationship between OSA and accidents for professional truck drivers – the first, Meuleners et al (2015), using objective methodologies both to identify road traffic accidents and those with OSA and the second, Catarino et al (2014), using subjective methodologies. The final two studies examine self-reported sleep related accident risk of drivers attending a sleep clinic (Basoglu and Sezai Tasbakan, 2013) and the driving performance, in terms of lane position variation, of a small

[1] Oxford English Dictionary http://oxforddictionaries.com/
[2] ICD-10-CD clinical information available at http://www.icd10data.com/ICD10CM/Codes/G00-G99/G40-G47/G47-/G47.33

sample of the general population in a driving simulator (May et al, 2016). Table 1 gives an overview of the study methodologies.

Table 1: Overview of study methodologies – Obstructive Sleep Apnea (SA)

Author(s), year, country	**Study Methodology**	**Risk group/ cases**	**Control group/ Controls**	**Effect measure**
Garbarino et al. 2015	**Meta-analysis** of 9 studies	Male drivers (mean age 40-60) years with AHI ≥5 and excessive daytime sleepiness	Drivers without OSA	Odds ratio (Weighed median)
Tregear et al. 2009	**Meta-analysis** (random effects) of 10 studies	Private drivers (9 studies) and long haul truck drivers (1 study) with sleep apnea as measured in the individual studies	Private drivers (9 studies) and long haul truck drivers (1 study) without OSA	Relative risk
Meuleners et al. 2015 Australia	Observational: case- control	Long distance heavy vehicle (≥12 tonne) drivers (99% male) involved in police reported accident	Long distance heavy vehicle (≥12 tonne) drivers who had not been involved in an accident (recruited at truck stops)	Adjusted odds ratio (logistic regression)
Catarino et al 2014 Portugal	Observational: cross-sectional [n=714]	Male truck drivers (age23-70) with Obstructive Sleep Apnea	Male truck drivers without Obstructive Sleep Apnea (age23-70)	Odds ratio
Basoglu et al. 2014 Turkey	Observational: cases matched by age and gender with controls	Drivers with Obstructive Sleep Apnea (AHI >5) attending a sleep clinic	Drivers who attended a sleep clinic because of snoring but AHI <5	Odds ratio
May et al. 2016 USA	Simulator study	Drivers from general population with AHI ≥15	Drivers from general population with AHI <10	Absolute difference (F test)

2.3 ANALYSIS AND RESULTS

As two of the six studies reported here were meta-analyses and the methodologies of the remaining four were diverse, no further meta-analyses were attempted. Table 2 summarises the exposure (independent) variable, the outcome (dependent) variable, and the effect direction, measure and description for each of the six studies.

Table 2: Summary of measures and results for studies examining Obstructive Sleep Apnea (OSA)

Author(s), Year, Country	Independent / Exposure variable	Dependant / outcome type	Effects on Road Safety		Main outcome - Description
Garbarino et al. 2015	Sleep apnea measured by full nighttime polysomnography. [n=2466; control=2791]	At least one accident reported via questionnaire or accident registry.	↗	Odds ratio = 2.83 (CI: 2.34-3.65)	Drivers with OSA are at a significantly increased risk of being involved in an accident when compared to individuals without OSA
	Sleep apnea with a AHI ≥5 assessed by full nighttime polysomnography. [n=1612; control=1803]	At least one accident reported via questionnaire or accident registry.	↗	Odds ratio = 2.83 (CI: 2.72-3.08)	Drivers with OSA with a AHI ≥5 are at a significantly increased risk of being involved in an accident when compared to individuals without OSA
	Sleep apnea with a AHI ≥10 assessed by full nighttime polysomnography. [n=53; control=820]	At least one accident reported via questionnaire or accident registry.	↗	Odds ratio = 3.68 (CI: 1.45-6.00)	Drivers with OSA with a AHI ≥10 are at a significantly increased risk of being involved in an accident when compared to individuals without OSA
	Sleep apnea with a AHI ≥20 assessed by full nighttime polysomnography. [n=135; control=132]	At least one accident reported via questionnaire or accident registary.	↗	Odds ratio = 2.81 (CI: 2.33-3.28)	Drivers with OSA with a AHI ≥20 are at a significantly increased risk of being involved in an accident when compared to individuals without OSA
Tregear et al. 2009	Sleep Apnea	Driver involved in an accident	↗	Relative Risk = 2.43 (CI 1.21-4.89; P = 0.013)	Significant negative effect on road safety: Drivers with OSA are at a significantly increased risk of experiencing a motor vehicle accident when compared to individuals without OSA
Meuleners et al. 2015. Australia	AHI >17 measured by FlowWizard diagnostic tool	Police reported accident during a journey of at least 200km	↗	Odds ratio: 3.42 (CI 1.34-8.72) N=100; control =100	HGV drivers with OSA were found to be over 3 times more likely to be involved in an accident than drivers without OSA
Catarino et al 2014 Portugal	Medical history of Obstructive Sleep Apnea (self-report) [n=13]	Accident in last 5 years (self-reported)	↗	Odds ratio = 6.42 (CI 1.64-25.1; p=0.01)	Drivers with a medical history of OSA are at a significantly increased risk of experiencing a motor vehicle accident when compared to individuals not reporting a medical history of OSA.
		Near miss (unexpected event with no physical/material damage) in last 5 years (self-reported)	—	Odds ratio = 2.62 (CI 0.79-8.59; p=0.11)	None-significant result
	Witnessed apnea -	Accident in last 5	—	Odds ratio = 1.6	None-significant result

	breathing pause whilst asleep (self-report) [n=83]	years (self-reported)		(CI 1-2.69; p=0.06)	
		Near miss (unexpected event with no physical/material damage) in last 5 years (self-reported)	↗	Odds ratio = 2.42 (CI 1.47-3.99; p=<0.01)	Drivers with a witnessed apnea have a significantly increased risk of experiencing a near miss incident when compared to individuals who did not report a witnessed apnea.
	High risk of sleep apnea measured by falling into at least 2 of the Berlin Questionnaire categories: snoring, sleepiness and fatigue, hypertension, BMI ≥ 30. [n=193]	Accident in last 5 years (self-reported)	—	Odds ratio = 1.44 (CI 0.97-2.14; p=0.06)	Non-significant result
		Near miss (unexpected event with no physical/material damage) in last 5 years (self-reported)	↗	Odds ratio = 2.05 (CI 1.37-3.05; p< 0.01)	Drivers assessed as having a high risk of having OSA have a significantly increased risk of experiencing a near miss incident when compared to individuals with low risk
Basoglu et al. 2014 Turkey	Obstructive Sleep Apnea: AHI of 5 events per hour and the presence of clinical symptoms (e.g. excessive daytime sleepiness, loud snoring, witnessed apneas, and nocturnal choking) or AHI of 15 events per hour without any OSAS symptoms. [n=312]	Accident due to sleepiness (self-reported) [Case n=66; control n=18]	↗	Odds ratio = 2.06 (CI 1.17-3.61; p=0.012)	Drivers with OSAS have 2 times higher risk of traffic accidents due to sleepiness than controls (snoring only)
May et al. 2016	Sleep apnea (AHI ≥ 15) and time spent driving (6x10 minute epochs) [n=22; control=23]	Lane position variability (30Hz, averaged per second and then per 10 min epoch)	↗	F(3.73, 160.34)=2.74; P=0.03	The decline in performance over time was significantly different between the apnea and control group, with the apnea group's decline being more pronounced
	Sleep apnea (AHI ≥ 15) [n=22; control=23]	Lane position variability (30Hz, averaged per second and then per 10 min epoch)	—	F(1,43)=4.03 P=0.051	No significant difference was found for the overall performance of the apnea group when compared with the control group

Key: ↗ = increase in accident risk; — = none significant result

The two meta-analyses (Garbarino et al. 2015; Tregear et al. 2009) include 16 unique studies and both conclude, with a relatively similar overall effect size (Odds ratio = 2.83 and Relative risk = 2.43 respectively), of the additional risk that OSA suffers have of being involved in a road traffic accident.

Meuleners et al. (2015) and Basoglu et al. (2014) also show an increased risk for OSA suffers whereas the results of Catarino et al (2014) and May et al (2016) have mixed results with some none significant results. There may however be methodological reasons for this. Catarino et al used subjective methods to assess OSA and so could only group participants according to apparent OSA symptoms rather than AHI scores which are used in clinical diagnosis. In addition May et al's sample was small and was drawn from the general population rather than those attending a sleep clinic for assessment so may not have included those with more severe OSA. As all studies show at least some element of increased risk for OSA suffers and greater weight can be applied to the meta-analyses, the evidence is sufficient to conclude that those with OSA have 2-3 times the risk of other drivers having a road traffic accident.

It is not clear from these studies whether the risk of a road traffic accident increases for those with more severe OSA. Garbarino et al's. (2015) meta-analysis was the only study to address this but they calculated a higher odds ratio for their moderately severe group (AHI ≥10) but not their most severe group (AHI ≥20). Truck drivers may be a group that is at higher risk. Meuleners et al. (2015) implies this and has a robust objective methodology and Catarino et al (2014) lends some support for this but it would be difficult to quantify this additional risk based solely on these two studies. While an overall increased risk with OSA populations is observed, there is no clear evidence as to which specific group of OSA sufferers are at increased risk of having a road traffic accident.

3 Supporting Documents

3.1 DESCRIPTION OF STUDIES

The following paragraphs give an overview of each paper included here with a summary of the relevant findings. For all studies, participants who were in the Obstructive Sleep Apnea (OSA) group were not being treated for OSA at the time of the study.

Garbarino et al (2015) selected studies based on the following criteria: Included male participants with the mean age of 40-60 years (standard deviation +10); were 'at least' case-control type studies with the number of controls not fewer than 20% of the cases; control participants specifically defined as not suffering from Sleep Apnea; report of accidents via questionnaire or register and a full night-time polysomnography with assessment of Apnea Hypopnea Index for all cases (AHI >=5 with Excessive Daytime Sleepiness via subjective or objective method). Nine studies were selected for inclusion in the meta-analysis. Combined and weighted median odds ratios were calculated for the total number of participants with OSA and with an AHI of greater or equal to 5, 10 and 15 respectively. The weighted median odds ratios were reported as follows (95% confidence intervals in brackets): 'total' odds ratio of 2.83 (2.34-3.65), 2.83 for AHI >=5 (2.72-3.08), 3.68 (1.45-6.00) for AHI>=10 and 2.81 (2.33-3.28) or AHI>=20. This suggests a significant increased risk of road traffic collisions for male drivers (non-professional) with OSA.

Tregear et al (2009) conducted a meta-analysis of 10 studies following a systematic literature review. Nine studies examined drivers with private motor vehicle licences and 1 studied long haul commercial truck drivers. All studies had a case group with individuals with OSA and a control group comprising of individuals without OSA. The majority of studies were classed as low quality by Tregear et al as they had a retrospective design, were reliant on self-report or no independent outcome assessment or had not controlled for potentially confounding variables. The random effects meta-analysis found that the relative risk (RR) of crashing for individuals with OSA compared to those without was significantly increased (RR = 2.43; 95% confidence interval: 1.21-4.89).

Meuleners et al (2015) used a case-control methodology to study the accident risk of OSA among long distance truck drivers in West Australia. Cases were 100 long distance heavy vehicle (≥12 tonnes) drivers (99% male) who were involved in a police-reported accident between Jan 2009 and Nov 2011 during a journey of at least 200km. Controls were 100 long distance heavy vehicle (≥12 tonnes) drivers (98% male) recruited from four truck stops between July 2009 and Nov 2011. Drivers were classed as suffering from OSA if they scored an AHI >17 following a self-administered overnight test with the measuring device 'Flow Wizard'. Logistic regression was used to control for confounding factors and to determine which factors were associated with accident involvement. Factors included in the model were age, BMI, smoking status, diagnosed health conditions, diagnosis of depression , use of prescription medications, use of caffeine to stay awake, regular exercise, completed fatigue training, involved in an accident in previous 5 years, and OSA. The adjusted odds ratio for accident involvement for drivers classed as having OSA was 3.42 (95% Confidence Interval: 1.34-8.72) suggesting that long haul truck drivers have a significantly increased risk for an accident if they show symptoms of OSA.

Catarino et al (2014) studied 714 male Portuguese truck drivers, 363 of which were long haul drivers. 244 drivers were interviewed and 470 filled in questionnaires to collect information on sociodemographic characteristics, work, and sleep habits and accidents' history, including near misses, over the preceding 5 years. A near miss was defined as an 'unexpected event that did not cause any physical or material damage and had limited immediate impact'. Three different measures of OSA were used: Witnessed Apnea where the participant had been observed as having pauses in their breathing during sleep (self-reported); a medical history of OSA (self-report); and a classification of being at 'high risk' of OSA as assessed by the Berlin Questionnaire. The Berlin questionnaire is a subjective screening tool for OSA and participants are judged as being high risk of OSA if they if they are included in two of the three categories of 'snoring', 'sleepiness and fatigue' and 'hypertension or obesity (BMI≥30)'. Catarino et al reported odds ratios (OR) that were adjusted for age, BMI, medications causing drowsiness, sleep schedule, alcohol intake, years of licence, and kilometres driven per day. Significantly increased accident risk was found for participants with a medical history of OSA (OR = 6.42; CI 1.64-25.1) and a significantly increased risk for a near miss incidents in participants measured as having a high risk of OSA (OR = 2.05; CI 1.37-3.05) and witnessed apnea (OR = 2.42; CI 1.47-3.99).

Basoglu and Sezai Tasbakan (2013) assessed the sleepiness related accident risk for 488 drivers that attended a University sleep laboratory in Turkey for an assessment of 'presumed' sleep disordered breathing. All participants underwent an overnight polysomnography assessment at the laboratory. Those with a AHI of > 5 with clinical symptoms such as excessive daytime sleepiness, loud snoring, witnessed apneas or nocturnal choking or with a AHI of 15 without clinical symptoms were assigned to the OSA group. A further 156 drivers matched for age and sex, with an AHI of < 5 were assigned to the primarily snoring group which acted as a control. All participants were asked whether they had been involved in an accident or near miss event caused by their own sleepiness. Participants in the OSA group had a significantly higher levels of daytime sleepiness (Epworth Sleepiness Scale Score) than the snoring group (p=<0.0001). Sixty-six (21%) of the OSA group reported a sleep related accident whereas 18 (12%) of the snoring group reported the same. This was associated with an increased risk of sleep related accidents for the OSA group (OR = 2.06; CI 1.17-3.61).

May et al. (2016) studied the driving performance of drivers with OSA symptoms compared with those without during a driving simulator trial. Forty-five (includes males and females) participants were recruited from the community and none had a prior diagnosis of OSA. OSA was assessed using an airflow apnea detection monitor (RUSleeping) overnight at home. If they had a Apnea Hypopnea Index (AHI) of ≥15 they were assigned to the 'Apnea' group. The control group consisted of individual with an AHI of less than 10 (AHI 10-15 excluded). Participants were excluded if they were taking sedative medications, were being treated for a sleep disorder, had a significant uncontrolled medical disorder (heart disease/diabetes) used excessive amounts of caffeine (more than 5 cups a day) or nicotine (more than 10-12 cigarettes a day), worked rotating or permanent night shifts or were considered to have excessive daytime sleepiness (measured by an Epworth Sleepiness Scale score > 10). Driving trials took place in a moderate-fidelity simulator which had a real car seat, steering wheel, brake and accelerator, with projected roadway, speedometer and car hood. Trials took place over two days. Day one involved a familiarisation 10-minute simulator drive and on the second day the participants drove for 60 minutes in a monotonous highway scenario with six passing cars and six slight curves. The variable of interest - lane position variability (LPV) was recorded at a sampling rate of 30hz and the average per second was recorded. Data were averaged into six 10-min epochs following the drive. There was no significant difference in overall performance in terms of LPV between the OSA and control groups. However for all participants, performance deteriorated over time (p < .001) and deterioration in performance was significantly worse over time for the OSA group (p=0.03).

3.2 LITERATURE SEARCH

A systematic literature search was undertaken to identify papers that examined the risk of being involved in a road traffic accident when the driver was fatigued. This section describes the search terms, screening and eligibility selection processes that were used to identify relevant papers.

The following criteria were applied to a key word search in the database Scopus. See Table 3 for full results.:

- Search field: TITLE-ABS-KEY
- published: year > 1990
- Document Type: "Review" and "Article"
- Source Type "Journal"
- Language: "English"

Table 3: Scopus search terms and results

Database: Scopus **Date:** 3 May 2016

search no.	search terms / operators / combined queries	hits
#1	"fatigue*" OR "sleep*" OR "tired*" OR "drowsy" OR "drowsiness" OR "alert*" OR "monoton*" OR "time on task" OR "mental* fatigue*" OR "mental* tired*"	393,733
#2	"Sleep disorde*" OR "Narcolepsy" OR "Apneoa" OR "'Apnea" OR "Sleep disordered breathing" OR "OSA"	72,103
#3	"road safety" OR "traffic safety" OR "driv*" OR "road" OR "transport" OR "traffic" OR "Pedestrian" OR "Rider"	1,586,152
#4	"collision*" OR "crash*" OR "accident*" OR "incident*" OR "Road casualt*" OR "Road fatalit*" OR "injur*"	1,164,341
#5	"risk*" OR "severit*" OR "frequenc*"	3,472,721
#6	#1 OR #2	405,751
#7	#6 AND #3 AND #4 AND #5	1,682

Due to the large number of search results, the search was limited to papers originating in the following countries: Europe, Israel, North America, Australia, New Zealand and Japan and publication period: 1 Jan 2006- 3 May 2016. This reduced the number of papers to be screened to 997.

Screening

A two stage screening process then took place. Table 4 shows the first stage where titles and if necessary abstracts were quickly assessed to eliminate papers that were not relevant and **Fehler! Verweisquelle konnte nicht gefunden werden.** shows the results of a more detailed title and abstract screening of the Not enough sleep/Driving while tired papers to identify particular road user groups and papers that were not relevant or could not be coded in the SafetyCube template (for next step of methodology see D4.1 main text). This second stage was also used to identify meta-analysis papers.

Table 4: 1st Title and abstract screening for relevance

Total number of studies to screen title/ abstract – 1st screening	997
-De-duplication	5
-Exclusion: not relevant (not addressing risk of fatigue in relation to road safety)	832
Remaining studies	
Sleep Disorders	51
Not enough sleep/Driving while tired	96
Other fatigue papers	12
Total	159

Table 5: 2nd title and abstract screening for relevance

Sleep disorders – title / abstract - 2nd Screening	51
Exclusion: included in meta-analysis	3
Exclusion: not relevant (not addressing risk of sleep disorder in relation to road safety)	11
- exclusion:- not possible to code in template (review/commentary/no figures/no control group)	8
Remaining studies	28
Sleep apnea	20
Insomnia	6
Hypersomnia	2
Studies to obtain full-texts: Sleep Apnea	**20**

Eligibility

The final stage was to identify the papers for which a full text could be obtained based on paper availability (Table 6).

Table 6:Eligible papers

Total number of studies to screen full-text	20
Full-text could be obtained	18
Reference list examined: Y/N	N
Eligible papers	**18**

Prioritisation

Once the full papers had been obtained they were assessed as to their suitability to be included in this synopsis based on the following prioritisation criteria:

- Prioritizing Step A: Meta-analysis;
- Prioritizing Step B: Studies examining crash risk for truck drivers published after the meta analysis literature search date;
- Prioritizing Step C: Studies examining crash risk for general driving population published after the meta analysis literature search dat ;
- Prioritizing Step D: simulator studies.

For each prioritisation step, papers from Europe were coded before papers from USA, Japan, Australia, with the most recent papers being coded first. The full list of 18 papers and the reasons why they were coded or not are shown in Table 7.

Table 7: Coding decisions

No.	Publication	Coded Y/N	Reason
1.	Tregear, S., Reston, J., Schoelles, K., & Phillips, B. (2009). Obstructive sleep apnea and risk of motor vehicle crash: Systematic review and meta-analysis. Journal of Clinical Sleep Medicine. Retrieved from http://www.scopus.com/inward/record.url?eid=2-s2.0-75749110233&partnerID=tZOtx3y1	Y	Priority A
2.	Garbarino, S., Pitidis, A., Giustini, M., Taggi, F., & Sanna, A. (2015). Motor vehicle accidents and obstructive sleep apnea syndrome: A methodology to calculate the related burden of injuries. Chronic Respiratory Disease, 12(4), 320–8. http://doi.org/10.1177/1479972315594624	Y	Priority A
3.	Catarino, R., Spratley, J., Catarino, I., Lunet, N., & Pais-Clemente, M. (2014). Sleepiness and sleep-disordered breathing in truck drivers : risk analysis of road accidents. Sleep & Breathing = Schlaf & Atmung, 18(1), 59–68. http://doi.org/10.1007/s11325-013-0848-x	Y	Priority B
4.	Meuleners, L., Fraser, M. L., Govorko, M. H., & Stevenson, M. R. (2015). Obstructive sleep apnea, health-related factors, and long distance heavy vehicle crashes in Western Australia: a case control study. Journal of Clinical Sleep Medicine : JCSM : Official Publication of the American Academy of Sleep Medicine, 11(4), 413–8. http://doi.org/10.5664/jcsm.4594	Y	Priority B
5.	Basoglu, O. K., & Tasbakan, M. S. (2014). Elevated risk of sleepiness-related motor vehicle accidents in patients with obstructive sleep apnea syndrome: a case-control study. Traffic Injury Prevention, 15(5), 470–6. http://doi.org/10.1080/15389588.2013.830213	Y	Priority C
6.	Irwin, E. D., Reicks, P., Beal, A., Byrnes, M., Matticks, C., & Beilman, G. (2014). A prospective study of the role of sleep related disordered breathing as a risk factor for motor vehicle crashes and the development of systemic complications in non-commercial drivers. World Journal of Emergency Surgery : WJES, 9(1), 2. http://doi.org/10.1186/1749-7922-9-2	N	Not possible to code
7.	Karimi, M., Hedner, J., Lombardi, C., Mcnicholas, W. T., Penzel, T., Riha, R. L., ... Grote, L. (2014). Driving habits and risk factors for traffic accidents among sleep apnea patients--a European multi-centre cohort study. Journal of Sleep Research, 23(6), 689–99. http://doi.org/10.1111/jsr.12171	N	Not possible to code – examined prevalence not risk

8.	Ward, K. L., Hillman, D. R., James, A., Bremner, A. P., Simpson, L., Cooper, M. N., ... Mukherjee, S. (2013). Excessive daytime sleepiness increases the risk of motor vehicle crash in obstructive sleep apnea. Journal of Clinical Sleep Medicine : JCSM : Official Publication of the American Academy of Sleep Medicine, 9(10), 1013–21. http://doi.org/10.5664/jcsm.3072	N	Not screened
9.	Philip, P., Sagaspe, P., Taillard, J., Chaumet, G., Bayon, V., Coste, O., ... Guilleminault, C. (2008). Maintenance of Wakefulness Test, obstructive sleep apnea syndrome, and driving risk. Annals of Neurology, 64(4), 410–6. http://doi.org/10.1002/ana.21448	N	No control
10.	YOSHINO, A., HIGUCHI, M., KAWANA, F., KATO, M., KAMATA, M., NAKANISHI, S., ... NARUI, K. (2006). Risk factors for traffic accidents in patients with obstructive sleep apnea syndrome. Sleep and Biological Rhythms, 4(2), 144–152. http://doi.org/10.1111/j.1479-8425.2006.00219.x	N	Pre meta-analysis
11.	May, J. F., Porter, B. E., & Ware, J. C. (2016). The deterioration of driving performance over time in drivers with untreated sleep apnea. Accident; Analysis and Prevention, 89, 95–102. http://doi.org/10.1016/j.aap.2016.01.002	Y	Priority D
12.	Demirdöğen Çetinoğlu, E., Görek Dilektaşlı, A., Demir, N. A., Özkaya, G., Acet, N. A., Durmuş, E., ... Ege, E. (2015). The relationship between driving simulation performance and obstructive sleep apnoea risk, daytime sleepiness, obesity and road traffic accident history of commercial drivers in Turkey. Sleep & Breathing = Schlaf & Atmung, 19(3), 865–72. http://doi.org/10.1007/s11325-014-1114-6	N	Not looking at driving risk
13.	Vakulin, A., Catcheside, P. G., Baulk, S. D., Antic, N. A., Banks, S., Dorrian, J., & McEvoy, R. D. (2014). Individual variability and predictors of driving simulator impairment in patients with obstructive sleep apnea. Journal of Clinical Sleep Medicine : JCSM : Official Publication of the American Academy of Sleep Medicine, 10(6), 647–55. http://doi.org/10.5664/jcsm.3792	N	Not possible to code
14.	Pizza, F., Contardi, S., Mondini, S., Trentin, L., & Cirignotta, F. (2009). Daytime sleepiness and driving performance in patients with obstructive sleep apnea: Comparison of the MSLT, the MWT, and a simulated driving task. Sleep, 32(3), 382–391. Retrieved from http://www.scopus.com/inward/record.url?eid=2-s2.0-62549112150&partnerID=tZOtx3y1	N	No risk measures
15.	Tippin, J. (2007). Driving impairment in patients with obstructive sleep apnea syndrome. Neurodiagnostic Journal. Retrieved from http://www.scopus.com/inward/record.url?eid=2-s2.0-34447259076&partnerID=tZOtx3y1	N	No control
16.	Pichel, F., Zamarrón, C., Magán, F., & Rodríguez, J. R. (2006). Sustained attention measurements in obstructive sleep apnea and risk of traffic accidents. Respiratory Medicine, 100(6), 1020–7. http://doi.org/10.1016/j.rmed.2005.09.036	N	Not possible to code
17.	Barger, L. K., Rajaratnam, S. M. W., Wang, W., O'Brien, C. S., Sullivan, J. P., Qadri, S., ... Czeisler, C. A. (2015). Common sleep disorders increase risk of motor vehicle crashes and adverse health outcomes in firefighters. Journal of Clinical Sleep Medicine : JCSM : Official Publication of the American Academy of Sleep Medicine, 11(3), 233–40. http://doi.org/10.5664/jcsm.4534	N	Not screened – not a priority
18.	Avis, K. T., Gamble, K. L., & Schwebel, D. C. (2015). Obstructive sleep apnea syndrome increases pedestrian injury risk in children. The Journal of Pediatrics, 166(1), 109–14. http://doi.org/10.1016/j.jpeds.2014.09.032	N	Not screened – not a priority

3.3 REFERENCES

Coded studies

Basoglu, O. K., & Tasbakan, M. S. (2014). Elevated risk of sleepiness-related motor vehicle accidents in patients with obstructive sleep apnea syndrome: a case-control study. *Traffic Injury Prevention*, *15*(5), 470–6. http://doi.org/10.1080/15389588.2013.830213

Catarino, R., Spratley, J., Catarino, I., Lunet, N., & Pais-Clemente, M. (2014). Sleepiness and sleep-disordered breathing in truck drivers : risk analysis of road accidents. *Sleep & Breathing = Schlaf & Atmung*, *18*(1), 59–68. http://doi.org/10.1007/s11325-013-0848-x

Garbarino, S., Pitidis, A., Giustini, M., Taggi, F., & Sanna, A. (2015). Motor vehicle accidents and obstructive sleep apnea syndrome: A methodology to calculate the related burden of injuries. *Chronic Respiratory Disease*, *12*(4), 320–8. http://doi.org/10.1177/1479972315594624

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Tregear, S., Reston, J., Schoelles, K., & Phillips, B. (2009). Obstructive sleep apnea and risk of motor vehicle crash: Systematic review and meta-analysis. *Journal of Clinical Sleep Medicine*. Retrieved from http://www.scopus.com/inward/record.url?eid=2-s2.0-75749110233&partnerID=tZOtx3y1

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NHS (2016) NHS choices. Obstructive Sleep apnoea diagnosis. Available at http://www.nhs.uk/Conditions/Sleep-apnoea/Pages/Diagnosis.aspx. [Accessed 30 Aug 2016]

Punjabi, N. M. (2008) The epidemiology of adult obstructive sleep apnea. Proc. Am. Thorac. Soc., 2008, 5: 136–143.

Smolensky, M. H., Di Milia, L., Ohayon, M. M., & Philip, P. (2011). Sleep disorders, medical conditions, and road accident risk. Accident; Analysis and Prevention, 43(2), 533–48. http://doi.org/10.1016/j.aap.2009.12.004

Insufficient Skills and Knowledge

Lack of skills and knowledge about any element of the road traffic system including:
Vehicle operation and manoeuvres, dangerous behaviour, traffic environment, trip planning

1 Summary

Alfonsi R., July 2016

1.1 COLOUR CODE: YELLOW

The influence of insufficient skills and knowledge on crash risk is not properly identified. The concepts are often combined without a clear picture of the specific contribution of each of them. The issue is often treated in studies covering larger topics (e.g. age, personal factors) and consequently its effect turns out to be confounded with that of other risk factors. Furthermore, the number of studies is limited. Results, mainly constituting of the outcome of correlation analysis, show a general negative contribution to road safety in terms of crash risk and risky behaviour, although not always statistically significant.

1.2 KEYWORDS

Skills, knowledge, operating errors, lifestyle, experience, competence, training, individual characteristics, culture, religion.

1.3 ABSTRACT

Insufficient skills and knowledge identify a lack of technical and theoretical functions in relation to different elements (vehicle properties and functions, traffic conditions, trip characteristics and life goals/personal tendencies), which is expected to increase the risk for road users of being involved in road accidents. Studies show, in this condition, a general tendency to be involved in road accidents or to commit violations, as well as to assume specific risky behaviours. Nevertheless, findings are almost entirely related to the issues of personal goals/tendencies and vehicle properties/functions, and it is not always feasible to separately identify the contribution of skills or knowledge. Moreover, they are mainly focused on young drivers and the effect of some personal characteristics is likely to be confused with that of other risk sources like "age" or "personal factors".

1.4 BACKGROUND

What are insufficient skills and knowledge?

Insufficient skills of road users constitute a deficiency that can lead to operating errors. It is defined in relation to different aspects such as: vehicle functions and manoeuvring (e.g. control of speed and position, shifting); specific task to be conducted in the traffic environment (e.g. communication, speed adjustment, observation), trip planning, and control over how life goals and personal tendencies affect driving behaviour.

Insufficient knowledge can be similarly measured in relation to the following aspects: effects of technical vehicle properties, traffic regulations, and issues affecting the trip (e.g. location, effects of time pressure in car, life goals and personal tendencies affecting driving behaviours).

How does insufficient skills and knowledge affect road safety?

Insufficient skills and knowledge are translated into a greater probability of being involved in road accidents as well as in violations with consequent citations. The risk factor, in relation to drivers, is linked to the tendency to commit operative errors while, in relation to Vulnerable Road Users, it seems to induce the assumption of not safe behaviours.

The safety risk arises from insufficient skills and knowledge in relation to vehicle properties and functions. In this respect, driver's experience reduces the risk; therefore young drivers are the most exposed category. Furthermore, the risk is linked to insufficient skills and knowledge in relation to personal goals and tendencies, intended as the uncontrolled/unmanaged effect of several life style traits able to affect road safety.

How frequently do insufficient skills and knowledge occur in traffic?

The risk related to the technical vehicle properties and functions is relevant especially for novice drivers, as competences are strictly related to the degree of driving experience.

On the other hand, the risk related to personal goals and tendencies can be assumed randomly distributed as riskier or safer lifestyles are the combination of multiple heterogeneous variables, sometimes with opposite effects and not necessarily linked to a specific segment of the population.

Which factors influence the effect of insufficient skills and knowledge on road safety?

The risk factor is influenced by the driver's experience (usually measured in terms of global mileage/kilometres driven or time since obtaining license), which determines the degree of technical competence. Furthermore, a fundamental role is played by personal goals and tendencies, which influence the road user behaviour through their dominant values and lifestyles.

How is the effect of insufficient skills and knowledge on road safety measured?

The methodology used in most studies is the submission of questionnaires to road users in order to collect information about involvement in negative events (e.g. accidents, citations), specific behaviours assumed or related intentions, as well as socio-economic characteristics. Data collection from official statistics and driving simulation studies are also employed in two different studies.

Data are treated through different types of regression analysis and through correlation analysis.

1.5 OVERVIEW OF RESULTS ON INSUFFICIENT SKILLS AND KNOWLEDGE

Life goals and personal tendencies, which compose the lifestyle, significantly and heterogeneously affect road safety of drivers and vulnerable road users. Religion constitutes a relevant factor of the individual life and, in general, it seems to positively influence road safety through the reduction of risky behaviours. The motives of driving constitute a further significant aspect of life style and driving without destination is significantly linked to the tendency to commit operative errors. The involvement in sports or amusement activities or a culture oriented lifestyle are linked to lower road safety risks, while an alcohol oriented lifestyle produces a contrary effect. Anti-social behaviours in general are related to high accident risk.

In relation to the technical characteristics of the vehicle, a higher perception of technical and maintenance ability is correlated to a higher driving speed. A high speed selection is also induced by spatial skills in a familiar environment. Knowledge and skills increase with the driver's experience, expressed as time since obtaining a license or kilometres driven, and this is linked to a lower road safety risk. Training activities aiming at improving skills and knowledge seem to influence only the driving style, without effects on safety aspects, although they could induce less safe intentions in novice drivers (probably because of the generated overconfidence).

2 Scientific details

2.1 METHOD

Literature review

In literature, insufficient skills and knowledge by road users as well as other related characteristics (included in the skills and knowledge concept in this report), are identified in different ways as potential road accident risk factors. For young drivers, Gregersen and Berg (1994) refer to the following factors contributing to a higher accident risk: actual knowledge and skills, amount of experience, individual level of development and maturity, social situation and lifestyle.

Driving experience for young drivers is recognized to be a more important safety factor than age (Wells et al., 2008). The experience gained during the years is able to compensate some cognitive decrements due to age, supporting adaptive behaviour and therefore alleviating some negative effects of the environment complexity (McPhee et al., 2008; Bolstad, 2001). Among others aspects, the experience affects visual search strategies and increases cognitive skills, which are more influential than the lack of vehicle control (Deery, 1999; Underwood, 2007). Lifestyle (identified as: way of living, personal interests and style, moral, ideology) with its individual, cultural and situational factors, outside the traffic context, is significantly linked to driving behaviour (Berg, 1994; Schulze, 1990). The exposition to other styles (e.g. by parents, significant persons) plays an influential role on road behaviour of drivers or vulnerable road users (Dunbar et al., 2001; Ferguson et al., 2001; Zeedyk et al., 2002). A significant component of lifestyle is religion, which, influencing how people deal with several events and situations, affects also their road behaviour in different forms (Rosenbloom et al., 2004; Klidas et al., 2003; Yildirim, 2007).

Description of studies

In Table 1 it is reported a description of the characteristics of the coded studies dealing with insufficient skills and knowledge (sorted by year of publication).

Table 1. Characteristics of coded studies dealing with aspects related to insufficient skills and knowledge

Author, year, country	Sample and study design	Method of analysis	Outcome indicator	Main results
Nabipour A. et al., 2015, Iran	Questionnaire survey for 1,200 students	Linear regression	Risky or safety behaviour	Involvement in religious activity induces the assumption of positive behaviours.
Sadia et al., 2015, Israel.	Web based survey with a sample of 297 participants, out of which 290 had a driver's license	Multiple linear regression models	Speed selection	Technical aversion induces the selection of low speeds
Rosenbloom T. et al, 2013, Israel	Questionnaire survey for a sample of 280 newly licensed drivers (140 having received simulator training and 140 having not)	Hierarchical multiple regression analysis	Safe driving intentions	People with simulator training show less safe driving intentions
Melinder K., 2006, International	Qualitative Comparative Analysis of fifteen Western European Countries and Norway	Correlation analysis	Death rate	Type of religion is the most important factor affecting the road safety high/low risk profile

Chliaoutakis J. et alias, 2005, Greece	Questionnaire survey for 324 adults (aged 18-65)	Multiple linear regression	Operative errors	Operative errors increase in presence of driving without destination and decrease in presence of amusement and sport activities
Mayhew D. Et al, 2003, Canada	Analysis of record and crash data for 40,661 novice drivers.	Analysis of the crash rate trend	Monthly change in crash rate	Time since licensure is linked to a decrease in crash rates
Mc Cartt A. et al, 2002, United States	Survival analysis based on telephone survey for 911 senior high school students	Multivariate Cox regression model	Involvement in road crash or citation	Months after licensure and mileage driven reduce the risk of involvement in road crash as well as in citation
Chliaoutakis J. et alias, 1999, Greece	Questionnaire survey for 241 young drivers	Logistic regression	No involvement in a traffic accident	Driving without destination increases the risk of accidents while religious, social and cultural activities decrease it.
Van Winsum W. et al, 1996, The Netherlands	Driving simulation for 16 drivers with an average age of 34	Correlation analysis	Steering performance	Steering competence does not affect road safety as errors and speed are compensated

Description of main research methods

The insufficient skills and knowledge topic is addressed mainly by surveys through submission of questionnaires (via web or telephone). As appropriate, sampling is referred to the entire population of drivers (usually aged 18-65) or limited to young drivers or more specifically to newly licensed. In some cases, other methods like driving simulation or survival analysis are employed.

Data collected are treated mainly through several types of Regression analysis (e.g., Multiple linear regression, Multivariate Cox Regression, Logistic regression). Correlation analyses are also conducted.

2.2 RESULTS

Life goals and personal tendencies, which can be referred to the general concept of lifestyle, are found to significantly affect road safety of drivers and vulnerable road users in different ways, both positively and negatively. A prominent component of lifestyle is religion.

For young students in Iran, both pedestrians and cyclists, where religion is an essential component of lifestyle, the involvement in religious activity or the possession of intrinsic religiosity are found to be beneficial in terms of reduction of risky behaviours on the road (Nabipour A. et al., 2015). In particular, dangerous playing in the road (e.g., deliberately running out in front of traffic, playing football on the road) decreases for people involved in Non Organizational Religious Activities (Beta = -0.031; pvalue = 0.037). An increase of planned protective behaviours (e.g using lights on a bike when it is dark, wearing a cycle helmet) is found for people involved in Organizational Religious Activities (Beta = -0.052; pvalue = 0.034) and for those with Intrinsic Religiosity (Beta =-0.032; pvalue= 0.012). Females are less engaged in planning protective behaviours and this is not in accordance to the evidences coming from western countries, where no differences are found. It is linked to specific Iranian cultural factors able to increase safety risk for the users; for example, females dress "chador" and do not use a cycle helmet on top of their headscarf. Finally, Intrinsic Religiosity is found to reduce the tendency to unsafe crossing behaviours, constituted for example by running across a road without looking or seeing a small gap in traffic and "go for it" (Beta =-0.024; pvalue= 0.005). The study shows also the relevance of the familiar educational environment; in fact, mothers with an elementary education are linked to people engaged in unsafe crossing, while those with a university education have sons less engaged in that type of behaviour.

The type of religion, besides the wealth of the country, is found to be the most important factor for a high/low risk profile in terms of road safety (Melinder K., 2006). In particular, the greater is the percentage of Catholic people (Roman or Orthodox) living in the countries (wealthy and not wealthy) the larger is the number of motor vehicle accident deaths (Correlation coeff. = 0.83; significance at 0.01%). Non wealthy countries have the largest number of accident deaths. Catholic countries also show low trust in other people while the analysis shows that trusting in people is correlated to low death rates (Corr. Coeff = -0.734; significance at 0.01%). Moreover, they are less able to deal with uncertainty (caused by the tendency of Catholic religion to stress certainties in life) and this aspect is found to be correlated to high death rates (Corr.coeff = 0.871; significance at 0.01%). Low death countries on the other hand, are normally wealthy, non catholic, trusting countries and, like the catholic ones, make use of speed and alcohol limits. Therefore, the consideration of culture factors like religion appears to be valuable in trying to understand the different performance of specific safety regulations in different contexts.

Religion (religious people or, at least, not ignorant of religious matters) is found to be associated to a high probability of not being involved in an accident (Beta = 0.4135). The positive effect of the religion is probably explained by the respect for human life and personality that this kind of people are expected to have (Chliaoutakis J. et alias, 1999).

Another significant aspect of life style resides on the motives of driving (Chliaoutakis J. et alias 2005; Chliaoutakis J. et alias, 1999). Driving without destination is significantly linked to the tendency to commit operative errors (Beta = 0.258; pvalue = 0.00) while driving to go to an amusement place increases the probability of not being involved in a traffic accident (Beta = 0.3137). The finding for driving without destination should be considered linked with the "theory of extra motives" (getting from A to B may not be the only motive of the drivers but may imply sensation seeking, anti-sociability, competition or expressing feelings).

Life style characterized by involvement in sports or amusement activity is more able to expose road users to lower risks. In fact, the involvement in amusement or sport activities is linked to a lower amount of operative errors (respectively, Beta = -0.192; pvalue = 0.007; Beta = -0.143; pvalue = 0.047), although the involvement in sports activities is found to be positively linked to the tendency to commit violations. Also the involvement in cultural activities plays a beneficial role for road safety being linked to the non-involvement in traffic accidents (Beta = 0.5892), while an alcohol oriented lifestyle produces a contrary effect (Beta = -0.4005). In general, high accident risk results to be related to traits of anti-sociability.

In relation to the technical characteristics of the vehicle, technical aversion, defined as aversion from performing technical tasks on the vehicle (Sadia et al., 2015), is found to give a strong contribution to driver's speed selection, both in motorway and in urban roads (respectively, Beta = -2,14, pvalue <0.05; Beta = -1,78, pvalue <0.05). Technical aversion induces a driver with scarce technical abilities to select lower speed, while higher perception of technical and maintenance abilities results in higher selected driving speed. The same study shows that spatial familiar tasks, defined as spatial skills in a familiar environment, have a significant negative role on urban streets; therefore people with knowledge of the environment and related skills tend to select high speed (Beta = 2,16; pvalue = <0.05).

Driver's experience is expected to increase knowledge and skills. In fact, time since licensure (Mayhew D. Et al, 2003) is significantly linked to a crash drop (% change) among novice drivers, in relation to all the type of accidents or conditions considered. Miles driven and months after licensure significantly reduce the risk of being involved in the first crash or being regarded by the first citation (Mc Cartt A. et al). Experience is found to significantly affect the driver's steering performance (Van Winsum W. et al, 1996). In fact, steering competence increases with kilometres driven and this reduces the tendency to commit operative errors (corr.coeff = -0,62; pvalue = <0.01). In this case, there is a neutral effect on road safety as operative errors are compensated by the assumption of a lower speed. Finally, the increase of skills and knowledge through simulator training (Rosenbloom T. et al, 2013) is found to induce less safe intentions in novice drivers (Beta = -0,12; pvalue = <0.05) as a better perception of personal abilities induces overconfidence. Nevertheless, the comparison between people trained and not trained does not show any difference in terms of theoretical traffic knowledge and severity safety events. Therefore, the effects appears to be confined only to driving style (e.g., people trained show a more reactive style in terms of headway, increasing their braking).

Table 2 reports the main outcomes of the coded studies on insufficient skills and knowledge (sorted by year of publication).

Table 2: Main outcomes of coded studies dealing with insufficient skills and knowledge

Author, Year, Country	Study type	Exposure variable	Outcome variable	Effects on road safety	Main outcome description
Nabipour A. et al., 2015, Iran	Observational	Organizational Religious Activity (ORA)	Dangerous playing in the road	–	The involvement in Organizational Religious Activity does not significantly affect the dangerous playing in the road
		Non Organizational Religious Activity (NORA)	Dangerous playing in the road	↘	The involvement in Non Organizational Religious Activities is significantly linked to a reduction of dangerous playing in the road.
		Intrinsic Religiosity (IR)	Dangerous playing in the road	–	Intrinsic Religiosity does not significantly affect the dangerous playing in the road
		Organizational Religious Activity (ORA)	Planned protective behaviour	↘	The involvement in Organizational Religious Activities significantly and positively affect planned protective behaviour
		Non Organizational Religious Activity (NORA)	Planned protective behaviour	–	The involvement in Non Organizational Religious Activity does not significantly affect planned protective behaviours
		Intrinsic Religiosity (IR)	Planned protective behaviour	↘	Intrinsic religiosity significantly and positively affect planned protective behaviour
		Organizational Religious Activity (ORA)	Unsafe crossing behaviour	–	The involvement in Organizational Religious Activity does not significantly affect the unsafe crossing behaviour
		Non Organizational Religious Activity (NORA)	Unsafe crossing behaviour	–	The involvement in Non Organizational Religious Activity does not significantly affect the unsafe crossing behaviour
		Intrinsic Religiosity (IR)	Unsafe crossing behaviour	↘	Intrinsic religiosity significantly and positively affect unsafe crossing behaviour

Author, Year, Country	Study type	Exposure variable	Outcome variable	Effects on road safety	Main outcome description
Sadia et al., 2015, Israel.	Observational	Female	Daily speed selection (Motorway and Urban roads)	–	Gender does not significantly affect daily speed selection
		Age over 50		–	Age over 50 does not significantly affect daily speed selection
		High frequency trips		–	High frequency trips do not significantly affect daily speed selection
		High frequency long trips		–	High frequency long trips do not significantly affect daily speed selection
		Driving improvement Course		–	Training through driving improvement course does not significantly affect daily speed selection
		Skills Safety Gap		↗	Skills safety gap (gap between a driver's self assessment of skills and the actual safety level) significantly induce high speed selection (urban and motorway environment)
		Risk awareness		↘	Risk awareness significantly induce low speed selection both in motorway and urban environment
		Law awareness		– ↘	Law awareness does not significantly influence daily speed selection in motorway while it significantly induce low speed selection in urban environment
		Technical Aversion		↘	Technical aversion significantly induce low speed selection both in motorway and urban environment
		Spatial familiar tasks		–	Spatial familiar tasks do not significantly affect daily speed selection
		Spatial unfamiliar tasks		–	Spatial unfamiliar tasks do not significantly affect daily speed selection
		Average driver perception		↗	The perception of the speed assume by other drivers (the average driver) significantly induces the selection of high speed
Rosenbloom T. et al, 2013, Israel	Experimental	Simulator training	Safe driving intentions	–	Simulator training significantly induces the assumptions of less safe driving intentions but practically is influential on driving style not on safety).
Melinder K., 2006, International	Observational	GNP per capita	SDR motor vehicle accident/100.000 inhabitants	↘	Higher levels of GNP per capita in the countries are significantly correlated to a lower Standard Death Rate
		Alcohol consumption		–	Alcohol consumption in the Countries is not significantly correlated to the SDR

Author, Year, Country	Study type	Exposure variable	Outcome variable	Effects on road safety	Main outcome description
		% of Catholics		↗	The higher the presence of catholic people in the Countries the higher (significantly) the SDR
		People's inability to deal with uncertainty		↗	People's inability to cope with uncertainty is significantly correlated to higher SDR
		%person trusting other people		↘	Trusting other people is significantly correlated to lower SDR
		Passenger cars/1000 inhabitants		–	Car diffusion among inhabitants is not significantly correlated to SDR
		km motor ways per km2 per inhabitants per area		–	The motorway kilometres available per inhabitants are not significantly correlated to SDR
		Speed limits		–	Speed limits are not significantly correlated to SDR
		Alcohol limits per ml blood		–	Alcohol limits are not significantly correlated to SDR
Chliaoutakis J. et alias, 2005, Greece	Observational	Driving without destination	Operative errors	↗	Driving without destination is significantly and positively related to operative errors
		Amusement		↘	The involvement in amusement activities is significantly and negatively related to operative errors
		Religion/tradition		–	The possession of values related to religion and tradition are not significantly linked to operative errors
		Sports		↘	The involvement in sports activities is negatively linked to operative errors
		Culture		–	The interest for cultural activities is not significantly linked to operative errors
Mayhew D. Et al, 2003, Canada	Observational	Time since licensure	Crash percent change	↘	Time since licensure is linked to a reduction of all type of crashes for novice drivers
Mc Cartt A. et al, 2002, United States	Observational	Miles driven	First crash	↘	The larger is the amount of miles driven the smaller is the risk of the first crash for beginning drivers
		Miles driven	First citation	↘	The larger is the amount of miles driven the smaller is the risk of the first citation for beginning drivers
		Months since licensure	First crash	↘	The longer is the period since licensure the smaller is the risk of the first crash for beginning drivers

Author, Year, Country	Study type	Exposure variable	Outcome variable	Effects on road safety	Main outcome description
		Months since licensure	First citation	↘	The longer is the period since licensure the smaller is the risk of the first citation for beginning drivers
Chliaoutakis J. et alias, 1999, Greece	Observational	Female	No involvement in a traffic accident	↘	The gender female is significantly related to a lower accident risk in young drivers
		Culture		↘	Culture as dominant lifestyle trait significantly and negatively influence the accident risk in young drivers
		Alcohol		↗	Alcohol oriented life style significantly and positively influence the accident risk in young drivers
		Religiousness		↘	Religiousness significantly and negatively influence the accident risk in young drivers
		Driving with destination other than work place		↗	Driving with destination other than work place significantly increases the accident risk in young drivers
		Driving to go to an amusement place		↘	Driving to go to an amusement place significantly decreases the accident risk in young drivers
Van Winsum W. et al, 1996, The Netherlands	Simulation	Total kilometre driven	Steering performance	↘	The driver's competence, expressed in total kilometre driven, significantly reduce the tendency to commit operating errors

*Effects on road safety are coded as: significantly positive (↘), significantly negative (↗), non-significant

Additional studies

Life goals and tendencies are affected by socio cultural values (shared values within groups such as families, friends or organizations) and motivational/personal factors, influencing driver's behaviour. Lifestyle behaviours like "cruise around in a car with friends" and "driving to friends", are usually recognized to be linked to road safety risks, and are strongly related to personality factors like thrill and anger (Sagberg et al., 2015). Moreover, cruising in adulthood is no longer part of a "normal" social life but is more related to behaviour problems (Møller et al, 2015).

The purpose of the journey and, therefore, the daily activity pattern, have a significant impact on the probability of being involved in car crashes, with trips without specific purpose being the most risky (Elias et al., 2010).

The experience increases driver's skills in terms of visual abilities, modifying the eye movement strategies and increasing their effectiveness (Underwood, 2007). For example, more experienced drivers show a greater number of short fixations distributed widely across the driving scene, with the result of collecting a large amount of information. More experienced drivers also need less processing time (indicated by mean fixation duration).

Modifying conditions

Insufficient skills and knowledge issues are strictly related to the personal factor of the age, which affects the driver's experience and the technical abilities. Furthermore, a prominent influence is played by the socio cultural factors, which determine different way of living, personal goals and tendencies.

Conclusion

Insufficient skills and knowledge are investigated in relation to driver's technical abilities as well as in relation to personal tendencies and lifestyles. In this latter case it is intended as an uncontrolled effect of several personal characteristics.

About personal tendencies and lifestyles, religion is found to be an influential role for all road users (drivers and vulnerable road users). In the most cases, its values are found to positively affect safe behaviours, although one study comparing catholic and not catholic countries finds higher road death rates for the catholic ones. A positive effect is also produced by the involvement in recreational, sport and cultural activities, linked to safer behaviours than those registered for people with anti-social tendencies.

Driving without a specific destination (probably linked to immaturity or other personal problems) is found to be a significant source of risk.

As lifestyle implies both risky behaviours and not risky behaviours and this can coexist, the use of the generic category does not ensure that a specific effect could be identified.

Technical abilities and competence increase with experience, expressed in terms of miles/kilometres driven or time since licensure. Experience is linked to a lower probability of being involved in road crashes or being cited. Furthermore, significant differences between experienced and not experienced drivers are found in relation to visual strategies, the former showing greater ability.
In relation to speed, technical aversion and poor competences induce safer behaviours (lower speed) compensating in this way scarce abilities.

The studies coded largely referred to a specific context, generally to a single country, with specific class of road users considered (mainly young drivers). No meta analysis are available and sometimes samples are small. Furthermore, multivariate regression models might be affected by omitted variable "bias" (i.e. variables other than those investigated might influence the issue considered) as well as correlations between characteristics that might limit the clear identification of the effect of specific variables; in this respect it is useful to stress that insufficient skills and knowledge topic takes into account effects specifically addressed in other risk factors (e.g., age, speeding, etc.).

Finally, results might be affected by "social desirability bias", with a consequent underreporting of some not socially desirable behaviours by people interviewed.

3 Supporting documents

3.1 METHODOLOGY

Literature Search strategy

Literature search was conducted in March 2016 using the Scopus Database. It was carried out separately for skills and knowledge and for each specific risk factor (vehicle, traffic, trip, life goals and personal tendencies). In the following tables are reported the search details (terms, linkage with logical operators, queries). The criteria assumed were the following: search for the fields of title, abstract and keywords, works published from 1990, document types confined to article or report, source type limited to journals, English language, engineering and social sciences as subject areas.

Insufficient skills (life goals and tendencies)

Database: Scopus **Date:** 25nd of March 2016

no.	search terms / logical operators / combined queries	hits
#1	("life goal*" OR "personal tendenc*" OR "personalit*" OR "lifestyle*" OR "personal value*" AND ("skill*" OR "ability*" OR "competence*") AND DOCTYPE (ar OR re) AND PUBYEAR > 1989 AND SRCTYPE (j) AND LANGUAGE (english) AND SUBJAREA (engi OR soci)	60,871
#2	("road casualt*" OR "road fatalit*" OR "traffic accident*" OR "road crash*") AND DOCTYPE (ar OR re) AND PUBYEAR > 1989 AND SRCTYPE (j) AND LANGUAGE (english) AND SUBJAREA (engi OR soci)	10,099
#3	("road safety" OR "traffic safety" OR "crash" OR "accident") AND ("collision" OR "risk") AND DOCTYPE (ar OR re) AND PUBYEAR > 1989 AND SRCTYPE (j) AND LANGUAGE (english) AND SUBJAREA (engi OR soci)	36,730
#4	("roadway*" OR "highway*" OR "intersection" OR "highway" OR "motorway" OR "built up area" OR "rural road" OR "urban road") AND DOCTYPE (ar OR re) AND PUBYEAR > 1989 AND SRCTYPE (j) AND LANGUAGE (english) AND SUBJAREA (engi OR soci)	100,847
#5	#1 AND #2 AND #4	290
#6	#1 AND #3 AND #4	427
#7	#5 OR #6	**438**

Results Literature Search

Database	Hits
Scopus (remaining papers after several limitations/exclusions)	438
Total number of studies to screen title/ abstract	**438**

Screening

Total number of studies to screen title/ abstract	438
-exclusion criteria (no risk factor)	415
Remaining studies	23
Not clear (full-text is needed)	16
Studies to obtain full-texts	**23**

Eligibility

Total number of studies to screen full-text	23
Full-text could be obtained	21
Reference list examined Y/N	N
Eligible papers	21

Screening of the full texts

Total number of studies to screen full paper	
no codable data - excluded	4
Full texts not screened due to limited time resources	15
Remaining studies	**2**

Insufficient skills (Vehicle manoeuvring)

Database: Scopus **Date:** 25th of March 2016

no.	search terms / logical operators / combined queries	hits
#1	("vehicle maneuvering*" OR "manoeuvre*" OR "speed control*" OR "position control* AND ("skill*" OR "ability*" OR "competence*") AND DOCTYPE (ar OR re) AND PUBYEAR > 1989 AND SRCTYPE (j) AND LANGUAGE (english) AND SUBJAREA (engi OR soci)	1,236
#2	("road casualt*" OR "road fatalit*" OR "traffic accident*" OR "road crash*") AND DOCTYPE (ar OR re) AND PUBYEAR > 1989 AND SRCTYPE (j) AND LANGUAGE (english) AND SUBJAREA (engi OR soci)	10,099
#3	("road safety" OR "traffic safety" OR "crash" OR "accident") AND ("collision" OR "risk") AND DOCTYPE (ar OR re) AND PUBYEAR > 1989 AND SRCTYPE (j) AND LANGUAGE (english) AND SUBJAREA (engi OR soci)	36,730
#4	("roadway*" OR "highway*" OR "intersection" OR "highway" OR "motorway" OR "built up area" OR "rural road" OR "urban road") AND DOCTYPE (ar OR re) AND PUBYEAR > 1989 AND SRCTYPE (j) AND LANGUAGE (english) AND SUBJAREA (engi OR soci)	100,847
#5	#1 AND #2 AND #4	51
#6	#1 AND #3 AND #4	78
#7	#5 OR #6	**84**

Results Literature Search

Database	Hits
Scopus (remaining papers after several limitations/exclusions)	84
Total number of studies to screen title/ abstract	**84**

Screening

Total number of studies to screen title/ abstract	84
-exclusion criteria (no risk factor)	67
Remaining studies	18

Not clear (full-text is needed)	12
Studies to obtain full-texts	**18**

Eligibility

Total number of studies to screen full-text	**19**
Full-text could be obtained	17
Reference list examined Y/N	N
Eligible papers	17

Screening of the full texts

Total number of studies to screen full paper	**17**
not the risk factor - excluded	2
Full texts not screened due to limited time resources	10
Remaining studies	**5**

Insufficient skills (Traffic situation)

Database: Scopus **Date:** 25nd of March 2016

no.	search terms / logical operators / combined queries	hits
#1	("speed adjustment*" OR "observation" OR "communication"AND ("skill*" OR "ability*" OR "competence*") AND DOCTYPE (ar OR re) AND PUBYEAR > 1989 AND SRCTYPE (j) AND LANGUAGE (english) AND SUBJAREA (engi OR soci)	142,693
#2	("road casualt*" OR "road fatalit*" OR "traffic accident*" OR "road crash*") AND DOCTYPE (ar OR re) AND PUBYEAR > 1989 AND SRCTYPE (j) AND LANGUAGE (english) AND SUBJAREA (engi OR soci)	10,099
#3	("road safety" OR "traffic safety" OR "crash" OR "accident") AND ("collision" OR "risk") AND DOCTYPE (ar OR re) AND PUBYEAR > 1989 AND SRCTYPE (j) AND LANGUAGE (english) AND SUBJAREA (engi OR soci)	36,730
#4	("roadway*" OR "highway*" OR "intersection" OR "highway" OR "motorway" OR "built up area" OR "rural road" OR "urban road") AND DOCTYPE (ar OR re) AND PUBYEAR > 1989 AND SRCTYPE (j) AND LANGUAGE (english) AND SUBJAREA (engi OR soci)	100,847
#5	#1 AND #2 AND #4	273
#6	#1 AND #3 AND #4	462
#7	#5 OR #6	**486**

Results Literature Search

Database	**Hits**
Scopus (remaining papers after several limitations/exclusions)	486
Total number of studies to screen title/ abstract	**486**

Screening

Total number of studies to screen title/ abstract	**486**
-exclusion criteria (no risk factor)	462
Remaining studies	24
Not clear (full-text is needed)	20

Studies to obtain full-texts	**24**

Eligibility

Total number of studies to screen full-text	**24**
Full-text could be obtained	23
Reference list examined Y/N	N
Eligible papers	23

Screening of the full texts

Total number of studies to screen full paper	
not the risk factor - excluded	2
no codeable data - excluded	2
Full texts not screened due to limited time resources	19
Remaining studies	**0**

Insufficient skills (trip)

Database: Scopus **Date:** 25nd of March 2016

no.	search terms / logical operators / combined queries	hits
#1	("trip planning*") AND ("skill*" OR "ability*" OR "competence*") AND DOCTYPE (ar OR re) AND PUBYEAR > 1989 AND SRCTYPE (j) AND LANGUAGE (english) AND SUBJAREA (engi OR soci)	39
#2	("road casualt*" OR "road fatalit*" OR "traffic accident*" OR "road crash*") AND DOCTYPE (ar OR re) AND PUBYEAR > 1989 AND SRCTYPE (j) AND LANGUAGE (english) AND SUBJAREA (engi OR soci)	10,096
#3	("road safety" OR "traffic safety" OR "crash" OR "accident") AND ("collision" OR "risk") AND DOCTYPE (ar OR re) AND PUBYEAR > 1989 AND SRCTYPE (j) AND LANGUAGE (english) AND SUBJAREA (engi OR soci)	36,712
#4	("roadway*" OR "highway*" OR "intersection" OR "highway" OR "motorway" OR "built up area" OR "rural road" OR "urban road") AND DOCTYPE (ar OR re) AND PUBYEAR > 1989 AND SRCTYPE (j) AND LANGUAGE (english) AND SUBJAREA (engi OR soci)	100,796
#5	#1 AND #2 AND #4	0
#6	#1 AND #3 AND #4	1
#7	#5 OR #6	**1**

Results Literature Search

Database	**Hits**
Scopus (remaining papers after several limitations/exclusions)	1
Total number of studies to screen title/ abstract	**1**

Screening

Total number of studies to screen title/ abstract	**1**
-exclusion criteria (no risk factor)	1
Remaining studies	0
Not clear (full-text is needed)	0

Studies to obtain full-texts	**0**

Insufficient knowledge (life goals and personal tendencies)

Database: Scopus **Date:** 25nd of March 2016

no.	search terms / logical operators / combined queries	hits
#1	("life goal*" OR "personal tendenc*" OR "personality*" OR "lifestyle*" OR "personal value*" AND ("knowledge*" OR "training*" OR "consciousness*") AND ("traffic*" OR "mobility*" OR "driving*") AND DOCTYPE (ar OR re) AND PUBYEAR > 1989 AND SRCTYPE (j) AND LANGUAGE (english) AND SUBJAREA (engi OR soci)	6,870
#2	("road casualt*" OR "road fatalit*" OR "traffic accident*" OR "road crash*") AND DOCTYPE (ar OR re) AND PUBYEAR > 1989 AND SRCTYPE (j) AND LANGUAGE (english) AND SUBJAREA (engi OR soci)	10,099
#3	("road safety" OR "traffic safety" OR "crash" OR "accident") AND ("collision" OR "risk") AND DOCTYPE (ar OR re) AND PUBYEAR > 1989 AND SRCTYPE (j) AND LANGUAGE (english) AND SUBJAREA (engi OR soci)	36,730
#4	("roadway*" OR "highway*" OR "intersection" OR "highway" OR "motorway" OR "built up area" OR "rural road" OR "urban road") AND DOCTYPE (ar OR re) AND PUBYEAR > 1989 AND SRCTYPE (j) AND LANGUAGE (english) AND SUBJAREA (engi OR soci)	100,847
#5	#1 AND #2 AND #4	272
#6	#1 AND #3 AND #4	383
#7	#5 OR #6	**393**

Results Literature Search

Database	Hits
Scopus (remaining papers after several limitations/exclusions)	393
Total number of studies to screen title/ abstract	**393**

Screening

Total number of studies to screen title/ abstract	**393**
- exclusion criteria (no risk factor)	384
Remaining studies	9
Not clear (full-text is needed)	5
Studies to obtain full-texts	**9**

Eligibility

Total number of studies to screen full-text	**9**
Full-text could be obtained	9
Reference list examined Y/N	N
Eligible papers	9

Screening of the full texts

Total number of studies to screen full paper	**9**
no codable data - excluded	3
Full texts not screened due to limited time resources	4

Remaining studies	2

Insufficient knowledge (vehicle properties)

Database: Scopus **Date:** 25nd of March 2016

no.	search terms / logical operators / combined queries	hits
#1	("technical aspect*" OR "propert*" AND ("knowledge*" OR "training*" OR "consciousness*") AND ("Vehicle*" OR "car*" OR "truck*" OR "motorcycle*") AND DOCTYPE (ar OR re) AND PUBYEAR > 1989 AND SRCTYPE (j) AND LANGUAGE (english) AND SUBJAREA (engi OR soci)	46,984
#2	("road casualt*" OR "road fatalit*" OR "traffic accident*" OR "road crash*") AND DOCTYPE (ar OR re) AND PUBYEAR > 1989 AND SRCTYPE (j) AND LANGUAGE (english) AND SUBJAREA (engi OR soci)	10,099
#3	("road safety" OR "traffic safety" OR "crash" OR "accident") AND ("collision" OR "risk") AND DOCTYPE (ar OR re) AND PUBYEAR > 1989 AND SRCTYPE (j) AND LANGUAGE (english) AND SUBJAREA (engi OR soci)	36,730
#4	("roadway*" OR "highway*" OR "intersection" OR "highway" OR "motorway" OR "built up area" OR "rural road" OR "urban road") AND DOCTYPE (ar OR re) AND PUBYEAR > 1989 AND SRCTYPE (j) AND LANGUAGE (english) AND SUBJAREA (engi OR soci)	100,847
#5	#1 AND #2 AND #4	84
#6	#1 AND #3 AND #4	164
#7	#5 OR #6	**183**

Results Literature Search

Database	Hits
Scopus (remaining papers after several limitations/exclusions)	183
Total number of studies to screen title/ abstract	**183**

Screening

Total number of studies to screen title/ abstract	183
-exclusion criteria (no risk factor)	183
Remaining studies	0
Not clear (full-text is needed)	0
Studies to obtain full-texts	**0**

Insufficient knowledge (traffic situation)

Database: Scopus **Date:** 25nd of March 2016

no.	search terms / logical operators / combined queries	hits
#1	(" rule*" OR "regulation*") AND ("knowledge*" OR "training*" OR "consciousness*") AND ("traffic*" OR "mobility*") AND DOCTYPE (ar OR re) AND PUBYEAR > 1989 AND SRCTYPE (j) AND LANGUAGE (english) AND SUBJAREA (engi OR soci)	106
#2	("road casualt*" OR "road fatalit*" OR "traffic accident*" OR "road crash*") AND DOCTYPE (ar OR re) AND PUBYEAR > 1989 AND SRCTYPE (j) AND LANGUAGE (english) AND SUBJAREA (engi OR soci)	10,099
#3	("road safety" OR "traffic safety" OR "crash" OR "accident") AND ("collision" OR "risk") AND	36,730

	DOCTYPE (ar OR re) AND PUBYEAR > 1989 AND SRCTYPE (j) AND LANGUAGE (english) AND SUBJAREA (engi OR soci)	
#4	("roadway*" OR "highway*" OR "intersection" OR "highway" OR "motorway" OR "built up area" OR "rural road" OR "urban road") AND DOCTYPE (ar OR re) AND PUBYEAR > 1989 AND SRCTYPE (j) AND LANGUAGE (english) AND SUBJAREA (engi OR soci)	100,847
#5	#1 AND #2 AND #4	32
#6	#1 AND #3 AND #4	34
#7	#5 OR #6	**39**

Results Literature Search

Database	**Hits**
Scopus (remaining papers after several limitations/exclusions)	39
Total number of studies to screen title/ abstract	**39**

Screening

Total number of studies to screen title/ abstract	**39**
-exclusion criteria (no risk factor)	35
Remaining studies	4
Not clear (full-text is needed)	4
Studies to obtain full-texts	**4**

Eligibility

Total number of studies to screen full-text	**4**
Full-text could be obtained	4
Reference list examined Y/N	N
Eligible papers	4

Screening of the full texts

Total number of studies to screen full paper	**4**
No risk factor	2
Full texts not screened due to limited time resources	2
Remaining studies	**0**

Insufficient knowledge (trip)

Database: Scopus **Date:** 25nd of March 2016

no.	**search terms / logical operators / combined queries**	**hits**
#1	("location*" OR "driving time*"OR "travel time*" OR "time pressure*") AND ("knowledge*" OR "training*" OR "consciousness*") AND ("traffic*" OR "mobility*") AND DOCTYPE (ar OR re) AND PUBYEAR > 1989 AND SRCTYPE (j) AND LANGUAGE (english) AND SUBJAREA (engi OR soci)	7.150
#2	("road casualt*" OR "road fatalit*" OR "traffic accident*" OR "road crash*") AND DOCTYPE (ar OR re) AND PUBYEAR > 1989 AND SRCTYPE (j) AND LANGUAGE (english) AND SUBJAREA (engi OR soci)	10,099
#3	("road safety" OR "traffic safety" OR "crash" OR "accident") AND ("collision" OR "risk") AND DOCTYPE (ar OR re) AND PUBYEAR > 1989 AND SRCTYPE (j) AND LANGUAGE (english) AND SUBJAREA (engi OR soci)	36,730

#4	("roadway*" OR "highway*" OR "intersection" OR "highway" OR "motorway" OR "built up area" OR "rural road" OR "urban road") AND DOCTYPE (ar OR re) AND PUBYEAR > 1989 AND SRCTYPE (j) AND LANGUAGE (english) AND SUBJAREA (engi OR soci)	100,847
#5	#1 AND #2 AND #4	258
#6	#1 AND #3 AND #4	418
#7	#5 OR #6	**447**

Results Literature Search

Database	**Hits**
Scopus (remaining papers after several limitations/exclusions)	447
Total number of studies to screen title/ abstract	**447**

Screening

Total number of studies to screen title/ abstract	**447**
-exclusion criteria (no risk factor)	439
Remaining studies	8
Not clear (full-text is needed)	8
Studies to obtain full-texts	**8**

Eligibility

Total number of studies to screen full-text	**8**
Full-text could be obtained	8
Reference list examined Y/N	N
Eligible papers	8

Screening of the full texts

Total number of studies to screen full paper	
No risk factor	2
Full texts not screened due to limited time resources	6
Remaining studies	**0**

All the studies identified have been coded according to the following rules:

- Prioritizing Step A (studies clearly addressing the risk factor)
- Prioritizing Step B (studies most recently published)
- Prioritizing Step C (studies from Europe)

Hereinafter are reported all the selected studies (see **Table 3**).

List of references resulting from search strategy (sorted by year of publication, meta-analysis first)

Table 3: List of references resulting from search strategy

	Publication	Coded Y/N	Reason
1	Møller M., Haustein S. (2013). Keep on cruising: Changes in lifestyle and driving style among male drivers between the age of 18 and 23, *Transportation Research part F*	N	No codable data
2	Møller M. (2004). An explorative study of the relationship between lifestyle and driving behaviour among young drivers, *Accident Analysis & Prevention, 36, 1081-1088*	N	No codable data
3	Chliaoutakis J.E., Koukouli S., Lajunen T., Tzamalouka G. (2005). Lifestyle traits as predictors of driving behaviour in urban areas of Greece, *Transportation Research part F, 8, 413-428*	Y	
4	Chliaoutakis J.E., Darviri C., Demakakos P.T. (1999). The impact of young drivers' lifestyle on their road traffic accident risk in greater Athens area, *Accident Analysis & Prevention, 31, 771-780*	Y	
5	Sagberg F., Selpi, Bianchi Piccinini G.F., Engström J. (2015). A review of research on driving styles and road safety, *Human Factors, 57, 1248-1275*	N	No codable data
6	Kouabenan D.R. (1998). Beliefs and the perception of risks and accidents, *Risk Analysis, 18, 243-252*	N	No codable data
7	Cerniglia L., Cimino S., Ballarotto G., Casini E., Ferrari A., Carbone P., Cersosimo M. (2015). Motor vehicle accidents and adolescents: An empirical study on their emotional and behavioral profiles, defense strategies and parental support, *Transportation Research Part F: Traffic Psychology and Behaviour, 35, 28-36*	N	Not screened
8	Lheureux F., Charlois C., Auzoult L., Minary J.-P. (2015). Me have a traffic accident? The effects of core self-evaluations on the perceived likelihood and perceived undesirability of traffic accidents, *Transportation Research Part F: Traffic Psychology and Behaviour, 34, 65-75*	N	Not screened
9	Scott-Parker B., Goode N., Salmon P. (2015). The driver, the road, the rules… and the rest? A systems-based approach to young driver road safety, *Accident Analysis & Prevention, 74, 297-305*	N	Not screened
10	Foo K.Y. (2015). Effects of familial climate on the adolescents' driving habits: a recent literature, *International Journal of Injury Control and Safety Promotion, 22, 127-135*	N	Not screened
11	Nordfjærn T., Simsekoglu T., Zavareh M.F., Hezaveh A.M., Mamdoohi A.R., Rundmo T. (2014). Road traffic culture and personality traits related to traffic safety in Turkish and Iranian samples, *Safety Science, 66, 36-46*	N	Not screened
12	Coogan M.A., Campbell M., Adler T.J., Forward S. (2014). Examining behavioral and attitudinal differences among groups in their traffic safety culture, *Transportation Research Part F: Traffic Psychology and Behaviour, 26, 303-316*	N	Not screened
13	Nordfjærn T. Simsekoglu T. (2014). Empathy, conformity, and cultural factors related to aberrant driving behaviour in a sample of Urban Turkish drivers, *Safety Science, 68, 55-64*	N	Not screened

	Publication	Coded Y/N	Reason
14	Warner H.W., Özkan T., Lajunen T., Tzamaloukas G.S. (2013). Cross-cultural comparison of driving skills among students in four different countries, *Safety Science, 57, 69-74*	N	Not screened
15	Murphy L.A., Robertson M.M., Huang Y.-H. (2012). The development of a conceptual model regarding the role of social modelling in safety behaviour: An integrated literature review, *Theoretical Issues in Ergonomics Science, 13, 286-302*	N	Not screened
16	Nichols A.L., Classen S., McPeek R., Breiner J. (2012). Does personality predict driving performance in middle and older age? an evidence-based literature review, *Traffic Injury Prevention, 13, 133-143*	N	Not screened
17	Adrian J., Postal V., Moessinger M., Rascle N., Charles A. (2011). Personality traits and executive functions related to on-road driving performance among older drivers, *Accident Analysis & Prevention, 43, 1652-1659*	N	Not screened
18	Di Milia L., Smolensky M.H., Costa G., Howarth H.D., Ohayon M.M., Philip P. (2011). Demographic factors, fatigue, and driving accidents: An examination of the published literature, *Accident Analysis & Prevention, 43, 516-532*	N	Not screened
19	Miller G., Taubman - Ben-Ari O. (2010). Driving styles among young novice drivers-The contribution of parental driving styles and personal characteristics, *Accident Analysis & Prevention, 42, 558-570*	N	Not screened
20	Orozova-Bekkevold I., Hels T. (2009) Road users' socio-economic status and road safety in Denmark, *Advances in Transportation Studies an international Journal*	N	Not screened
21	Mather R.D., DeLucia P.R. (2007) Testing for effects of racial attitudes and visual contrast on the speed of a driver's response to a pedestrian	N	Not screened
22	Lund J., Aarø L.E. (2004) Accident prevention. Presentation of a model placing emphasis on human, structural and cultural factors	N	Not screened
23	Kujala T., Mäkelä J., Kotilainen I., Tokkonen T. (2016). The Attentional Demand of Automobile Driving Revisited: Occlusion Distance as a Function of Task-Relevant Event Density in Realistic Driving Scenarios, *Human Factors, 58, 163-180*	N	No risk factor
24	Sadia R., Bekhor S., Polus A. (2015). Individual Selection of Driving Speeds: Analysis of a Stated Preference Survey, *Journal of Transportation Safety & Security, 7, 291-306*	Y	
25	Rosenbloom T., Eldror E. (2014). Effectiveness evaluation of simulative workshops for newly licensed drivers, *Accident Analysis and Prevention, 63, 30-36*	Y	
26	Kaber D., Zhang Y., Jin S., Mosaly P., Garner M. (2012). Effects of hazard exposure and roadway complexity on young and older driver situation awareness and performance, *Transportation Research part F, 15, 600-611*	N	No risk factor
27	Van Winsum W., Godthelp H. (1996). Speed choice and steering behavior in curve driving, *Human Factors, 38, 434-441*	Y	
28	Mayhew D., Simpson H., Pak A. (2003). Changes in collision rates among novice drivers during the first months of driving	Y	

	Publication	Coded Y/N	Reason
29	Mc Cartt A., Shabanova I., Leaf W. (2002). Driving experience, crashes and traffic citations of teenage beginning drivers	Y	
30	Freeman P., Neyens D.M., Wagner J., Switzer F., Alexander K., Pidgeon P. (2015). A video based run-off-road training program with practice and evaluation in a simulator	N	Not screened
31	Cao S., Qin Y., Zhao L., Shen M. (2015). Modeling the development of vehicle lateral control skills in a cognitive architecture	N	Not screened
32	Li X., Yan X., Wong S.C. (2015). Effects of fog, driver experience and gender on driving behavior on S-curved road segments	N	Not screened
33	Markkula G., Benderius O., Wahde M. (2014).Comparing and validating models of driver steering behaviour in collision avoidance and vehicle stabilisation	N	Not screened
34	Pérez-Zuriaga A.M., Camacho-Torregrosa F.J., Campoy-Ungría J.M., García A.,"Application of global positioning system and questionnaires data for the study of driver behaviour on two-lane rural roads",2013,	N	Not screened
35	Adrian J., Postal V., Moessinger M., Rascle N., Charles A. (2011). Personality traits and executive functions related to on-road driving performance among older drivers.	N	Not screened
36	Di Stefano M., Macdonald W. (2003). Assessment of older drivers: Relationships among on-road errors, medical conditions and test outcome	N	Not screened
37	Macadam C.C. (2003). Understanding and modeling the human driver	N	Not screened
38	Navon D. (2003). The paradox of driving speed: Two adverse effects on highway accident rate	N	Not screened
39	Taieb-Maimon M., Shinar D. (2001). Minimum and comfortable driving headways: Reality versus perception	N	Not screened
40	Comte S.L., Jamson A.H. (2000). Traditional and innovative speed-reducing measures for curves: An investigation of driver behaviour using a driving simulator	N	Not screened
41	Brookhuis K., De Waard D., Mulder B. (1994). Measuring driving performance by car-following in traffic	N	Not screened
42	Bélanger A., Gagnon S., Yamin S. (2010) Capturing the serial nature of older drivers' responses towards challenging events: A simulator study, *Accident Analysis and Prevention, 42, 809-817*	N	No risk factor
43	Trick L.M., Toxopeus R., Wilson D. (2010). The effects of visibility conditions, traffic density, and navigational challenge on speed compensation and driving performance in older adults, *Accident Analysis and Prevention, 42, 1661-1671*	N	No risk factor
44	Konstantopoulos P., Chapman P., Crundall D. (2010). Driver's visual attention as a function of driving experience and visibility. Using a driving simulator to explore drivers' eye movements in day, night and rain driving, *Accident Analysis and Prevention, 42, 827-834*	N	No codable data
45	Underwood G. (2007). Visual attention and the transition from novice to advanced driver, *Ergonomics, 50 , 1235-1249*	N	No codable data

	Publication	Coded Y/N	Reason
46	Stahl P., Donmez B., Jamieson G.A. (2016). Supporting anticipation in driving through attentional and interpretational in-vehicle displays	N	Not screened
47	Dadashova B., Arenas-Ramírez B., Mira-Mcwilliams J., Aparicio-Izquierdo F. (2016). Methodological development for selection of significant predictors explaining fatal road accidents	N	Not screened
48	Naujoks F., Purucker C., Neukum A. (2016). Secondary task engagement and vehicle automation - Comparing the effects of different automation levels in an on-road experiment	N	Not screened
49	Chen F., Wang J., Deng Y. (2015). Road safety risk evaluation by means of improved entropy TOPSIS-RSR	N	Not screened
50	Prat F., Gras M.E., Planes M., González-Iglesias B., Sullman M.J.M. (2015). Psychological predictors of texting while driving among university students	N	Not screened
51	Malik H., Larue G.S., Rakotonirainy A., Maire F. (2015). Fuzzy Logic to Evaluate Driving Maneuvers: An Integrated Approach to Improve Training	N	Not screened
52	Cicchino J.B., McCartt A.T. (2015). Critical older driver errors in a national sample of serious U.S. crashes	N	Not screened
53	Theofilatos A., Yannis G. (2015). A review of powered-two-wheeler behaviour and safety	N	Not screened
54	Cristea M., Delhomme P. (2015). Comprehension and acceptability of on-board traffic information: Beliefs and driving behaviour	N	Not screened
55	Baurès R., Oberfeld D., Tournier I., Hecht H., Cavallo V. (2014). Arrival-time judgments on multiple-lane streets: The failure to ignore irrelevant traffic	N	Not screened
56	Long K., Liu Y., Han L.D. (2013). Impact of countdown timer on driving maneuvers after the yellow onset at signalized intersections: An empirical study in Changsha, China	N	Not screened
57	Barton B.K., Lew R., Kovesdi C., Cottrell N.D., Ulrich T. (2013). Developmental differences in auditory detection and localization of approaching vehicles	N	Not screened
58	Scialfa C.T., Borkenhagen D., Lyon J., Deschênes M., Horswill M., Wetton M. (2012). The effects of driving experience on responses to a static hazard perception test	N	Not screened
59	Bromberg S., Oron-Gilad T., Ronen A., Borowsky A., Parmet Y. (2012).The perception of pedestrians from the perspective of elderly experienced and experienced drivers	N	Not screened
60	Meston C.N., Jennings M.B., Cheesman M.F. (2011). Older adults' views of their communication difficulties and needs while driving in a motor vehicle	N	Not screened
61	Crundall D. (2009). The deceleration detection flicker Test: A measure of experience?	N	Not screened
62	Hutton K.A., Sibley C.G., Harper D.N., Hunt M. (2001). Modifying driver behaviour with passenger feedback	N	Not screened
63	Renge K. (2000) Effect of driving experience on drivers' decoding process of	N	Not screened

	Publication	Coded Y/N	Reason
	roadway interpersonal communication		
64	Katila A., Keskinen E., Hatakka M. (1996). Conflicting goals of skid training	N	Not screened
65	Holland C.A., Rabbitt P.M.A. (1994). The problems of being an older driver: comparing the perceptions of an expert group and older drivers	N	Not screened
66	Elias W., Toledo T., Shiftan Y. (2010).The effect of daily-activity patterns on crash involvement, *Accident Analysis and Prevention, 42, 1682-1688*	N	No codable data
67	Factor R., Mahalel D., Yair G. (2007). The social accident: A theoretical model and a research agenda for studying the influence of social and cultural characteristics on motor vehicle accidents, *Accident Analysis and Prevention, 39, 914-921*	N	No codable data
68	Melinder K. (2007). Socio-cultural characteristics of high versus low risk societies regarding road traffic safety, *Safety Science, 45, 397-414*	Y	
69	Nabipour A.R., Khanjani N., Nakhaee N., Moradlou H.Z., Sullman M.J.M. (2015). The relationship between religion and the on-road behaviour of adolescents in Iran, *Tranportation Research Prt F, 29, 113-120*	Y	
70	Factor R., Yair G., Mahalel D. (2010). Who by accident? the social morphology of car accidents	N	No risk factor
71	Fuentes C., Eugnia Gras M., Font-Mayolas S., Bertran C., Sullman M.J.M., Ballester D. (2010). Expectations of efficacy, social influence and age as predictors of helmet-use in a sample of Spanish adolescents	N	Not screened
72	Hedlund J., Compton R. (2005). Graduated driver licensing research in 2004 and 2005	N	Not screened
73	Vakili V., Danaei M., Askarian M., Palenik C.J., Abdollahifard G. (2012). Transportation Behaviors in Shiraz, Iran	N	Not screened
74	Zhao J., Mann R.E., Chipman M., Adlaf E., Stoduto G., Smart R.G. (2006).The impact of driver education on self-reported collisions among young drivers with a graduated license	N	Not screened
75	Al-Saleh K., Bendak S. (2012). Drivers' behaviour at roundabouts in Riyadh	N	Not screened
76	Arosanyin G.T., Olowosulu A.T., Oyeyemi G.M. (2013). An examination of some safety issues among commercial motorcyclists in Nigeria: A case study	N	No risk factor
77	Bassani M., Dalmazzo D., Marinelli G., Cirillo C. (2014). The effects of road geometrics and traffic regulations on driver-preferred speeds in northern Italy. An exploratory analysis	N	No risk factor
78	Hatfield J., Fernandes R., Job R.F.S., Smith K. (2007). Misunderstanding of right-of-way rules at various pedestrian crossing types: Observational study and survey	N	Not screened
78	Nævestad T.-O., Phillips R.O., Elvebakk B. (2015). Traffic accidents triggered by drivers at work - A survey and analysis of contributing factors	N	Not screened
79	Xu Y., Li Y., Jiang L. (2014). The effects of situational factors and impulsiveness on drivers' intentions to violate traffic rules: Difference of driving experience	N	Not screened

	Publication	Coded Y/N	Reason
80	Polders E., Daniels S., Casters W., Brijs T. (2015). Identifying Crash Patterns on Roundabouts	N	Not screened
81	Bélanger A., Gagnon S., Stinchcombe A. (2015). Crash avoidance in response to challenging driving events: The roles of age, serialization, and driving simulator platform	N	Not screened
82	Öz B., Özkan T., Lajunen T. (2013). An investigation of professional drivers: Organizational safety climate, driver behaviours and performance	N	Not screened
83	Peer E. (2011). The time-saving bias, speed choices and driving behavior	N	No risk factor
84	Dogan E., Steg L., Delhomme P. (2011).The influence of multiple goals on driving behavior: The case of safety, time saving, and fuel saving	N	No risk factor
85	Marmeleira J.F., Godinho M.B., Fernandes O.M. (2009). The effects of an exercise program on several abilities associated with driving performance in older adults",	N	Not screened

3.2 REFERENCES

Studies coded

Chliaoutakis J.E., Darviri C., Demakakos P.T. (1999). The impact of young drivers' lifestyle on their road traffic accident risk in greater Athens area, Accident Analysis & Prevention, 31, 771-780

Chliaoutakis J.E., Koukouli S., Lajunen T., Tzamalouka G. (2005). Lifestyle traits as predictors of driving behaviour in urban areas of Greece, Transportation Research part F, 8, 413-428

Mayhew D., Simpson H., Pak A. (2003). Changes in collision rates among novice drivers during the first months of driving

Mc Cartt A., Shabanova I., Leaf W. (2002). Driving experience, crashes and traffic citations of teenage beginning drivers

Melinder K. (2007). Socio-cultural characteristics of high versus low risk societies regarding road traffic safety, Safety Science, 45, 397-414

Nabipour A.R., Khanjani N., Nakhaee N., Moradlou H.Z., Sullman M.J.M. (2015). The relationship between religion and the on-road behaviour of adolescents in Iran, Tranportation Research Prt F, 29, 113-120

Rosenbloom T., Eldror E. (2014). Effectiveness evaluation of simulative workshops for newly licensed drivers, Accident Analysis and Prevention, 63, 30-36

Sadia R., Bekhor S., Polus A. (2015). Individual Selection of Driving Speeds: Analysis of a Stated Preference Survey, Journal of Transportation Safety & Security, 7, 291-306

Van Winsum W., Godthelp H. (1996). Speed choice and steering behavior in curve driving, Human Factors, 38, 434-441

Additional studies analyzed

Berg, H.Y., (1194). Lifestyle, Traffic and Young Drivers. An interview study. *VTI rapport No389 A.*

Bolstad, C. A. (2001). Situation awareness: does it change with age? *Proceedings of the human factors and ergonomics society 45th annual meeting, 272-276*

Deery, H.A (1999). Hazard and risk perception among young novice drivers. *Journal of safety research 30 (4), 225-236.*

Dunbar, G., Hill, R., Lewis, V., (2001). Children's attentional skills and road behavior. *Journal of Experimental Psychology (7), 227-234*

Elias W., Toledo T., Shiftan Y. (2010).The effect of daily-activity patterns on crash involvement, Accident Analysis and Prevention, 42, 1682-1688

Ferguson, S.A, Williams, A.F., Chaplin, J.F., Reinfurt, D.W., De Leonardis, D.M. (2001). Relationship of parent driving records to the driving records of their children. *Accident Analysis and Prevention (33), 229-234*.

Gregersen, N.P., Berg, H.Y., (1994). Lifestyle and accidents among young drivers. *Accident Analysis and Prevention*, 26(3), 297-303.

Klidas, A., Vinken, H., Vulto, W., Lievense, P. (2003). Culture and Self-regulation. A Comparative Study on Cultural Contingencies and Self-regulation in Road Transport safety in the Netherlands. Main report. *Dutch Ministry of Transport, Public Works and Water Management.*

Konstantopoulos P., Chapman P., Crundall D. (2010). Driver's visual attention as a function of driving experience and visibility. Using a driving simulator to explore drivers' eye movements in day, night and rain driving, Accident Analysis and Prevention, 42, 827-834

Mc Phee, L., Scialfa, C. T., Dennis, W. M., Ho, G., Caird, J. K. (2004). Age differences in visual search for traffic signs during a simulated conversation. *Human factors, 46(4), 674-685.*

Møller M. (2004). An explorative study of the relationship between lifestyle and driving behaviour among young drivers, Accident Analysis & Prevention, 36, 1081-1088

Møller M., Haustein S. (2013). Keep on cruising: Changes in lifestyle and driving style among male drivers between the age of 18 and 23, Transportation Research part F

Rosenbloom, T., Nemrodov, D., Barkan, H. (2004). For heaven's sake follow the rules: Pedestrian's behavior in an ultra-orthodox and a non hortodox city. *Transportation Research Part F, 7 (6), 395-404.*

Sagberg F., Selpi, Bianchi Piccinini G.F., Engström J. (2015). A review of research on driving styles and road safety, Human Factors, 57, 1248-1275

Schulze, H. (1990). Lifestyle, leisure style and traffic behavior of young drivers. *Proceedings of Road Safety and Traffic Environment in Europe.VTI rapport 364 A.*

Trick L.M., Toxopeus R., Wilson D. (2010). The effects of visibility conditions, traffic density, and navigational challenge on speed compensation and driving performance in older adults, Accident Analysis and Prevention, 42, 1661-1671

Underwood, G. (2007). Visual attention and the transition from novice to advanced driver. *Ergonomics 50 (8), 1235-1249.*

Wells, P., Tong, S., Sexton, B., Grayson, G., Jones, E., (2008). Cohort II: A Study of New Drivers. Road Safety Research Report No. 81. *Department for Transport, London.*

Yildirim, Z. (2007). Religiousness, conservatism and their relationship with traffic behaviours (Matser Thesis). *Middle East Technical University*

Zeedyk, M.S., Wallace, L., Spry, L. (2002). Stop, look, listen and think? What young children really do when crossing the road? *Accident Analysis and Prevention (34), 43-50*.

Observation Errors

Failure to perceive information in the environment e.g. 'look but did not see' errors

1 Summary

Jänsch, M., September 2016

1.1 COLOUR CODE: GREY

In depth accident data shows that observation errors in traffic are often the causes of accidents. However little has been found in literature on observation errors that are related to a wrong strategy of observation e.g. "looked but failed to see".

1.2 KEY WORDS

Observation error, observation bias, observation strategy.

1.3 ABSTRACT

Next to other factors like distraction or a low activation, observation errors of road users are responsible for a failure in the processing of relevant information when navigating in traffic and potentially lead to an accident. Observation errors mostly occur due to a wrong focus of attention where the attention was not aimed towards the relevant objects at the right time, or immediate relevant information was missed (e.g. looked but failed to see). Observation errors are among the most frequent failures in the human task of information processing when driving.

1.4 BACKGROUND

What are observation errors?

Observation errors are part of information processing failures of a road user when coping with the task of participating in traffic. These information processing failures occur when the relevant information could have been acquired by the road user, however it was not acquired in time or it was not acquired at all. The participant could have been able to gather the necessary information by reason of adequate perception conditions, however failed to do so.

The observation errors as analysed in this chapter refer to errors which are related to a wrong focus of attention. While other errors of Information processing e.g. distraction or a low activation (fatigue, alcohol etc.) are handled as separate risk factors. Errors based on a wrong focus of attention are failures which happen in situations when whilst observing the traffic situation the attention was aimed towards the relevant objects, but the immediate relevant information (e.g. collision opponent) was missed. So the road user had either not looked in the right direction at the right time or he had looked adequately but failed to see the relevant information.

What is the effect of observation errors on road safety?

Unlike errors which occur due to a wrong estimation or a misjudgement of the situation, observation errors often lead to critical events where another road user or an important signal was completely missed in the information processing process. This often results in accidents where no reaction to avoid the accident could be taken. However according to in depth accident data (GIDAS), accidents caused by observation errors have no significant influence on the frequency of severe injuries.

How frequent do observation errors occur?

Road traffic accidents are frequently caused by observation errors. An analysis of in depth accident data (GIDAS) shows that over 90% of the causes of accidents are human failures. Among these human failures, about 1 quarter (24.5%) were from the category of information processing which includes observation errors. Observation errors regarding a wrong focus of attention had occurred with 7% of road users that had caused an accident.

Which factors influence the frequency of observation errors?

Observational errors are influenced by various factors. The analysis of accident data shows that the time of day and thus the lighting conditions have a significant effect on the frequency of observation errors. Also the location of the accident has an influence on observation errors as in urban traffic; with a lot of relevant information available to navigate through traffic observation errors are more common. The analysis of "looked but failed to see" accidents (Koustanai et al., 2007) revealed that specific traffic situations and types of involved road users (e.g. two-wheeled vehicles) lead to failures at a perceptual and a processing stage.

2 Scientific Details

2.1 METHODOLOGY

A literature search was carried out in two databases (Scopus and a KFV-internal literature database) with separate search strategies (for a detailed description see "Supporting documents"). One relevant study on observation errors was identified:

> Statistical analysis of "looked-but-failed-to-see" accidents: Highlighting the involvement of two distinct mechanisms, Koustanai A. et al., 2007.

Results

The study conducted a principal components analysis of two sets of in depth accident cases: (1) accidents due to a failure at a perceptual stage and (2) accidents attributable to a failure at a processing stage. For both types of failures typical accident scenarios with respect to infrastructure components, traffic situations and road user types as accident opponents were identified. As a result, the authors of the study assume that the perceptual failure is rather caused by internal factors (knowledge of the driving activity and learned scanning strategies) whereas processing failure is caused by more external factors (cue availability in the visual environment leads to a wrong understanding), which both disorient visual scanning strategies.

Accident characteristics

The analysis of the data from the Hannover accidents of the GIDAS data was done using the ACAS codes which describe (mostly human) causation factors which led to the accident occurrence. Observation errors in ACAS are part of the human failure category of "Information admission". In this category observation errors may occur due to distraction (internal, inside vehicle, outside vehicle); low activation (fatigue, alcohol etc.); wrong identification due to excessive demands; or due to a wrong focus of attention. For this analysis of observation errors only cases were chosen that had occurred due to a wrong focus of attention as the other types of observation errors are covered by the respective risk factors, e.g. distraction or fatigue.

The examination of the GIDAS data (GIDAS Hannover accidents; years 2008-2014 with ACAS-codes; data basis: 2599 accidents) showed that accidents with observation errors (wrong focus of attention) are significantly different from accidents where observation errors did not occur regarding the following accident characteristics (main outcomes):

- accident site (more observation accidents occur on urban roads),
- accident location (observation accidents rarely occur in bends),
- type of road user (more observation accidents occur among pedestrians),
- time of day (observation errors occur less often at night time).

The above mentioned characteristics of accidents caused by observation errors are displayed in. There are certainly more characteristics of accidents on which observation errors have an influence, however due to low case numbers no significant influence could be proved there.

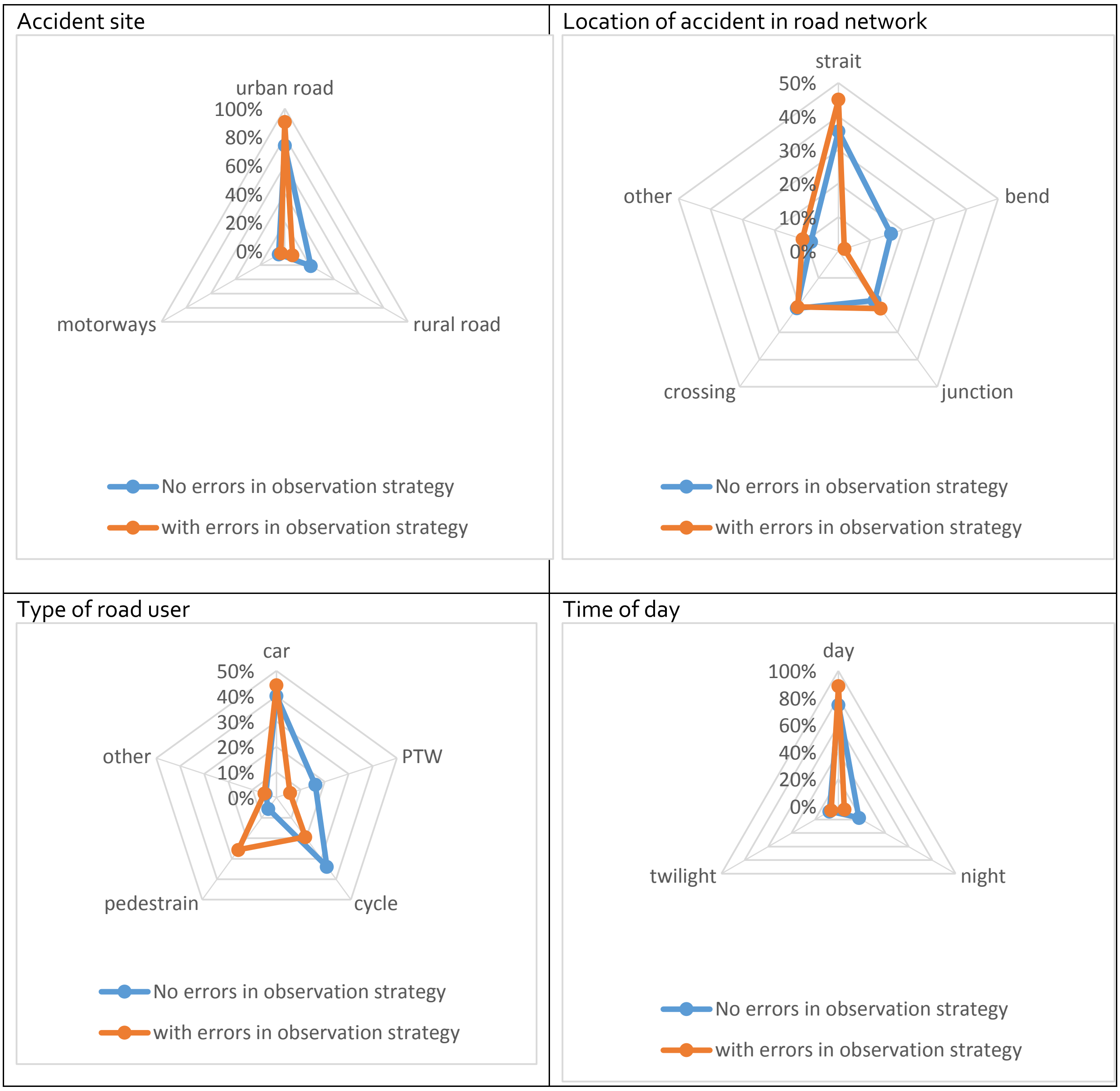

Figure 1: Differences of accidents with and without observation errors regarding the accidents site, accident location in the road network and the type of road user

The accident site describes whether the accident happened on an urban road (inside city limits), on a rural road (outside city limits), or on a motorway. Accidents with errors from the observation strategy happen significantly more often on urban roads (90.6%) compared with all accidents (73.9%), while they are underrepresented on rural roads at 6.3% compared to accidents without observation errors at 21.2%. There is no specific risk of accidents due to errors in the observation strategy when looking at the location in the road network, however, these accidents occur particularly seldom in bends (1.9%) compared to accidents without observation errors (16.4%). Accidents with observation errors occur often among pedestrians (25.6%) while riders of bicycles and powered two wheelers seem to be more concentrated as they have lower frequencies compared to accidents without observation errors. In general most accidents occur during the day time. Interestingly accidents due to observation errors occur more often during day time and less often during night time compared to all accidents without observation errors.

3 Supporting Documents

3.1 LITERATURE SEARCH STRATEGY

A literature search was conducted in March 2016 for the topics “misjudgement” and “observation errors”. It was carried out in the database Scopus which is a large abstract and citation database of peer-reviewed literature.

Database: Scopus **Date:** 20th of March 2016

no.	search terms / logical operators / combined queries	hits
#1	"misjudgement" OR "underestim*" OR "overestim*" OR "misunderstand*" OR "observation* error" OR "observation* bias"	157,576
#2	"road casualties" OR "road fatalities" OR "traffic accident" OR "road crash" OR "road violation" OR "traffic rule"	46,011
#3	("road safety" OR "traffic safety") AND ("risk" OR "collision")	4,617
#4	#1 AND #2	355
#5	#1 AND 3	51
#6	#4 OR #5	**381**

Table 1: Used search terms, logical operators, and combined queries of literature search (Scopus)

Detailed search terms, as well as their linkage with logical operators and combined queries are shown in Table 1. Results were limited to “article” and “review” and in a further step to the languages “English” and “German”. The quantity of studies was further reduced by limiting the source type to “Journal” as well as excluding various countries. As on study scope we only considered European countries, as well as Russia. As a last reduction step we limited the remaining studies to subject area “Engineering”.
This led to a final sample of **34 studies** of literature search in database Scopus (Table 2).

An additional literature search was conducted in a KFV-internal literature database (‘DOK-DAT’) using the following search terms:

- "misjudgement" OR "underestim*" OR "overestim*" OR "misunderstand*" OR "observation* error" OR "observation* bias".

With the above mentioned limitations **1 study** remained as relevant from DOK-DAT.

Results Literature Search

Database	**Hits**
Scopus (remaining papers after several limitations/exclusions)	34
DOK-DAT	1

Total number of studies to screen title/ abstract	**35**

Table 2: Results of both databases after limitations

In total the literature search led to 35 potential studies (**Table 2**). In a second step the abstracts of these studies were screened for relevance. This screening procedure resulted in 27 studies that seemed not to be relevant for the topics "misjudgement" or "observation errors" (**Table 3**). For the remaining 8 studies the full text was obtained. The screening of the full text resulted in 5 studies that were relevant for risks on misjudgement, and 1 study that was relevant for risks on observation errors (**Table 4**). Two studies were found not to be relevant for the topics which are analysed.

Screening

Total number of studies to screen title/ abstract	**35**
Exclusion criteria: Not relevant for the topic	27
Studies to obtain full-texts	**8**

Table 3: Screening of abstracts

Screening of the full texts

Total number of studies to screen full paper	**8**
Studies on misjudgement	5
Studies on observation errors	1
Not relevant studies	2

Table 4: Screening of full texts

3.2 REFERENCES

After screening the full text of the studies only one study remained relevant on observational errors:

Statistical analysis of "looked-but-failed-to-see" accidents: Highlighting the involvement of two distinct mechanisms, Koustanai A. et al., 2007.

Functional Impairment - Cognitive Impairment

Reduced ability (long term) in terms of cognitive function e.g. reduced attention, memory or thought processing due to illness, disorder, injury or age

1 Summary

Hay, M., Etienne, V., Gabaude, C., & Paire-Ficout, L., August 2016

1.1 COLOUR CODE: YELLOW

Depending on the type of cognitive impairment considered (neurocognitive disorders, depression or other psychiatric disorders), results on crash risk are inconsistent. Neurocognitive disorders do not seem to increase the pedestrians' crash risk, but increase drivers' crash risk. Depression significantly increases the risk of injury but results related to crash responsibility are inconsistent (no significant effect or increase of the crash risk). Depression also decreases the road mobility among men and their risk for crash involvement. Regarding the other psychiatric disorders, results are also inconsistent: psychological distress decreases crash risk, whereas psychiatric disorders increase it.

1.2 KEYWORDS

Dementia, Alzheimer's disease, Parkinson's disease, Mild cognitive impairment, Depression, Psychiatric disorders, Neurocognitive disorders, crash risk, road safety

1.3 ABSTRACT

Cognitive impairment is characterized by a deterioration of cognitive functions such as attention, memory or executive functions. The reviewed studies focused on the effect of neurocognitive disorders (dementia, Alzheimer's or Parkinson's diseases), depression, and other psychiatric disorders on crash risk or on driving performances. Case-control, cross- sectional and observational study designs were mainly used to investigate the effect of cognitive impairment on road safety. The reviewed studies have mostly been conducted on car drivers from the United States and the European Union. Studies generally indicated a higher risk of crash or driving errors for mild to severe neurocognitively impaired drivers. Discrepant findings about depression and other psychiatric disorders have been revealed. Studies on cognitive impairment presented several limitations: i) small sample size, ii) medical conditions difficult to control and often self-reported, and iii) analyses performed on self-reported crash data or on driving simulator performance.

1.4 BACKGROUND

What is cognitive impairment?

According to the Fifth edition of the Diagnostic and Statistical Manual of Mental Disorder (DSM-V), the cognitive impairment ranges along a continuum from mild cognitive impairment (MCI) or mild neurocognitive disorder (NCD) to severe dementia (American Psychiatric Association, 2013). Mild NCD is characterized by a moderate cognitive decline of one or more cognitive domains that does not prevent from performing complex daily living activities, but rather enhances their cognitive cost (Simpson, 2014). Dementia is a poly-symptomatic brain disease which causes disturbances of several higher cognitive functions that can negatively affect daily activities such as driving (Simpson, 2014).

How does cognitive impairment affect road safety?

Travelling in general (walking, driving, or riding a motorbike or cycling) is a complex activity which requires cognitive abilities such as attention, memory, visual-spatial abilities, or executive functions.

A large number of articles addressed the question of whether cognitive impairment increases the crash risk or not, and whether people are less fit to drive. However, finding a good criteria to decide whether a driver is more at risk and thus, not able to drive anymore, is challenging. Moreover, studies showed that even if impaired, drivers can self-regulate their driving habits and behaviour by adopting compensation strategies (Ball et al., 1998; Charlton et al., 2006; Molnar et al., 2013).

How often does the cognitive impairment occur? (prevalence)

Recent reviews indicated that the prevalence of MCI in older adults (60+) ranges from 10 to 20% (Langa & Levine, 2014; Roberts & Knopman, 2013). People who suffered from MCI have an increased risk (20 to 40%) of progression to dementia (Mitchell & Shiri-Feshki, 2009; Panza et al., 2005; Roberts & Knopman, 2013). The prevalence of dementia increases with aging (Ward, Arrighi, Michels, & Cedarbaum, 2012) and can reach 5 to 10% in older adults (65+) (Hugo & Ganguli, 2014). The prevalence of depression in the general population worldwide ranges from 1.6 to 3.5% (Moussavi et al., 2007; Üstün, Ayuso-Mateos, Chatterji, Mathers, & Murray, 2004) and can reach 20% in older adults (65+, Mathers, Fat, & Boerma, 2008).

How is the effect of cognitive impairment on road safety measured?

The effect of cognitive impairment on road safety can be measured thanks to regression analyses aiming at identifying the risk of crash, traffic violation or injury related to the cognitive impairment. The crash-related data can come from police crash reports or self-reported questionnaires. Driving performances (number and type of driving errors), assessed either on a driving simulator or on-road, can also be compared between cognitively impaired drivers and healthy controls.

Which factors influence the effect of cognitive impairment on road safety?

The factors which could influence the effect of cognitive impairment on road safety are personal characteristics such as the age or gender, but also the exposure (for example, the annual mileage driven), and the familiarity with the testing route.

1.5 OVERVIEW OF THE RESULTS

In literature, the research on the effect of cognitive impairment on road safety can be divided into three categories: i) effect of neurocognitive disorders (dementia, Alzheimer's, or Parkinson's diseases), ii) effect of depression, and iii) effect of other psychiatric disorders (psychological distress or mixed neurological impairments). Among the 16 reviewed studies, only one focused on the effect of dementia on pedestrian crash risk, and the others focused on cognitively impaired drivers. 10 studies were based on crash data, coming from self-reports, police crash reports, or national crash database; and 6 were based on on-road (3 studies) or driving simulator (3 studies) performances. Overall, the review-type analysis revealed that neurocognitive disorders increased the crash risk and degraded driving performances. Depression and other psychiatric disorders did not seem to increase the crash risk, however, the results were less consistent.

1.6 NOTES ON ANALYSIS METHODS

The method chosen for the analysis of the risk associated with cognitive impairment is a review type analysis, because of the heterogeneity of the study designs and methods. The generalization of results was difficult because groups were not homogeneous, and medical/psychological or psychiatric conditions varied greatly from person to person. In conclusion, the effects of neurocognitive disorders on drivers' road safety have been well covered, with analyses performed on crash data and on driving data (global driving performance, number of errors) collected from both on the road and on driving simulator evaluations. Further studies are needed to better understand the impact of cognitive impairment on the road safety of pedestrians.

2 Scientific Overview

2.1 LITERATURE REVIEW

Normal cognitive aging is associated with a natural decline of the mental capacity (Anstey & Low, 2004). However, cognitive aging can also be pathological and consequently leads to cognitive impairment. According to the International Classification of Diseases (10th revision), cognitive impairment relates to mental disorders caused by a cerebral disease or brain injury which lead to cerebral dysfunction.

MCI is characterized by an impaired memory, learning difficulties and difficulty to stay focussed on a task. The cognitive capacity of a person who suffers from MCI is below the normally cognitive level expected in person of the same age, but does not prevent them from performing activities of daily living. MCI can be investigated by standardized neuropsychological tests or by a specific clinical assessment.

Age, sex, genetic factors, level of education, vascular risk factor, cardiovascular outcomes, and neuropsychiatric condition are important risk factors for MCI (see Roberts & Knopman, 2013 for a review). In addition, medical risk factors (inflammation, obstructive sleep apnea or stroke), psychiatric risk factors (depression, late life anxiety, post-traumatic stress disorder, or head injury), or lifestyle and environmental factors (smoking or a heavy alcohol consumption) are also associated with dementia (see Hugo & Ganguli, 2014, for a review).

As cognitive impairment affects the cognitive domains required while travelling in general (walking, driving, riding or cycling), it could have negative effect on road safety.

2.2 DESCRIPTION OF THE AVAILABLE STUDIES

Among the 16 coded studies, eight were cross-sectional, four were case-control, and four were cohort studies (Table 1). Most of these studies focused on the impact of cognitive impairment on driver safety and few related to cognitively impaired pedestrians. The crash risk related to cognitive impairment was investigated either using self-reported crashes, police reports crashes, national crash database, on-road driving performances or driving simulator performances. Different types of analyses have been conducted to study this topic, such as regression (given the odds ratio or relative risk) or ANOVAs (given the absolute difference). Age, gender, severity of the disease, number of km driven, and familiarity with the route were often controlled variables.

Table 1. Description of the main characteristics of the coded studies dealing with cognitive impairment (sorted by year of publication)

Author, Year, Country	Risk factor	Sample, method/ design and analysis type	Risk / Control groups	Data type / Outcomes	Control variables
Aduen et al., 2015, United States	Depression	Observational cross-sectional study Odds ratio	Depression group: n = 251 / Healthy control group: n = 1828	Crash (self-report): Crash involvement, moving	Age, gender, education, income, marital status, average

				violations, injuries, crash responsibility	annual miles driven
Askan et al., 2015, United States	Alzheimer's disease Parkinson's disease	Observational cross-sectional study Absolute difference	Alzheimer's disease group: n = 32 / Parkinson's disease group: n = 39 / Healthy control group: n = 77	On-road driving assessment: Secondary tasks performances, on-road driving performances	Age: all drivers were > 70 years old
El Farouki et al., 2014, France	Depression	Observational, case control study Odds ratio	Low depressive group: n = 142 / Medium depressive group: n = 264 / High depressive group: n = 223 / Very low depressive group (controls): n = 148	Crash (self-report): Crash responsibility	
Park et al., 2011, Korea South	Low cognitive performances	Observational cross-sectional study Odds ratio	Fail at the Cognitive-Perceptual Assessment for driving (CPAD): n = 35 / Pass at the CPAD (controls): n = 68	Driving simulator assessment: Crash and error types.	Age
Martinuik et al., 2010, Australia	Psychological distress	Observational, cohort study Relative risk	Moderate psychological distress (PsyD) group: n = 7664 / High PsyD group: n = 4992 / Very high PsyD group: n = 1535 / No or low PsyD group (controls): n = 5822	Crash (national crash database): Crash involvement.	Sex, age, country of birth, remoteness, risky driving behavior, hours driving per week, and number of attempts at driving test
Vaux et al., 2010, United States	Alzheimer's disease Parkinson's disease	Observational cross-sectional study Absolute difference	Alzheimer's disease group: n = 6 / Parkinson's disease group: n = 8 / Healthy control group: n = 18	Driving simulator assessment: Sensibility to detect collision	
Uc et al., 2009, United States	Parkinson's disease	Observational, cross sectional study Absolute difference	Parkinson's disease group: n = 84 / Healthy control group: n = 182	On-road driving assessment: Number and type of errors	Age, education, gender, and familiarity with the testing route
Gorrie et al., 2008, Australia	Dementia	Observational, cross sectional study Odds ratio	Pedestrians with high neurofibrillary tangles (NFT): n = 22 (19 responsible for the crash) / Pedestrians with low NFT: n = 30 (19 responsible for the crash)	Crash: Fatal crash	
Sagberg et al., 2006, Norway	Depression Other psychiatric disorders	Observational, case-control study Odds ratio	Cases: at-fault drivers: n = 2226 / Controls: not at-fault drivers: n = 1840	Crash (self-report): Crash responsibility	Age; annual driven distance
Uc et al., 2006, United States	Alzheimer's disease	Observational, cross sectional study Odds ratio	Mild Alzheimer's disease group: n = 61 / Healthy control group: n = 115	Driving simulator assessment: Risk for rear-end collisions (REC)	Age and number of miles/week

				and risky avoidance behaviors	
Grace et al., 2005, United States	Alzheimer's disease Parkinson's disease	Observational, cross sectional study Absolute difference	Alzheimer's disease group: n = 20 / Parkinson's disease group: n = 21 / Healthy control group: n = 21	On-road driving assessment: Number of errors	
Meindorfner et al., 2005, Germany	Parkinson's disease	Observational, cohort study Odds ratio	Active drivers: n = 3066	Crash (self-report): Crash involvement and responsibility	
Parmentier et al., 2005, France	Depression	Observational, cohort study Absolute difference Odds ratio	MEN: Depressed in 2001: n = 35 / Depressed in 2000 and 2001: n = 34 / Depressed in 2000: n = 34 / Never depressed (controls): n = 7418 or 7401 depending on the analysis WOMEN: Depressed in 2001: n = 40 / Depressed in 2000 and 2001: n = 37 / Depressed in 2000: n = 36 / Never depressed (controls): n = 2030	Crash (self-report): Crash involvement.	
Vernon et al., 2002, United States	Neurocognitive disorders Other psychiatric disorders	Observational, case-control study Relative risk	Cases n = 68770 / Controls: n = 68770	Crash (police report): Crash involvement and responsibility, traffic violations (citations)	Age, sex, place of residence
Cooper et al., 1993, United States	Dementia	Observational, cohort study Absolute difference	Dementia group: n = 165 / Healthy control group: n = 165	Crash (national crash database): Crash involvement.	
Drachman & Sweaver, 1993, United States	Alzheimer's disease	Observational, case-control study Odds ratio	Alzheimer's disease group: n = 83 / Matched / paired healthy control group: n = 83	Crash (self-report): Crash involvement	Age, gender

2.3 DESCRIPTION OF THE ANALYSIS CARRIED OUT

No meta-analysis was found. In the 16 articles, the analyses were performed using three main approaches: (1) crash analysis from national crash database, police crash reports, or self-reporting; (2) on-road driving assessment from a qualitative score given by a driving instructor and/or an experimenter; (3) driving simulator assessment by counting the number of rear-end collisions, risky avoidance behaviours, and driving errors. As the designs and methods of these 16 studies were heterogeneous, a review-type analysis was conducted to investigate the crash risk associated with cognitive impairment.

Overview of the results

Table 2. Main results of the reviewed studies and effects on road safety. Key: ↗ Increased risk; NS result not statistically significant; ↘ reduced risk

Types of cognitive impairment	Road safety indicators	Effect on road safety	Main outcomes
Neurocognitive disorders	Crash involvement (data from self-reports, police crash reports or national database)	↗	- **Dementia** significantly increases the risk of drivers' crash involvement (Cooper, Tallman, Tuokko, & Beattie, 1993; Vernon et al., 2002) - **Alzheimer disease** significantly increases the risk of drivers' crash involvement (Drachman & Swearer, 1993) - **Parkinson's disease** significantly increases the risk of drivers' crash involvement (Meindorfner et al., 2005)
	Crash responsibility (data from self-reports, police crash reports or national database)	↗	- **Dementia** significantly increases the pedestrians' and drivers' at-fault crash risk (Gorrie, Brown, & Waite, 2008; Vernon et al., 2002) - Moderate **Parkinson's disease** significantly increases the drivers' at-fault crash risk, contrary to more advanced disease (Meindorfner et al., 2005)
	Traffic violations (data from police crash reports)	↗	- **Learning and memory problems** related to Alzheimer's disease increases the risk of traffic violations for restricted drivers (driving limitations in terms of speed, area, and time of the day, Vernon et al., 2002)
	On-road driving data	↗	- **Alzheimer's and Parkinson's diseases** significantly degrade the drivers' on-road driving performances (Aksan, Anderson, Dawson, Uc, & Rizzo, 2015; Grace et al., 2005; Uc et al., 2009)
	Simulated driving data	↗	- Drivers with **low cognitive performances** have a significantly increased crash risk and a higher risk of committing steering, vehicle positioning and lane change driving errors (Park et al., 2011) - **Alzheimer's and Parkinson's diseases** significantly reduce the sensibility to detect collision (Vaux, Ni, Rizzo, Uc, & Andersen, 2010) - **Alzheimer's disease** significantly increases the risky avoidance behaviour by promoting the abrupt slowing and prematurely stopping (Uc, Rizzo, Anderson, Shi, & Dawson, 2006)
Depression	Crash involvement (data from self-reports)	NS or ↘	Inconsistent results: - Non-significant effect of depression on the crash risk (Aduen, Kofler, Cox, Sarver, & Lunsford, 2015) - Significant decrease of the crash risk among men who reduced their road mobility (Parmentier et al., 2005)
	Crash responsibility (data from self-reports)	NS or ↗	Inconsistent results: - Non-significant effect of depression on the risk of crash responsibility (Aduen et al., 2015; El Farouki et al., 2014) - Significant increase of the risk for crash responsibility with depression (Sagberg, 2006)
	Traffic violations (data from self-reports)	NS	Non-significant effect of depression on the traffic violations risk (Aduen et al., 2015)
	Injury from collision	↗	Significant increase of the risk for injury after collision (Aduen et

	(data from self-reports)		al., 2015)
Other psychiatric disorders	Crash involvement (data from self-reports or police crash reports)	↘ or ↗ depending on the disorder considered	Inconsistent results: - Significant crash risk reduction with moderate psychiatric disorder but no longer significant for more severe disorder (Martiniuk et al., 2010) - Significant increase of crash risk with psychiatric disorders (Vernon et al., 2002).
	Crash responsibility (data from police crash reports or national database)	NS or ↗	Inconsistent results: - Non-significant effect of psychiatric disorders on the risk for at-fault crash (Sagberg, 2006) - Significant increase risk (Vernon et al., 2002)
	Traffic violations (data from police crash reports)	↗	Significant increase of the risk of traffic violations for the unrestricted drivers (Vernon et al., 2002)

Modifying conditions

The conditions that might modify the cognitive impairment-risk relationship could be:

- personal factors, such as age, gender, level of education, severity of the disease,
- environmental factors, such as living place (urban versus rural areas), familiarity with the testing route, number of years holding a driving license, or annual driven distance.

Conclusion

Neurocognitive disorders: the number of studies dealing with neurocognitive disorders as a risk factor is quite important. Main results indicate that dementia significantly increases the risk of drivers' crash involvement and pedestrians' and drivers' at-fault crash risk. Moreover, Alzheimer's and Parkinson's diseases significantly degrade the drivers' on-road driving performances observed in both on-road and driving simulator studies. Drivers with low cognitive performances have a significantly increased crash risk and a higher risk of committing steering, vehicle positioning and lane changes driving errors.

Depression: the number of studies dealing with depression as a risk factor is quite small. Results are inconsistent. Overall, crash involvement does not appear to increase with depression while injury after collision appears to increase.

Other psychiatric disorders: the number of studies dealing with other psychiatric disorders as a risk factor is very small. Inconsistent results were recorded.

Bias and transferability

The sample size was small and often raised the issue of transferability of results. The number of people with disorders can be too small for the effect to be statistically significant.

A great variability in the cognitive impairment group was often observed in literature dealing with this population. Even if inclusive criteria were controlled, it is difficult to homogenize all conditions. For example, the definition of the *other psychiatric disorders* group given by Vernon et al. (2002) seems too broad: all persons with a history of psychiatric or emotional conditions such as psychotic illness, including suicidal tendencies, perceptual distortions, psychomotor retardation, schizophrenia, major depressive disorders, bipolar disorders and/or organic brain syndromes were included. A more detailed analysis on the different categories of psychiatric profiles would give perhaps other results. Possible underreporting of medical conditions can occur.

Risks can be attributed to one factor (e.g. learning and memory troubles) or they can be due to another (e.g. psychiatric disorders), combined effects should be taken into consideration.

Finally, the number of studies dealing with depression and other psychiatric disorders was small and results were inconsistent. Thus, results were difficult to generalize.

3 Supporting Documents

3.1 METHODOLOGY

Below we describe first the method of the literature search, and subsequently the main research methods used for investigating the cognitive impairment-risk relationship.

Literature search strategy

Three international databases had been explored for the identification of the relevant studies about cognitive impairment and traffic risk:

- **Sciencedirect** (part of Elsevier databases), which hosts over 12 million pieces of content from 3,500 academic journals;
- **Web of science** (previously known as ISI Web of Knowledge), which hosts over 37 million from 9,000 sources;
- **Pubmed**, a free search engine accessing primarily the MEDLINE database of references and abstracts on life sciences and biomedical topics.

In the tables below are described the combination of search terms in each of these three databases and the number of articles found in each case (see Table 3,

Table 4, and Table 5).

Table 3. Results from Sciencedirect database (date: 30th march 2016)

search no.	search terms / operators / combined queries	hits
#1	"cognitive impairment" OR "cognitive deficit" OR "cognitive disorder"	105,473
#2	"road casualties" OR "road fatalities" OR "traffic accident" OR "road crash"	17,847
#3	("road safety" OR "traffic safety") AND ("collision" OR "risk")	55,297
#4	"dementia" OR "Alzheimer" OR "MCI" OR "Mild cognitive impairment" OR "Parkinson" OR "depressive symptoms" OR "depression" OR "Mood disorder" OR "unipolar disorder" OR "bipolar disorder" OR "psychiatric disorder"	1,082,723
#5	#1 AND #2 AND #4	529
#6	#1 AND #3 AND #4	993
#7	#5 OR #6	1,274

Limitations/ Exclusions:

- Search field: TITLE-ABS-KEY
- published: 1990 to current
- Source Type: "Journal"

Table 4. Results from Web of Science database (date: 30th march 2016)

search no.	search terms / operators / combined queries	hits
#1	"cognitive impairment" OR "cognitive deficit" OR "cognitive disorder"	91,490
#2	"road casualties" OR "road fatalities" OR "traffic accident" OR "road crash"	7,467
#3	("road safety" OR "traffic safety") AND ("collision" OR "risk")	2,587
#4	"dementia" OR "Alzheimer" OR "MCI" OR "Mild cognitive impairment" OR "Parkinson" OR "depressive symptoms" OR "depression" OR "Mood disorder" OR "unipolar disorder" OR "bipolar disorder" OR "psychiatric disorder"	1,090,788
#5	#2 AND #4	148
#6	#3 AND #4	65
#7	#5 OR #6	210

Limitations/ Exclusions:

- Search field: TS = Topic (title, abstract, key words, authors keywords)
- published: 1990 to current
- Source Type: "Journal"
- Language : English

Table 5.Results from Pubmed database (date: 30th march 2016)

search no.	search terms / operators / combined queries	hits
#1	"cognitive impairment" OR "cognitive deficit" OR "cognitive disorder"	38,152
#2	"road casualties" OR "road fatalities" OR "traffic accident" OR "road crash"	3,811
#3	("road safety" OR "traffic safety") AND ("collision" OR "risk")	1,355
#4	"dementia" OR "Alzheimer" OR "MCI" OR "Mild cognitive impairment" OR "Parkinson" OR "depressive symptoms" OR "depression" OR "Mood disorder" OR "unipolar disorder" OR "bipolar disorder" OR "psychiatric disorder"	557,569
#5	#1 AND #2 AND #4	54
#6	#1 AND#3 AND #4	26
#7	#5 OR #6	79

Limitations/ Exclusions:

- Search field: TS = Topic (title, abstract, key words, authors keywords)
- published: 1990 to current
- Source Type: "Journal"
- Language : English

This search strategy resulted in **346 studies to screen** (Table 6).

Table 6. Results of the literature search

Database	Hits
Scopus (after exclusions of unrelevant papers)*	209
Web of Science (after exclusions of unrelevant papers) *	97
Pubmed(after exclusions of unrelevant papers) *	40
Total number of studies to screen title/ abstract	346

*: not in English or French or not in a peer reviewed journal

Among these 346 studies, 260 have been excluded. The exclusion criteria are presented below in Table 7.

Table 7. Results from the first screening

Total number of studies to screen title/ abstract	346
-De-duplication	114 (remaining: 232)
-exclusion criteria : no risk factor	126 (remaining: 106)
-exclusion criteria B : part of a meta-analysis	15 (remaining: 91)
-exclusion criteria C : research not conducted in OECD countries	5 (remaining: 86)
Remaining studies	86
Not clear (full-text is needed)	33 (among the 86)
Studies to obtain full-texts	86

Among the 86 remaining studies, 61 full texts have been obtained and were eligible to be coded.

Table 8. Eligibility

Total number of studies to screen full-text	86
Full-text could be obtained	61
Reference list examined Y/N	No
Eligible papers	16

The 61 references were screened on potential relevance for coding (Table 9). The inspection of abstracts and/or full texts provided further information on whether the article was relevant for coding. Among the 61 references, 45 were not selected because articles did not refer to cognitive impairment or age was the only risk factor investigated. Then, the 16 remaining articles were coded.

The prioritizing coding steps were:

- Prioritizing Step A (meta-analysis first);

- Prioritizing Step B (best fitting in coding scheme);
- Prioritizing Step C (published more recently);
- Prioritizing Step D (Central-European countries before others).

Table 9. Screening of the full texts

Total number of eligible papers	**61**
-exclusion criteria "no cognitive impairment" or "age only"	19
-exclusion criteria "prediction"	13
-exclusion criteria "other risk factor"	5
-exclusion criteria "at-risk drivers screening"	4
-exclusion criteria "no driving safety outcome"	2
-exclusion criteria "no available data"	2
Remaining studies	16
Studies dealing with MCI, dementia, Alzheimer's disease or Parkinson's disease	10
Studies dealing with depressive symptoms	3
Studies dealing with other psychiatric disorders or mixed	3

The detailed list of eligible papers and the reasons why the articles have been included or excluded on the global analysis are presented in the Table 10.

Table 10. List of references resulting from search strategy (sorted by year of publication)

No.	Publication	Coded	Reason
1.	Aduen, P. A., Kofler, M. J., Cox, D. J., Sarver, D. E., & Lunsford, E. (2015). Motor vehicle driving in high incidence psychiatric disability: Comparison of drivers with ADHD, depression, and no known psychopathology. Journal of Psychiatric Research, 64, 59–66.	Y	Prioritizing Step B
2.	Aksan, N., Anderson, S. W., Dawson, J., Uc, E., & Rizzo, M. (2015). Cognitive functioning differentially predicts different dimensions of older drivers' on-road safety. Accident Analysis & Prevention, 75, 236–244.	Y	Prioritizing Step C
3.	Guo, F., Fang, Y., & Antin, J. F. (2015). Older driver fitness-to-drive evaluation using naturalistic driving data. Strategic Highway Research Program (SHRP 2) and Special Issue: Fourth International Symposium on Naturalistic Driving ResearchFourth International Symposium on Naturalistic Driving Research, 54, 49.e29–54.	N	No cognitive impairment Age only
4.	Hird, M. A., Vesely, K. A., Christie, L. E., Alves, M. A., Pongmoragot, J., Saposnik, G., & Schweizer, T. A. (2015). Is it safe to drive after acute mild stroke? A preliminary report. Journal of the Neurological Sciences, 354(1–2), 46–50.	N	Stroke
5.	El Farouki, K., Lagarde, E., Orriols, L., Bouvard, M.-P., Contrand, B., & Galera, C. (2014). The Increased Risk of Road Crashes in Attention Deficit Hyperactivity Disorder (ADHD) Adult Drivers: Driven by Distraction? Results from a Responsibility Case-Control Study. Plos One, 9(12), e115002.	Y	Prioritizing Step B

6.	MacLeod, K. E., Satariano, W. A., & Ragland, D. R. (2014). The impact of health problems on driving status among older adults. Journal of Transport & Health, 1(2), 86–94.	N	Outcome = driving cessation
7.	Orriols, L., Avalos-Fernandez, M., Moore, N., Philip, P., Delorme, B., Laumon, B., … Lagarde, E. (2014). Long-term chronic diseases and crash responsibility: A record linkage study. Accident Analysis & Prevention, 71, 137–143.	N	No cognitive impairment
8.	Staplin, L., Gish, K. W., & Sifrit, K. J. (2014). Using cognitive status to predict crash risk: Blazing new trails? Journal of Safety Research, 48, 19–25.	N	Crash risk prediction
9.	Bowers, A. R., Anastasio, R. J., Sheldon, S. S., O'Connor, M. G., Hollis, A. M., Howe, P. D., & Horowitz, T. S. (2013). Can we improve clinical prediction of at-risk older drivers? Accident Analysis & Prevention, 59, 537–547.	N	At-risk older drivers prediction
10.	Ferreira, I. S., Simões, M. R., & Marôco, J. (2013). Cognitive and psychomotor tests as predictors of on-road driving ability in older primary care patients. Transportation Research Part F: Traffic Psychology and Behaviour, 21, 146–158.	N	On-road driving ability prediction
11.	Hoggarth, P. A., Innes, C. R. H., Dalrymple-Alford, J. C., & Jones, R. D. (2013). Prospective study of healthy older drivers: No increase in crash involvement or traffic citations at 24 months following a failed on-road assessment. Transportation Research Part F: Traffic Psychology and Behaviour, 16, 73–80.	N	No cognitive impairment Age only
12.	Marino, M., de Belvis, A., Basso, D., Avolio, M., Pelone, F., Tanzariello, M., & Ricciardi, W. (2013). Interventions to evaluate fitness to drive among people with chronic conditions: Systematic review of literature. Accident Analysis & Prevention, 50, 377–396.	N	Fitness to drive prediction
13.	Nakagawa, Y., Park, K., & Kumagai, Y. (2013). Elderly drivers' everyday behavior as a predictor of crash involvement—Questionnaire responses by drivers' family members. Accident Analysis & Prevention, 50, 397–404.	N	At-risk older drivers screening
14.	Staplin, L., Gish, K. W., Lococo, K. H., Joyce, J. J., & Sifrit, K. J. (2013). The Maze Test: A significant predictor of older driver crash risk. Accident Analysis & Prevention, 50, 483–489.	N	Crash risk prediction
15.	Anstey, K. J., Horswill, M. S., Wood, J. M., & Hatherly, C. (2012). The role of cognitive and visual abilities as predictors in the Multifactorial Model of Driving Safety. Accident Analysis & Prevention, 45, 766–774.	N	Capacity to drive safely prediction
16.	Eby, D. W., & Molnar, L. J. (2012). Cognitive impairment and driving safety. PTW + Cognitive Impairment and Driving Safety, 49, 261–262.	N	No available data
17.	Ferreira, I. S., Simões, M. R., & Marôco, J. (2012). The Addenbrooke's Cognitive Examination Revised as a potential screening test for elderly drivers. PTW + Cognitive Impairment and Driving Safety, 49, 278–286.	N	Fitness to drive prediction
18.	Ortoleva, C., Brugger, C., Van der Linden, M., & Walder, B. (2012). Prediction of Driving Capacity After Traumatic Brain Injury: A Systematic Review. Journal of Head Trauma Rehabilitation, 27(4), 302–313.	N	Traumatic brain injured patients
19.	Hill, L., Rybar, J., Baird, S., Concha-Garcia, S., Coimbra, R., & Patrick, K. (2011). Road safe seniors: Screening for age-related driving disorders in inpatient and outpatient settings. Journal of Safety Research, 42(3), 165–169.	N	At-risk older drivers screening

20.	Park, S.-W., Choi, E. S., Lim, M. H., Kim, E. J., Hwang, S. I., Choi, K.-I., … Jung, H.-E. (2011). Association Between Unsafe Driving Performance and Cognitive-Perceptual Dysfunction in Older Drivers. PM&R, 3(3), 198–203.	Y	Prioritizing step B
21.	Rapoport, M. J., Zagorski, B., Seitz, D., Herrmann, N., Molnar, F., & Redelmeier, D. A. (2011). At-Fault Motor Vehicle Crash Risk in Elderly Patients Treated With Antidepressants. The American Journal of Geriatric Psychiatry, 19(12), 998–1006.	N	Effect of the antidepressants
22.	Selander, H., Lee, H. C., Johansson, K., & Falkmer, T. (2011). Older drivers: On-road and off-road test results. Accident Analysis & Prevention, 43(4), 1348–1354.	N	No cognitive impairment Age only
23.	Ackerman, M. L., Vance, D. E., Wadley, V. G., & Ball, K. K. (2010). Indicators of self-rated driving across 3 years among a community-based sample of older adults. Transportation Research Part F: Traffic Psychology and Behaviour, 13(5), 307–314.	N	No cognitive impairment Age only
24.	Baird, S., Hill, L., Rybar, J., Concha-Garcia, S., Coimbra, R., & Patrick, K. (2010). Age-related driving disorders: Screening in hospitals and outpatients settings. Geriatrics & Gerontology International, 10(4), 288–294.	N	At-risk older drivers screening
25.	Clarke, D. D., Ward, P., Bartle, C., & Truman, W. (2010). Older drivers' road traffic crashes in the UK. Accident Analysis & Prevention, 42(4), 1018–1024.	N	No cognitive impairment Age only
26.	Iverson, D. J., Gronseth, G. S., Reger, M. A., Classen, S., Dubinsky, R. M., & Rizzo, M. (2010). Practice Parameter update: Evaluation and management of driving risk in dementia. Neurology, 74(16), 1316–1324.	N	At-risk older drivers screening
27.	Martiniuk, A. L. C., Ivers, R. Q., Glozier, N., Patton, G. C., Senserrick, T., Boufous, S., … Norton, R. (2010). Does Psychological Distress Increase the Risk for Motor Vehicle Crashes in Young People? Findings From the DRIVE Study. Journal of Adolescent Health, 47(5), 488–495.	Y	Prioritizing step B
28.	Schultheis, M. T., Weisser, V., Ang, J., Elovic, E., Nead, R., Sestito, N., … Millis, S. R. (2010). Examining the Relationship Between Cognition and Driving Performance in Multiple Sclerosis. Archives of Physical Medicine and Rehabilitation, 91(3), 465–473.	N	Driving performances prediction
29.	Vaux, L. M., Ni, R., Rizzo, M., Uc, E. Y., & Andersen, G. J. (2010). Detection of imminent collisions by drivers with Alzheimer's disease and Parkinson's disease: A preliminary study. Assessing Safety with Driving Simulators, 42(3), 852–858.	Y	Prioritizing step B
30.	Kay, L. G., Bundy, A. C., & Clemson, L. M. (2009). Predicting Fitness to Drive in People With Cognitive Impairments by Using DriveSafe and DriveAware. Archives of Physical Medicine and Rehabilitation, 90(9), 1514–1522.	N	Fitness to drive prediction
31.	Meuser, T. M., Carr, D. B., & Ulfarsson, G. F. (2009). Motor-vehicle crash history and licensing outcomes for older drivers reported as medically impaired in Missouri. Accident Analysis & Prevention, 41(2), 246–252.	N	No specific cognitive impairment
32.	Skyving, M., Berg, H.-Y., & Laflamme, L. (2009). Older drivers' involvement in fatal RTCs. Do crashes fatal to them differ from crashes involving them but fatal to others? Safety Science, 47(5), 640–646.	N	No cognitive impairment Age only
33.	Uc, E. Y., Rizzo, M., Johnson, A. M., Dastrup, E., Anderson, S. W., & Dawson, J. D. (2009). Road safety in drivers with Parkinson disease. Neurology, 73(24), 2112–2119.	Y	Prioritizing step B

34.	Boufous, S., Finch, C., Hayen, A., & Williamson, A. (2008). The impact of environmental, vehicle and driver characteristics on injury severity in older drivers hospitalized as a result of a traffic crash. Journal of Safety Research, 39(1), 65–72.	N	No cognitive impairment Age only
35.	Gorrie, C. A., Brown, J., & Waite, P. M. E. (2008). Crash characteristics of older pedestrian fatalities: Dementia pathology may be related to 'at risk' traffic situations. Accident Analysis & Prevention, 40(3), 912–919.	Y	Prioritizing step B
36.	Stav, W. B., Justiss, M. D., McCarthy, D. P., Mann, W. C., & Lanford, D. N. (2008). Predictability of clinical assessments for driving performance. Journal of Safety Research, 39(1), 1–7.	N	No cognitive impairment Driving performances prediction
37.	Sagberg, F. (2006). Driver health and crash involvement: A case-control study. Accident Analysis & Prevention, 38(1), 28–34.	Y	Prioritizing step D
38.	Uc, E. Y., Rizzo, M., Anderson, S. W., Shi, Q., & Dawson, J. D. (2006). Unsafe rear-end collision avoidance in Alzheimer's disease. Journal of the Neurological Sciences, 251(1–2), 35–43.	Y	Prioritizing step B
39.	Vance, D. E., Roenker, D. L., Cissell, G. M., Edwards, J. D., Wadley, V. G., & Ball, K. K. (2006). Predictors of driving exposure and avoidance in a field study of older drivers from the state of Maryland. Accident Analysis & Prevention, 38(4), 823–831.	N	No cognitive impairment Age only
40.	Adler, G., Rottunda, S., & Dysken, M. (2005). The older driver with dementia: An updated literature review. Journal of Safety Research, 36(4), 399–407.	N	No available data
41.	Brown, L. B., Ott, B. R., Papandonatos, G. D., Sui, Y., Ready, R. E., & Morris, J. C. (2005). Prediction of on-road driving performance in patients with early Alzheimer's disease. Journal of The American Geriatrics Society, 53(1), 94–98.	N	On-road driving performances prediction
42.	Grace, J., Amick, M. M., D'Abreu, A., Festa, E. K., Heindel, W. C., & Ott, B. R. (2005). Neuropsychological deficits associated with driving performance in Parkinson's and Alzheimer's disease. Journal of the International Neuropsychological Society : JINS, 11(6), 766–775.	Y	Prioritizing step B
43.	Meindorfner, C., Korner, Y., Moller, J. C., Stiasny-Kolster, K., Oertel, G. H., & Kruger, H. P. (2005). Driving in Parkinson's disease: Mobility, accidents, and sudden onset of sleep at the wheel. Movement Disorders, 20(7), 832–842.	Y	Prioritizing step B
44.	Parmentier, G., Chastang, J. F., Nabi, H., Chiron, M., Lafont, S., & Lagarde, E. (2005). Road mobility and the risk of road traffic accident as a driver - The impact of medical conditions and life events. Accident Analysis and Prevention, 37(6), 1121–1134.	Y	Prioritizing step D
45.	Whelihan, W. M., DiCarlo, M. A., & Paul, R. H. (2005). The relationship of neuropsychological functioning to driving competence in older persons with early cognitive decline. Archives of Clinical Neuropsychology, 20(2), 217–228.	N	On-road driving performances prediction
46.	DeYoung, D. J., & Gebers, M. A. (2004). An examination of the characteristics and traffic risks of drivers suspended/revoked for different reasons. Journal of Safety Research, 35(3), 287–295.	N	No cognitive impairment
47.	Langford, J., Fitzharris, M., Newstead, S., & Koppel, S. (2004). Some consequences of different older driver licensing procedures in Australia. Accident Analysis & Prevention, 36(6), 993–1001.	N	No cognitive impairment Age only

48.	Di Stefano, M., & Macdonald, W. (2003). Assessment of older drivers: Relationships among on-road errors, medical conditions and test outcome. Senior Transportation Safety and Mobility, 34(4), 415–429.	N	Fitness to drive prediction
49.	Fontaine, H. (2003). Âge des conducteurs de voiture et accidents de la route: Quel risque pour les seniors ? Recherche - Transports - Sécurité, 79–80, 107–120.	N	No cognitive impairment Age only
50.	Lee, H. C., Cameron, D., & Lee, A. H. (2003). Assessing the driving performance of older adult drivers: on-road versus simulated driving. Accident Analysis and Prevention, 35(5), 797–803.	N	No cognitive impairment Age only
51.	Li, G., Braver, E. R., & Chen, L.-H. (2003). Fragility versus excessive crash involvement as determinants of high death rates per vehicle-mile of travel among older drivers. Accident Analysis & Prevention, 35(2), 227–235.	N	No cognitive impairment Age only
52.	Owsley, C., McGwin Jr., G., & McNeal, S. F. (2003). Impact of impulsiveness, venturesomeness, and empathy on driving by older adults. Senior Transportation Safety and Mobility, 34(4), 353–359.	N	No cognitive impairment Personality traits
53.	Fisk, G. D., Owsley, C., & Mennemeier, M. (2002). Vision, attention, and self-reported driving behaviors in community-dwelling stroke survivors. Archives of Physical Medicine and Rehabilitation, 83(4), 469–477.	N	Stroke
54.	Vernon, D. D., Diller, E. M., Cook, L. J., Reading, J. C., Suruda, A. J., & Dean, J. M. (2002). Evaluating the crash and citation rates of Utah drivers licensed with medical conditions, 1992–1996. Accident Analysis & Prevention, 34(2), 237–246.	Y	Prioritizing step D
55.	Janke, M. K. (2001). Assessing older drivers: Two studies. Journal of Safety Research, 32(1), 43–74.	N	No cognitive impairment Age only
56.	Lyman, J. M., McGwin Jr, G., & Sims, R. V. (2001). Factors related to driving difficulty and habits in older drivers. Accident Analysis & Prevention, 33(3), 413–421.	N	Outcome = driving habits and driving characteristics
57.	Zhang, J., Lindsay, J., Clarke, K., Robbins, G., & Mao, Y. (2000). Factors affecting the severity of motor vehicle traffic crashes involving elderly drivers in Ontario. Accident Analysis & Prevention, 32(1), 117–125.	N	No cognitive impairment Age only
58.	Hu, P. S., Trumble, D. A., Foley, D. J., Eberhard, J. W., & Wallace, R. B. (1998). Crash risks of older drivers: a panel data analysis. Accident Analysis & Prevention, 30, 569–81.	N	No cognitive impairment Age only
59.	Cooper, P. J., Tallman, K., Tuokko, H., & Beattie, B. L. (1993). Vehicle crash involvement and cognitive deficit in older drivers. Journal of Safety Research, 24(1), 9–17.	Y	Prioritizing step B
60.	Drachman, D. A., & Swearer, J. M. (1993). Driving and Alzheimer's disease: the risk of crashes. Neurology, 43, 2448–56.	Y	Prioritizing step B
61.	Hansotia, P. (1993). Seizure disorders, diabetes mellitus, and cerebrovascular disease. Considerations for older drivers. Clinics in Geriatric Medicine, 9(2), 323–39.	N	Diabetes and epilepsy

Detailed analysis of study designs and methods

Table 11. Sample characteristics and objectives of the 16 coded studies (sorted by year of publication)

Author, Year, Country	Sample, method/ design and analysis type	Risk group	Control group	Research conditions	Control variables
Aduen et al., 2015, United States	Observational cross-sectional study Odds ratio	Depression group: n = 251	Healthy control group: n = 1828	Investigation of the risk for traffic collisions, moving violations, collision-related injuries, and collision fault, related to depression.	Age, gender, education, income, marital status, average annual miles driven
Askan et al., 2015, United States	Observational cross-sectional study Absolute difference	Alzheimer's disease group: n = 32 Parkinson's disease group: n = 39	Healthy control group: n = 77	Investigation of the effect of navigation-related secondary tasks on the on-road driving safety errors among older drivers suffering from Alzheimer's and Parkinson's diseases.	Age: all drivers were > 70 years old
El Farouki et al., 2014, France	Observational, case control study Odds ratio	Low depressive group: n = 142 Medium depressive group: n = 264 High depressive group: n = 223	Very low depressive group: n = 148	Investigation of the risk for crash responsibility related to depression	
Park et al., 2011, Korea South	Observational cross-sectional study Odds ratio	Fail at the Cognitive-Perceptual Assessment for driving (CPAD): n = 35	Pass at the CPAD: n = 68	Investigation of the risk for drivers aged 65 or older for crash or dangerous manoeuvers on driving simulator related to low cognitive performances assessed by the CPAD.	Age
Martinuik et al., 2010, Australia	Observational, cohort study Relative risk	Moderate psychological distress (PsyD) group: n = 7664 High PsyD group: n = 4992 Very high PsyD group: n = 1535	No or low PsyD group: n = 5822	Investigation of the crash risk for novice drivers (17-24 years) who suffering from psychological distress.	Sex, age, country of birth, remoteness, risky driving behavior, hours driving per week, and number of attempts at driving test
Vaux et al., 2010, United States	Observational cross-sectional study Absolute difference	Alzheimer's disease group: n = 6 Parkinson's disease group: n = 8 Neurodegenerative disease (AD + PD) group: n = 14	Healthy control group: n = 18	Investigation of the impact of neurodegenerative diseases, namely Alzheimer's disease and Parkinson's disease on the ability to detect impending collisions.	
Uc et al., 2009, United States	Observational, cross sectional study	Parkinson's disease group: n = 84	Healthy control group: n =	On-road driving assessment of drivers suffering from Parkinson's	1/ Age, education, and gender

Author, Year, Country	Sample, method/ design and analysis type	Risk group	Control group	Research conditions	Control variables
	Absolute difference		182	disease and identification of the type of driving safety errors committed by these drivers.	2/ Age, education, gender, and familiarity with the testing route
Gorrie et al., 2008, Australia	Observational, cross sectional study Odds ratio	Pedestrians with high neurofibrillary tangles (NFT, attesting for dementia): n = 22 with 19 considered at least partially responsible for the crash	Pedestrians with low NFT: n = 30 with 19 considered at least partially responsible for the crash	Investigation of the fatal crash risk for older pedestrians aged 65 and older related to dementia (attested by the presence of lots of neurofibrillary tangles in their brain)	
Sagberg et al., 2006, Norway	Observational, case-control study Odds ratio	Cases: at-fault drivers: n = 2226	Controls: not at-fault drivers: n = 1840	Investigation of the relative crash involvement risk related to the subjective symptom of feeling depressed and neurological impairments (such as Parkinson's disease or multiple sclerosis).	Age; annual driven distance
Uc et al., 2006, United States	Observational, cross sectional study Odds ratio	Mild Alzheimer's disease group: n = 61	Healthy control group: n = 115	Investigation of the risk for rear-end collisions (REC) and risky avoidance behaviors in a simulator-based driving evaluation among drivers suffering from AD.	Age and number of miles/week
Grace et al., 2005, United States	Observational, cross sectional study Absolute difference	Alzheimer's disease group: n = 20 Parkinson's disease group: n = 21 Neurodegenerative disease (AD + PD): n = 41	Healthy control group: n = 21	Investigation of the on-road driving performances of patients who suffered either from Alzheimer's or Parkinson's disease.	
Meindorfner et al., 2005, Germany	Observational, cohort study Odds ratio	Moderate or advanced Parkinson's disease group: n = NA (n total of active drivers = 3066)	Minor Parkinson's disease group: n = NA (n of total active drivers = 3066)	Investigation of the risk of accident involvement and causation among patients who suffered from Parkinson's disease, related to the disease severity.	
Parmentier et al., 2005, France	Observational, cohort study Absolute difference	MEN: Depressed in 2001 only: n = 35 Depressed in 2000 and 2001: n = 34 Depressed in 2000	Never depressed men: n = 7418 or 7401 depending	Investigation of the risk for road traffic accidents related to self-reported medical conditions such as depression.	

Author, Year, Country	Sample, method/ design and analysis type	Risk group	Control group	Research conditions	Control variables
	Odds ratio	only: n = 34 WOMEN: Depressed in 2001 only: n = 40 Depressed in 2000 and 2001: n = 37 Depressed in 2000 only: n = 36	on the analysis Never depressed women: n = 2030		
Vernon et al., 2002, United States	Observational, case-control study Relative risk	Cases n = 68770	Controls: n = 68770	Investigation of the risk of crashes, at-fault crashes and citations for cognitively impaired drivers (i.e. who suffered from neurological problems, learning, memory and communication problems or psychiatric disorders), depending on their driving restriction status over a 5-year period.	Age, sex, place of residence
Cooper et al., 1993, United States	Observational, cohort study Absolute difference	Dementia group: n = 165	Healthy control group: n = 165	Comparison of the crash involvement between drivers with dementia and their matched healthy controls.	
Drachman & Sweaver, 1993, United States	Obsevational, case-control study Odds ratio	Alzheimer's disease group: n = 83	Matched / paired healthy control group: n = 83	Investigation of the annual risk for crashes for patients suffering from AD, in comparison with other drivers.	Age, gender

3.2 EXPLORATORY ANALYSIS OF RESULTS

Table 12.Detailed effects of cognitive impairment on road safety outcomes (sorted by year of publication)

Author, year, country	Risk factor	Outcome variable	Effects on Road Safety		Main outcome – description
Aduen et al., 2015, United Sates	Depressive symptoms	1 violation (last 3 years)	–	OR = 1. 40 CI95% = 0.97 – 1.93 p = NS	Non-significant effect on road safety
		2 or more violations (last 3 years)	–	OR = 1. 20 CI95% = 0.70 – 2.06 p = NS	Non-significant effect on road safety
		1 collision (last 3 years)	–	OR = 1. 24 CI95% = 0.86 – 1.79 p = NS	Non-significant effect on road safety
		2 or more collisions (last	–	OR = 1. 55	Non-significant effect on road

		3 years)		CI95% = 0.85 – 2.82 p = NS	safety
		Injury from collisions (n = 73 depressed drivers + 416 healthy controls)	↗	OR = 2.25 CI95% = 1.05 – 4.82 $p<0.05$	Depression is associated with self-reported injury following a collision.
		At-fault collisions (n = 73 depressed drivers + 416 healthy controls)	_	OR = 1. 47 CI95% = 0.84 – 2.60 p = NS	Non-significant effect on road safety
Askan et al., 2015, United States	Neurodegenerative disease (AD or PD)	Global secondary task driving performance	↗	$p<0.001$	Diseased drivers made more global errors during the secondary tasks than HC.
		Landmark and sign identification	↗	$p<0.001$	Diseased drivers made more errors during the Secondary task 1 (i.e. landmark / sign identification) than HC.
		Route following	↗	$p<0.001$	Diseased drivers made more errors during the Secondary task 2 (i.e. route following) than HC.
		Total number of errors (baseline)	↗	$p = 0.028$	Diseased drivers made more errors while driving during baseline segments than HC.
		Lane change errors (baseline)	_	$p = 0.266$	Non-significant effect on road safety
		Lane observance errors (baseline)	↗	$p = 0.002$	Diseased drivers made more errors related to lane observance while driving during baseline segments than HC.
		Speed control errors (baseline)	_	$p = 0.851$	Non-significant effect on road safety
		Traffic signs errors (baseline)	_	$p = 0.464$	Non-significant effect on road safety
		Stop sign errors (baseline)	_	$p = 0.788$	Non-significant effect on road safety
		Turns errors (baseline)	_	$p = 0.690$	Non-significant effect on road safety
		Curb errors (baseline)	_	$p = 0.412$	Non-significant effect on road safety
		Total number of errors (secondary task)	↗	$p = 0.011$	Diseased drivers made more errors while driving during on-task segments than HC.
		Lane change errors (secondary task)	_	$p = 0.405$	Non-significant effect on road safety

		Lane observance errors (secondary task)	↗	p = 0.017	Diseased drivers made more errors related to lane observance while driving during on-task segments than HC.
		Speed control errors (secondary task)	_	p = 0.567	Non-significant effect on road safety
		Traffic signs errors (secondary task)	_	p = 0.181	Non-significant effect on road safety
		Stop sign errors (secondary task)	_	p = 0.052	Non-significant effect on road safety
		Turns errors (secondary task)	↗	p<0.001	Diseased drivers made more errors related to turns while driving during on-task segments than HC.
		Curb errors (secondary task)	_	p = 0.081	Non-significant effect on road safety
El Farouki et al., 2014, France	Low depressive disorders	Crash responsibility	_	OR = 1.05 Ci95% = 0.63 – 1.75 p = NS	Low depressive drivers were not significantly more at risk to be responsible for a crash than very low depressive drivers
	Medium depressive disorders	Crash responsibility	_	OR = 1.47 Ci95% = 0.91 – 2.39 p = NS	Medium depressive drivers were not more at risk to be responsible for a crash than very low depressive drivers
	High depressive disorders	Crash responsibility	_	OR = 1.74 Ci95% = 0.99 – 3.08 p = NS	High depressive drivers were not more at risk to be responsible for a crash than very low depressive drivers
Park et al., 2011, Korea South	Failure at the Cognitive-Perceptual Assessment for Driving (CPAD) and Age: >65	Crash (older drivers (OD) who failed CPAS versus drivers who passed)	↗	OR = 4.0 CI 95% = 1.5 – 10.7 p<0.05	OD who failed CPAD have a higher risk for crash than drivers who passed CPAD
		Crash (OD who failed CPAS versus OD who passed)	↗	OR = 2.3 CI 95% = 0.6 – 8.5 p<0.05	OD who failed CPAD have a higher risk for crash than OD who passed CPAD
		Controlling speed (OD who failed CPAS versus drivers who passed)	_	OR = 2.6 CI 95% = 0.7 – 9.2 p = NS	Non-significant effect on road safety
		Controlling speed (OD who failed CPAS versus OD who passed)	_	OR = 0.6 CI 95% = 0.2 – 2.4 p = NS	Non-significant effect on road safety
		Braking (OD who failed CPAS versus drivers who	_	OR = 0.5 CI 95% = 0.1 – 4.4 p = NS	Non-significant effect on road safety

		passed)			
		Braking (OD who failed CPAS versus OD who passed)	–	OR = 0.2 CI 95% = 0.0 – 1.7 p = NS	Non-significant effect on road safety
		Steering (OD who failed CPAS versus drivers who passed)	↗	OR = 3.5 CI 95% = 1.5 – 8.3 p<0.05	OD who failed CPAD have a higher risk for steering-related driving errors than drivers who passed CPAD
		Steering (OD who failed CPAS versus OD who passed)	↗	OR = 2.5 CI 95% = 0.8 – 7.8 p<0.05	OD who failed CPAD have a higher risk for steering-related driving errors than OD who passed CPAD
		Vehicle positioning (OD who failed CPAS versus drivers who passed)	↗	OR = 2.8 CI 95% = 1.1 – 7.0 p<0.05	OD who failed CPAD have a higher risk for vehicle positioning-related driving errors than drivers who passed CPAD
		Vehicle positioning (OD who failed CPAS versus OD who passed)	↗	OR = 2.7 CI 95% = 0.7 – 9.7 p<0.05	OD who failed CPAD have a higher risk for vehicle positioning-related driving errors than OD who passed CPAD
		Lane changes (OD who failed CPAS versus drivers who passed)	↗	OR = 6.5 CI 95% = 2.3 – 18.3 p<0.05	OD who failed CPAD have a higher risk for lane changes-related driving errors than drivers who passed CPAD
		Lane changes (OD who failed CPAS versus OD who passed)	↗	OR = 3.0 CI 95% = 0.8 – 10.8 p<0.05	OD who failed CPAD have a higher risk for lane changes-related driving errors than OD who passed CPAD
		Turns (OD who failed CPAS versus drivers who passed)	–	OR = 0.7 CI 95% = 0.2 – 2.6 p = NS	Non-significant effect on road safety
		Turns (OD who failed CPAS versus OD who passed)	–	OR = 0.5 CI 95% = 0.1 – 2.3 p = NS	Non-significant effect on road safety
Martinuik et al., 2010, Australia	Moderate psychological distress (PsyD)	Crash involvement	↘	RR = 0.85 CI 95% = 0.74 - 0.97 p = 0.02	The moderately PsyD novice drivers showed a significant lower risk of crash than the no or low PsyD novice drivers.
		Number of single vehicle crashes	–	RR = 0.94 CI 95% = 0.69 - 1.28 p = 0.69	Non-significant effect on road safety
	High PsyD	Crash involvement	–	RR = 0.95 CI 95% = 0.82 – 1.11 p = 0.53	Non-significant effect on road safety

		Number of single vehicle crashes	_	RR = 1.06 CI 95% = 0.76 - 1.49 p = 0.72	Non-significant effect on road safety
	Very high PsyD	Crash involvement	_	RR = 0.91 CI 95% = 0.73 – 1.13 p = 0.38	Non-significant effect on road safety
		Number of single vehicle crashes	_	RR = 1.28 CI 95% = 0.81 - 2.03 p = 0.29	Non-significant effect on road safety
Vaux et al., 2010, United States	Neurodegenerative diseases: Alzheimer's disease (AD) and Parkinson's disease (PD)	Sensitivity to detect collision	↗	F(1, 30) = 12.2 p<0.001	Neurodegenerative disease (AD or PD) patients were significantly less sensitive to detect collisions than HC
	AD	Sensitivity to detect collision	↗	p=0.01	AD patients were significantly less sensitive to detect collisions than HC
	PD	Sensitivity to detect collision	↗	p=0.02	PD patients were significantly less sensitive to detect collisions than HC
Uc et al., 2009, United States	Parkinson disease (PD) (Analyses only adjusted for age gender and education)	Total error	↗	p < 0.001	PD patients committed significantly more errors in total than HC
		Lane observance	↗	p < 0.001	PD patients committed significantly more errors related to lane observance than HC
		Turns	↗	p < 0.001	PD patients committed significantly more errors related to turns than HC
		Lane change	_	p = 0.68	Non-significant effect on road safety
		Stop signs	↗	p = 0.02	PD patients committed significantly more errors related to stop signs than HC
		Control of speed	↗	p < 0.001	PD patients committed significantly more errors related to the control of speed than HC
		Traffic signals	_	p = 0.96	Non-significant effect on road safety
		Pulling away from curb	_	p = 0.14	Non-significant effect on road safety
		Parallel parking	↗	p < 0.01	PD patients committed

					significantly more parallel parking errors than HC
		Curves	_	$p = 0.56$	Non-significant effect on road safety
		Railroad crossing	_	$p = 0.24$	Non-significant effect on road safety
		Overtaking	_	$p = 0.051$	Non-significant effect on road safety
		Serious errors	↗	$p < 0.001$	PD patients committed significantly more serious errors than HC. On the 76 error types, 30 were classified as "serious", which were seen across all the different error categories
	PD (Analyses adjusted for age gender, education, and familiarity with the testing route)	Total error	↗	$p < 0.01$	PD patients committed significantly more errors in total than HC
		Lane observance	↗	$p < 0.01$	PD patients committed significantly more errors related to lane observance than HC
		Turns	_	$p = 0.30$	Non-significant effect on road safety
		Lane change	_	p 0.67	Non-significant effect on road safety
		Stop signs	↗	$p = 0.03$	PD patients committed significantly more errors related to stop signs than HC
		Control of speed	_	$p = 0.28$	Non-significant effect on road safety
		Traffic signals	_	$p = 0.94$	Non-significant effect on road safety
		Pulling away from curb	_	$p = 0.78$	Non-significant effect on road safety
		Parallel parking	_	$p = 0.93$	Non-significant effect on road safety
		Curves	_	$p = 0.90$	Non-significant effect on road safety
		Railroad crossing	_	$p = 0.59$	Non-significant effect on road safety
		Overtaking	_	$p = 0.16$	Non-significant effect on road safety

		Serious errors	_	p = 0.10	Non-significant effect on road safety
Gorrie et al., 2008, Australia	Dementia (high NFT) within all participants	Pedestrian responsibility	_	OR = 3.66 CI 95% = 0.8 – 15.0 p = 0.07	Non-significant effect on road safety
		Complexity = Low versus High	_	OR = 3.20 CI 95% = 0.76 – 13.0 p = 0.12	Non-significant effect on road safety
		Complexity = Moderate versus High	_	OR = 0.40 CI 95% = 0.1 – 1.8 p = 0.26	Non-significant effect on road safety
		Vehicle movement = turning / merging versus forward	_	OR = 0.0000027 CI 95% = 0.0013 – 0.0061 p = 0.97	Non-significant effect on road safety
		Vehicle movement = reversing vehicle versus forward	_	OR = 4.50 CI 95% = 0.8 – 25.1 p = 0.08	Non-significant effect on road safety
		Lane proximity to kerb near versus far	_	OR = 2.15 CI 95% = 0.58 – 8.0 p = 0.25	Non-significant effect on road safety
		Adjacent activity = yes versus no	_	OR = 1.12 CI 95% = 0.27 – 4.5 p = 0.86	Non-significant effect on road safety
		Distance to the pedestrian crossing = 0-10 m versus on crossing	_	OR = 0.63 CI 95% = 0.05 - 7.45 p = 0.71	Non-significant effect on road safety
		Distance to the pedestrian crossing = 10-50 m versus on crossing	_	OR = 5.0 CI 95% = 0.345 – 71.9 p = 0.23	Non-significant effect on road safety
		Distance to the pedestrian crossing = 50-100 m versus on crossing	_	OR = 1.67 CI 95% = 0.19 - 14.05 p = 0.64	Non-significant effect on road safety
		Distance to the pedestrian crossing = >100 m versus on crossing	_	OR = 1.66 CI 95% = 0.35 – 7.8 p = 0.52	Non-significant effect on road safety
		Speed limit = <60 km/h versus 60 km/h	_	OR = 1.13 CI 95% = 0.28 – 4.3 p = 0.86	Non-significant effect on road safety
		Speed limit = > 60 km/h versus 60 km/h	_	OR = 1.80 CI 95% = 0.30 - 10.6 p = 0.51	Non-significant effect on road safety
		Designated pedestrian	_	OR = 3.0	Non-significant effect on road

		crossing location = traffic light versus zebra crossing		CI 95% = 0.23 - 39.6 p = 0.41	safety
		Designated pedestrian crossing location = not designated crossing versus zebra crossing	_	OR = 3.23 CI 95% = 0.33 - 31.5 p = 0.31	Non-significant effect on road safety
		Lighting = dusk versus daylight	_	OR = 0.61 CI 95% = 0.10 - 3.79 p = 0.60	Non-significant effect on road safety
		Lighting = darkness versus daylight	_	OR = 0.74 CI 95% = 0.16 - 3.55 p = 0.71	Non-significant effect on road safety
		Accident location = intersection versus two-way undivided	_	OR = 0.96 CI 95% = 0.21 - 4.42 p = 0.96	Non-significant effect on road safety
		Accident location = divided road way versus two-way undivided	_	OR = 2.17 CI 95% = 0.45 - 10.44 p = 0.33	Non-significant effect on road safety
		Accident location = other versus two-way undivided	_	OR = 5.05 Ci 95% = 0.96 – 26.66 p = 0.05	Non-significant effect on road safety
		Type of vehicle = SUV / van / small truck versus car	_	OR = 2.10 Ci 95% =0.61 – 7.27 p =0.23	Non-significant effect on road safety
		Type of vehicle = bus / large truck versus car	_	OR = 0.32 Ci 95% = 0.03 – 3.18 p =0.33	Non-significant effect on road safety
	Dementia (high NFT) within participants at least responsible for the crash	Complexity = Low versus High	_	OR = 8.50 Ci 95% = 0.88 – 83.07 p = 0.06	Non-significant effect on road safety
		Complexity = Moderate versus High	_	OR = 0.61 Ci 95% = 0.12 – 3.16 p = 0.55	Non-significant effect on road safety
		Vehicle movement = turning / merging versus forward	_	OR = 0.0000019 Ci 95% = 0 - 0 p = 0.97	Non-significant effect on road safety
		Vehicle movement = reversing vehicle versus forward	_	OR = 3.23 Ci 95% = 0.55 – 18.9 p = 0.19	Non-significant effect on road safety
		Lane proximity to kerb near versus far	_	OR = 3.30 Ci 95% = 0.66 – 16.85 p = 0.15	Non-significant effect on road safety

		Adjacent activity = yes versus no	_	OR = 2.43 Ci 95% = 0.38 – 15.27 p = 0.34	Non-significant effect on road safety
		Distance to the pedestrian crossing = 0-10 m versus on crossing	_	OR = 0.66 Ci 95% = 0.04 – 11.2 p = 0.77	Non-significant effect on road safety
		Distance to the pedestrian crossing = 10-50 m versus on crossing	_	OR = 2.60 Ci 95% = 0.16 – 45.15 p = 0.46	Non-significant effect on road safety
		Distance to the pedestrian crossing = 50-100 m versus on crossing	_	OR = 0.89 Ci 95% = 0.08 – 9.1 p = 0.92	Non-significant effect on road safety
		Distance to the pedestrian crossing = >100 m versus on crossing	_	OR = 1.11 Ci 95% = 0.16 – 7.51 p = 0.91	Non-significant effect on road safety
		Speed limit = <60 km/h versus 60 km/h	_	OR = 1.37 Ci 95% = 0.29 - 6.40 p = 0.68	Non-significant effect on road safety
		Speed limit = > 60 km/h versus 60 km/h	_	OR = 2.0 Ci 95% = 2.77 – 15.3 p = 0.47	Non-significant effect on road safety
		Designated pedestrian crossing location = not designated crossing versus traffic light	_	OR = 0.90 Ci 95% = 0.16 – 5.01 p = 0.90	Non-significant effect on road safety
		Lighting = dusk versus daylight	_	OR = 0.80 Ci 95% = 0.10 – 6.55 p = 0.84	Non-significant effect on road safety
		Lighting = darkness versus daylight	_	OR = 0.40 Ci 95% = 0.06 – 2.57 p = 0.33	Non-significant effect on road safety
		Accident location = intersection versus two-way undivided	_	OR = 0.62 Ci 95% = 0.07 – 5.35 p = 0.67	Non-significant effect on road safety
		Accident location = divided road way versus two-way undivided	_	OR = 1.25 Ci 95% = 0.19 - 8.45 p = 0.81	Non-significant effect on road safety
		Accident location = other versus two-way undivided	_	OR = 5.0 Ci 95% = 0.69 – 64.40 p = 0.23	Non-significant effect on road safety
		Type of vehicle = SUV / van / small truck versus	_	OR = 1.42 Ci 95% = 0.33 – 6.18	Non-significant effect on road safety

		car		p = 0.64	
		Type of vehicle = bus / large truck versus car	_	OR = 0.36 Ci 95% = 0.05 – 2.37 p = 0.29	Non-significant effect on road safety
Sagberg et al., 2006, Norway	Depressive symptoms	Crash responsibility	↗	OR = 2.23 CI 95% = 0.98 - 3.48 p = 0.03	Feeling depressed increased significantly the risk of being responsible for a crash
	Dementia (neurological impairments)	Crash responsibility	_	OR = 1.49 CI 95% = 0.69 - 3.22 p = NS	Non-significant effect on road safety
Uc et al., 2006, United States	Alzheimer's Disease (AD)	Risky avoidance behaviour (global)	↗	OR = 3.53 p = 0.014	Drivers with AD were significantly at higher odds of unsafe avoidance behavior than HC.
		Rear-end collision (REC)	_	OR = 0.38 p = 0.80	Crash rates were not significantly different between AD and HC groups.
		Risky avoidance behavior : abrupt slowing	↗	OR = 2.52 p = 0.02	Drivers with AD were significantly at higher odds of slowing down abruptly than HC.
		Risky avoidance behavior : prematurely stopping	↗	OR = 2.33 p = 0.015	Drivers with AD were significantly at higher odds of stopping prematurely than HC.
		Risky avoidance behavior : swerving out of the lane	_	OR = 3.32 p = 0.78	Non-significant effect on road safety
Grace et al., 2005, United States	Neurodfegene rative disease (AD or PD)	Number of on-road driving errors	↗	F = 17.99 p = 0.001	All diseased drivers made significantly more driving errors than HC.
	AD	Number of on-road driving errors	↗	p = 0.001	PD drivers made significantly more driving errors than HC.
	PD	Number of on-road driving errors	↗	p = 0.001	AD drivers made significantly more driving errors than HC.
	AD versus PD	Number of on-road driving errors	↗	p = 0.003	AD drivers made significantly more driving errors than PD drivers.
Meindorfner et al., 2005, Germany	Moderate PD	Accident involvement	↗	oR = 1.42 Ci 95% = 1.12 - 1.81 p<0.005	Drivers with moderate PD were significantly at higher odds of being involved in an accident than drivers with minor PD.
		Accident causation	↗	oR = 1.45 Ci 95% = 1.09 - 1.92 p<0.05	Drivers with moderate PD were significantly at higher odds of being responsible for

					accident than drivers with minor PD.
	Advanced PD	Accident involvement	↗	oR = 1.51 Ci 95% = 1.05 - 2.18 p<0.05	Drivers with advanced PD were significantly at higher odds of being involved in an accident than drivers with minor PD.
		Accident causation	_	oR = 1.20 Ci 95% = 0.78 - 1.86 p = NS	Non-significant effect on road safety
Parmentier et al., 2005, France	Depression Men	Road mobility change	↘	p < 0.001	Depression entailed a decrease in the road mobility among men.
	Depression Women	Road mobility change	_	p = 0.23	Non-significant effect on road safety
	Depression only in 2000 Men	Road mobility change	_	p = 0.94	Non-significant effect on road safety
	Depression only in 2001 Men	Road mobility change	_	p = 0.08	Non-significant effect on road safety
	Depression in 2000 and 2001	Road mobility change	↘	p < 0.001	Men showed a greater decrease in the road mobility when they suffered from depression both in 2000 and 2001. The more the depression lasted, the more the men reduced their road mobility.
	Depression in 2001 only and changes in road mobility	Road traffic accident	_	OR = 1.00 p = NS	Non-significant effect on road safety
	Depression in 2000 and 2001 and changes in road mobility	Road traffic accident	↘	OR = 0.96 p < 0.001	Men who suffered from depression in 2000 and 2001 and who reduced their mobility between 2000 and 2002 were at lower risk of RTA than drivers who did not suffer from depression in 2000 and 2001 and who did not change their mobility between the same period of time.
Vernon et al., 2002, United States	Neurological problem (Not restricted drivers)	Crash	↗	RR = 1.62 Ci 95% = 1.32 – 1.99 p <0.05	Drivers with neurological problems and unrestricted driving were at higher risk of crashes than their peers.
		At-fault crash	↗	RR = 2.20 Ci 95% = 1.71 – 2.84	Drivers with neurological problems and unrestricted

				$p < 0.05$	driving were at higher risk of at-fault crashes than their peers.
		Citation	–	RR = 0.92 Ci 95% = 0.76 – 1.10 p = NS	Non-significant effect on road safety
	Neurological problem (Restricted drivers)	Crash	–	RR = 1.33 Ci 95% = 0.78 - 2.28 p = NS	Non-significant effect on road safety
		At-fault crash	–	RR = 1.40 Ci 95% = 0.71 – 2.76 p = NS	Non-significant effect on road safety
		Citation	–	RR = 0.76 Ci 95% = 0.44 - 1.29 p = NS	Non-significant effect on road safety
	Learning, memory and communicatio n problem (Not-restricted drivers)	Crash	↗	RR = 2.19 Ci 95% = 1.33 – 3.61 $p < 0.05$	Drivers with learning, memory and communication problems and unrestricted driving were at higher risk of crashes than their peers.
		At-fault crash	↗	RR = 3.32 Ci 95% = 1.84 - 5.99 $p < 0.05$	Drivers with learning, memory and communication problems and unrestricted driving were at higher risk of at-fault crashes than their peers.
		Citation	–	RR = 1.26 Ci 95% = 0.85 - 1.86 p = NS	Non-significant effect on road safety
	Learning, memory and communicatio n problem (Restricted drivers)	Citation	↗	RR = 11.63 Ci 95% = 3.58 – 37.78 $p < 0.05$	Drivers with learning, memory and communication problems and unrestricted driving were at higher risk of citations than their peers.
	Psychiatric disorder (Not restricted drivers)	Crash	↗	RR = 1.57 Ci 95% = 1.46 – 1.67 $p < 0.05$	Drivers with psychiatric disorders and unrestricted driving were at higher risk of crashes than their peers.
		At-fault crash	↗	RR = 1.85 Ci 95% = 1.69 - 2.01 $p < 0.05$	Drivers with psychiatric disorders and unrestricted driving were at higher risk of at-fault crashes than their peers.
		Citation	↗	RR = 1.23 Ci 95% = 1.17 – 1.30 $p < 0.05$	Drivers with psychiatric disorders and unrestricted driving were at higher risk of citations than their peers.
	Psychiatric	Crash	↗	RR = 1.87	Drivers with psychiatric

	disorder (Restricted drivers)			Ci 95% = 1.11 – 3.17 p < 0.05	disorders and restricted driving were at higher risk of crashes than their peers.
		At-fault crash	↗	RR = 2.89 Ci 95% = 1.64 – 5.07 p < 0.05	Drivers with psychiatric disorders and restricted driving were at higher risk of at-fault crashes than their peers.
		Citation	–	RR = 0.84 Ci 95% = 0.53 – 1.33 p = NS	Non-significant effect on road safety
Cooper et al., 1993	Dementia	Crash	↗	Chi² (df = 1) = 5.72 p = 0.02	Dementia group was significantly more involved in accidents than the HC group (61 versus 25, respectively).
Drachman & Sweaver, 1993, United States	Alzheimer's disease (AD)	Annual crash risk	↗	OR = 3.75 CI95% = 1.24 – 11.30 p<0.05	AD patients, during all years of driving post-AD combined, were more likely to have incurred crashes than their matched controls.

3.3 SUMMARISING THE RESULTS

A review-type analysis was conducted to investigate the effect of cognitive impairment such as dementia, Alzheimer's disease, Parkinson's disease, depression or other psychiatric disorders on road safety. The main effects are summarized in Table 13.

Table 13. Main outcomes of coded articles according to types of cognitive impairment

Types of cognitive impairment	Road safety indicators	Main outcomes
Neurocognitive disorders	Crash involvement (data from self-reports, police crash reports or national database)	- **Dementia** significantly increases the risk of drivers' crash involvement (Cooper et al., 1993; Vernon et al., 2002) - **Alzheimer disease** significantly increases the risk of drivers' crash involvement (Drachman & Swearer, 1993) - **Parkinson's disease** significantly increases the risk of drivers' crash involvement (Meindorfner et al., 2005)
	Crash responsibility (data from self-reports, police crash reports or national database)	- **Dementia** significantly increases the pedestrians' and drivers' at-fault crash risk (Gorrie et al., 2008; Vernon et al., 2002) - Moderate **Parkinson's disease** significantly increases the drivers' at-fault crash risk, contrary to more advanced disease (Meindorfner et al., 2005)
	Traffic violations (data from police crash reports)	- **Learning and memory problems** related to Alzheimer's disease increases the risk of traffic violations for restricted drivers (driving limitations in terms of speed, area, and time of the day, Vernon et al., 2002)
	On-road driving data	- **Alzheimer's and Parkinson's diseases** significantly degrade the drivers' on-road driving performances (Aksan et al., 2015; Grace et al., 2005; Uc et al., 2009)
	Simulated driving data	- Drivers with **low cognitive performances** have a significantly

		increased crash risk and a higher risk of committing steering, vehicle positioning and lane changes driving errors (Park et al., 2011) - **Alzheimer's and Parkinson's diseases** significantly reduce the sensibility to detect collision (Vaux et al., 2010) - **Alzheimer's disease** significantly increases the risky avoidance behaviour by promoting the abrupt slowing and prematurely stopping (Uc, Rizzo, Anderson, Shi, & Dawson, 2006)
Depression	Crash involvement (data from self-reports)	Inconsistent results: - Non-significant effect of depression on the crash risk (Aduen et al., 2015) - Significant decrease of the crash risk among men who reduced their road mobility (Parmentier et al., 2005)
	Crash responsibility (data from self-reports)	Inconsistent results: - Non-significant effect of depression on the risk of crash responsibility (Aduen et al., 2015; El Farouki et al., 2014) - Significant increase of the risk for crash responsibility with depression (Sagberg, 2006)
	Traffic violations (data from self-reports)	Non-significant effect of depression on the traffic violations risk (Aduen et al., 2015)
	Injury from collision (data from self-reports)	Significant increase of the risk for injury after collision (Aduen et al., 2015)
Other psychiatric disorders	Crash involvement (data from self-reports or police crash reports)	Inconsistent results: - Significant crash risk reduction with moderate psychiatric disorder but it no longer significant for more severe disorder (Martiniuk et al., 2010) - Significant increase of crash risk with psychiatric disorders (Vernon et al., 2002).
	Crash responsibility (data from police crash reports or national database)	Inconsistent results: - Non-significant effect of psychiatric disorders on the risk for at-fault crash (Sagberg, 2006) - Significant increase risk (Vernon et al., 2002)
	Traffic violations (data from police crash reports)	Significant increase of the risk of traffic violations for the unrestricted drivers (Vernon et al., 2002)

3.4 FULL LIST OF STUDIES

Table 14. List of the coded studies (sorted by year of publication)

Reference	Study summary	Bias
Aduen, P. A., Kofler, M. J., Cox, D. J., Sarver, D. E., & Lunsford, E. (2015). Motor vehicle driving in high incidence psychiatric disability: Comparison of drivers with ADHD, depression, and no known	This study investigated the risk factor for traffic violations or collisions related to depression and ADHD. The authors conducted an observational, cross-sectional study. The outcomes were the retrospective self-reported traffic collisions, moving violations, collision-related injuries, and collision fault for the last three years. The exposure variables were depression and ADHD (three groups: drivers with depressive symptoms, drivers with ADHD, and healthy controls, HC). To predict the relative risk for collisions, violations, injuries, and collision fault for drivers with depression or ADHD relative to HC, a multinomial logistic regression was performed. The results showed that Depression was uniquely associated with self-reported injury following	This study relied exclusively on retrospective self-report data, and diagnostic status was based on self-report and responses to a well validated measure. Thus, the extent to which the findings generalize to adults

Reference	Study summary	Bias
psychopathology. Journal of Psychiatric Research, 64, 59–66.	a collision. More precisely, the depressed drivers experienced a 125% increased risk for self-reported injuries from collisions relative to HC drivers. Moreover, ADHD but not Depression was a unique risk factor for multiple motor vehicle violations and collisions. This increased risk was remarkable, such that drivers with ADHD were 2.3 and 2.2 times more likely to report multiple violations and multiple collisions relative to HC drivers.	with clearly defined Depression, or correspond to official police, hospital, and/or Department of Motor Vehicles records is unknown.
Aksan, N., Anderson, S. W., Dawson, J., Uc, E., & Rizzo, M. (2015). Cognitive functioning differentially predicts different dimensions of older drivers' on-road safety. Accident Analysis & Prevention, 75, 236–244.	This study investigated the effect of navigation-related secondary tasks on the on-road driving safety errors of older drivers suffering from neurodegenerative diseases (Alzheimer's and Parkinson's diseases). The authors conducted an observational, cross-sectional study. The outcome was performances at two secondary driving tasks and the number of driving errors during simple and dual driving tasks (i.e. global errors and errors related to lane change, lane observance, speed control, traffic signs, stop sign, turns, curbs). The exposure variable was the disease (two modalities: Alzheimer's disease: AD or Parkinson's disease: PD, and no disease, healthy controls: HC). The different outcome measures were compared between groups (AD and PD versus HC) thanks to a one-way anova and Tukey's HSD post hoc tests. The results showed that drivers with and without neurodegenerative diseases made more safety errors while concurrently performing secondary navigation tasks compared to baseline driving when they were not performing secondary tasks. Moreover, the findings indicated that older drivers with neurodegenerative diseases are less safe than healthy drivers. In addition, drivers with AD or PD made more safety errors particularly during navigation. The only error type to show disease specificity was stop sign errors. PD patients committed more of these errors in both baseline and secondary task segments compared to AD patients.	
El Farouki, K., Lagarde, E., Orriols, L., Bouvard, M.-P., Contrand, B., & Galera, C. (2014). The Increased Risk of Road Crashes in Attention Deficit Hyperactivity Disorder (ADHD) Adult Drivers: Driven by Distraction? Results from a Responsibility Case-Control Study. Plos One, 9(12), e115002.	This study investigated the risk for crash responsibility related to the depressive disorders. The authors conducted an observational case-control study. The outcome was crash responsibility (two categories: responsible or not responsible for a crash). The exposure variable was the depressive disorders. The population was divided into four quartiles depending on the severity of the depression, with the first quartile including the lowest scores and the fourth quartile including the highest score. To test the relationship between responsibility for road traffic crash and the depressive disorders, multivariate, logistic regression was performed. The results showed that the depressive disorders were not significantly associated with the crash responsibility.	The assessment of psychiatric disorders was based on subjective evaluation and not on clinical diagnosis
Park, S.-W., Choi, E. S., Lim, M. H., Kim, E. J., Hwang, S. I., Choi, K.-I., ... Jung, H.-E. (2011). Association Between Unsafe Driving Performance and Cognitive-Perceptual Dysfunction in Older Drivers. PM&R, 3(3), 198–203.	This study investigated the risk for drivers aged 65 or older for crashes or dangerous manoeuvers during a simulated driving evaluation related to low cognitive performances assessed by the Cognitive-Perceptual Assessment for Driving (CPAD). The authors conducted an observational, cross-sectional study. The outcome were the driving performances assessed on a driving simulator (the number of crashes and unsafe performances in controlling speed, braking, steering, vehicle positioning, making lane changes, and making turns). The exposure variable was the "pass" or "fail" result at the CPAD. To test association between the CPAD result and driving performance, a logistic regression was performed. The results showed that the unsafe driving performance and the car crashes during a simulated driving	Methodological limitation: the driving performance was evaluated in a virtual environment, which is not identical to on-road driving.

Reference	Study summary	Bias
	evaluation were more prevalent in older drivers than in younger ones. In addition, older drivers' unsafe performance in steering, vehicle positioning, making lane changes, and car crashes were associated with cognitive-perceptual dysfunction.	
Martiniuk, A. L. C., Ivers, R. Q., Glozier, N., Patton, G. C., Senserrick, T., Boufous, S., ... Norton, R. (2010). Does Psychological Distress Increase the Risk for Motor Vehicle Crashes in Young People? Findings From the DRIVE Study. Journal of Adolescent Health, 47(5), 488–495.	This study investigated the crash risk for novice drivers (17-24 years) who suffered from psychological distress. The authors conducted a cohort study. The outcomes were the crash involvement (yes/no) and the number of motor vehicle crashes. The exposure variable was the level of psychological distress (four modalities: low, moderate, high or very high psychological distress). To test the relationship between the crash risk and the psychological distress, the Poisson regression was used. The results indicated that compared to no or low psychological distress, the moderate psychological distress had a positive effect on road safety by preventing young drivers from crashes. This finding may be explained by the fact that the mild anxiety associated with moderate levels of distress could heighten vigilance while driving. This mild anxiety could also be associated with other personality characteristics such as neuroticism which may reduce the likelihood of risk taking. Furthermore, any effect of the two highest categories of psychological distress (reflecting a true mental disorder) was associated with reduced risk of crash. This result should be interpreted with caution because the 95% CI for the no or low distressed group overlapped with those for the high and very highly distressed groups, and no increasing trend or clear pattern was observed for the relative risks with crash in increasing distress groups.	
Vaux, L. M., Ni, R., Rizzo, M., Uc, E. Y., & Andersen, G. J. (2010). Detection of imminent collisions by drivers with Alzheimer's disease and Parkinson's disease: A preliminary study. Assessing Safety with Driving Simulators, 42(3), 852–858.	This study investigated the impact of neurodegenerative diseases, namely Alzheimer's disease (AD) and Parkinson's disease (PD) on the ability to detect impending collisions. The authors conducted an observational cross-sectional study. The outcome was the sensitivity to detect collision on a computerized collision detection task. The exposure variable was the neurodegenerative disease (three groups: AD drivers, PD drivers, and healthy controls). To test the relationship between the neurodegenerative disease and the ability to detect collision, anova was performed. The results showed that patients suffering from neurodegenerative disease, such as AD or PD, were less able to detect collision than healthy controls.	Small sample size: only 6 drivers with AD and 8 with PD
Uc, E. Y., Rizzo, M., Johnson, A. M., Dastrup, E., Anderson, S. W., & Dawson, J. D. (2009). Road safety in drivers with Parkinson disease. Neurology, 73(24), 2112–2119.	This study investigated whether drivers suffering from Parkinson's disease (PD) committed more on-road driving errors than HC. This study also aimed at identifying the type of driving safety errors committed by these drivers. The authors conducted an experimental study. The participants completed a standardized on-road driving test in order to assess their driving safety. The outcome were the number of driving safety errors (i.e. total, lane observance, turns, lane change, stop signs, control of speed, traffic signals, pulling away from curve, parallel parking, curves, railroad crossing, overtaking and serious errors). The exposure variable was PD (two groups of participants: PD drivers and healthy controls (HC)). To compare the number of driving errors committed by PD drivers and HC, Wilcoxon rank sum test was used. Adjustments for age, gender, and education on one hand, and for age, gender, education and familiarity with the testing route, on the other hand, were performed using regression techniques. The results showed that PD drivers committed more driving safety errors on the road than HC. The most frequently observed error categories in the PD group were lane observance, turn, lane change, stop sign, speed	

Reference	Study summary	Bias
	control, and turn errors. Familiarity with the driving environment was a mitigating factor in drivers with PD. These results are in agreement with other studies which indicated diminished driving safety in persons with PD.	
Gorrie, C. A., Brown, J., & Waite, P. M. E. (2008). Crash characteristics of older pedestrian fatalities: Dementia pathology may be related to 'at risk' traffic situations. Accident Analysis & Prevention, 40(3), 912–919.	This study investigated the fatal crash risk for pedestrians aged 65 or older who suffered from dementia, measured by the proportion of neurofibrillary tangles (NFT) in their brain (which is a hallmark of Alzheimer's disease). The authors conducted an observational cross-sectional study. The outcome were the fatal crash characteristics such as: vehicle movement, lane proximity to kerb, adjacent activity, distance to designated pedestrian crossing, speed limit, designated pedestrian crossing location, lighting, accident location, type of vehicle involved; complexity of the crash scene (low, moderate or high); and the pedestrian's responsibility for the crash (at-fault or not at-fault). The exposure variable was dementia (with two modalities: low or high level of NFT). To test the relationship between the fatal crash characteristics and dementia, logistic regressions were carried out. The results showed that compared to those with no or low NFT, pedestrians with moderate to high NFT scores: 1) tended to be more at least partially responsible for the crash (i.e. they tended to have behaved unexpectedly such as walked into the traffic, disobeyed a traffic signal, etc.); 2) tended to be more impacted by reversing vehicles; 3) tended to be unexpectedly at high risk of an at-fault crash occurring in a 'low' complexity crash location (e.g. a quiet urban street with little traffic flow), suggesting that when walking in a traffic environment that is not perceived as dangerous, the pedestrians with moderate to high NFT may not pay enough attention to their surroundings or anticipate vehicle movements.	Small sample size Sample heterogeneity: in addition to dementia, participants had various medical conditions (for example alcohol, depression, osteoporosis, hip replacements, etc.) that could also explain the crash occurrence
Sagberg, F. (2006). Driver health and crash involvement: A case-control study. Accident Analysis & Prevention, 38(1), 28–34.	This study investigated the relative crash involvement risk related to the subjective symptom of feeling depressed and neurological impairments (such as Parkinson's disease or multiple sclerosis). The authors conducted an observational, case-control study. The outcome was the responsibility for a crash (at-fault or not at-fault). The exposure variables were the subjective symptoms of feeling depressed or the neurological impairments. To test the relationship between the depression or neurological impairments and the crash responsibility, a logical regression analysis was performed. The results showed that feeling depressed significantly enhanced the risk of being responsible for a crash, but not the neurological impairments.	The classification of the respondents as "feeling depressed" seems have been made only according to the self-reported symptoms and not according to a specific evaluation performed by a specialist. Hence, the interpretation of the results has to take it into account. The exact number of participants in each category is not mentioned (the number of at-fault / not at-fault drivers who feel depressed, and the number of at-fault / not at-fault drivers with neurological impairment) The low response rate may imply that the sample is biased compared to the total population of crash-

Reference	Study summary	Bias
		involved drivers. For example, drivers at fault for a crash are less likely to fill in and return the questionnaires. There might be risks associated with combinations of different medical conditions and/or use of medicinal drugs.
Uc, E. Y., Rizzo, M., Anderson, S. W., Shi, Q., & Dawson, J. D. (2006). Unsafe rear-end collision avoidance in Alzheimer's disease. Journal of the Neurological Sciences, 251(1–2), 35–43.	This study investigated the risk for rear-end collisions (REC) and risky avoidance behaviors in a simulator-based driving evaluation related to the Alzheimer's disease (AD). The authors conducted an observational, cross-sectional study. The outcome was the unsafe avoidance behavior, i.e. the involvement in a REC or a risky avoidance behavior (abrupt slowing, prematurely stopping or swerving out of the lane). The exposure variable was the Alzheimer's disease (two modalities: exposed / non-exposed). To test the relationship between the AD and the risky avoidance driving behavior, the Fisher's Exact test was used. The results supposed that drivers with AD were less capable than HC of responding effectively in collision avoidance situations that may lead to an REC. Although the likelihood of REC was not significantly higher in AD, these drivers reacted slower and were more likely to respond unsafely by slowing down abruptly or stopping prematurely before reaching the intersection than HC.	
Grace, J., Amick, M. M., D'Abreu, A., Festa, E. K., Heindel, W. C., & Ott, B. R. (2005). Neuropsychological deficits associated with driving performance in Parkinson's and Alzheimer's disease. Journal of the International Neuropsychological Society : JINS, 11(6), 766–775.	This study investigated the on-road driving performances of patients who suffered from either Alzheimer's disease (AD) or Parkinson's disease (PD). The authors conducted an observational, cross-sectional study. The outcome was the number of driving errors. The exposure variable was the neurodegenerative disease (three groups: AD, PD and healthy controls, HC). To compare the on-road driving performances between AD, PD and HC groups, ANOVA and post hoc Bonferoni t tests were performed. The results showed that the AD group made more driving errors compared to PD drivers and HC. More precisely, the AD group frequently made operational errors such as hesitant driving and diminished awareness of the traffic environment; tactical errors such as problems with changing lanes smoothly; and most strikingly, strategic judgment errors such as making a turn into a one way street. Moreover, the PD drivers group made more driving errors than the HC. However, they rarely made operational or strategic judgment errors. They made tactical errors requiring head turning such as such as not scanning when pulling out into traffic or checking blind spots. The tactical errors seen in the PD group suggests that interventions may help ameliorate some of their problems with driving. Interventions may not be so feasible in the AD group because of the broader range of their driving errors.	
Meindorfner, C., Korner, Y., Moller, J. C., Stiasny-Kolster, K., Oertel, G. H., & Kruger, H. P. (2005). Driving in Parkinson's disease: Mobility, accidents, and sudden onset of sleep at the wheel. Movement	This study investigated the risk of accident involvement and causation among patients who suffered from Parkinson's disease (PD), related to the disease severity. The authors conducted a cohort study. The outcomes were accident involvement and responsibility for the accident ("accident causation") over the last five years. The exposure variable was the PD, with three categories of subjective disease severity ("minor", "moderate", and "advanced"). To test the relationship between PD severity and accident causation /involvement, logistic regressions were used. The results showed that the PD severity was a significant predictor of the accident involvement.	The Parkinson's disease severity was subjectively assessed by the patients.

Reference	Study summary	Bias
Disorders, 20(7), 832–842.	In details, patients who suffered from moderate to advanced PD were at higher odds of being involved in an accident than patients who suffered from a minor PD. In addition, the results showed that only patients with moderate PD were at higher odds of being responsible for an accident than patients with a minor PD.	
Parmentier, G., Chastang, J. F., Nabi, H., Chiron, M., Lafont, S., & Lagarde, E. (2005). Road mobility and the risk of road traffic accident as a driver - The impact of medical conditions and life events. Accident Analysis and Prevention, 37(6), 1121–1134.	This study investigated the risk of road traffic accidents related to self-reported medical conditions such as depression. The authors conducted a cohort study. The outcomes were the changes in road mobility between 2000 and 2001 and the road traffic accidents. The exposure variables were depression (three levels of depression: only in 2000, only in 2001, or in 2000 and in 2001) and the change on road mobility between 2000 and 2001 (binary variable, yes/no). To test the effect of depression and road mobility change, univariate and multivariate analyses using the general linear model were performed. The impact of significant mobility changes among depressed participants on the risk of RT was assessed using odds-ratios. The results showed that depression had a greater effect on men mobility than on women mobility. The depression was related to reduce mobility among men. More precisely, the more the depression lasted, the more men reduced their road mobility. This result suggested that depression had a progressive and long-lasting impact on mobility. However, as the odds-ratio estimates were very close to 1, the changes in road mobility due to depression appear to have a small impact on the risk of RTA.	Self-declared depression
Vernon, D. D., Diller, E. M., Cook, L. J., Reading, J. C., Suruda, A. J., & Dean, J. M. (2002). Evaluating the crash and citation rates of Utah drivers licensed with medical conditions, 1992–1996. Accident Analysis & Prevention, 34(2), 237–246.	This study investigated the risk of crashes, at-fault crashes and citations for cognitively impaired drivers (i.e. who suffered from neurological problems, learning, memory and communication problems or psychiatric disorders), depending on their driving restriction status over a 5-year period. The authors conducted an observational, retrospective case-control study. The outcomes were the crash involvement, the crash responsibility and the citations. The exposure variables were the self-reported medical conditions. The estimation of the relative risk associated with the cognitive impairments and the driving restriction status was based on a Chi² distribution. The results showed that, overall, drivers with medical conditions had similar rates of citation but higher rates of crash and at-fault crash than their peers. It should be also noticed that the relative risk values for restricted drivers, who are presumably the most impaired, do not appear markedly different from those for unrestricted drivers.	The exposure (number of miles driven) was not available and hence, not taken into account in the analysis. The authors supposed that drivers of similar age, sex and place of residence would likely drive the same amounts. Hence, they matched case and controls for these variables. Self-reporting medical conditions
Cooper, P. J., Tallman, K., Tuokko, H., & Beattie, B. L. (1993). Vehicle crash involvement and cognitive deficit in older drivers. Journal of Safety Research, 24(1), 9–17.	This study compared the crash involvement between drivers with dementia and their matched healthy controls. The authors conducted a cohort study. The outcome was the number of crash during a specific period of time (from the onset of symptoms to the date the participant stopped driving). The exposure variable was the dementia (two groups of drivers: one group with dementia and one matched healthy control group). To compare the number of crashes between both groups, non-parametric tests of univariate comparisons were performed. The results showed that drivers with dementia were 2.5 times more involved in accidents than their control peers.	
Drachman, D. A., & Swearer, J. M. (1993). Driving and Alzheimer's disease: the risk of crashes. Neurology, 43, 2448–	This study investigated the annual risk for crashes related to the Alzheimer's disease (AD). The authors conducted an observational, case-control study. The outcome was the crash-per-year rate. The exposure variables were the Alzheimer's disease (AD). To test the relationship between the AD and the risk of crash, a logistic regression was performed. The results showed that AD patients had more than	

Reference	Study summary	Bias
56.	twice as many reported crashes per year as did their matched controls. Hence, the AD patients had a higher risk of crash during all years of driving post-AD combined, than had their peers.	

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Functional impairment - Hearing loss

Reduced hearing due to a physiological cause

1 Summary

Sandin, J., August 2016

1.1 COLOUR CODE: GREY

Reduced hearing, or hearing loss, is generally not considered to reduce road safety, but there is limited and inconsistent research on the subject. There is a lack of studies that can quantify the effect of hearing loss on road safety in terms of crash risk, and overall they cannot show a clear association between hearing loss and increased crash risk.

1.2 KEYWORDS

Hearing loss, Hearing impairment, Sensory impairment

1.3 ABSTRACT

Hearing loss is one of the most frequent sensory deficits, of which prevalence increases with age. Hearing loss is generally not considered to reduce road safety, but there is limited and inconsistent research on the subject. There is a lack of studies that can quantify the effect of reduced hearing on road safety in terms of crash risk, and overall they cannot show a clear association between reduced hearing and increased crash risk. The studies have used approaches similar to case-control, which means that the crash rates of individuals with hearing loss (cases) are compared with crash rates of individuals without hearing loss (controls).

1.4 BACKGROUND

What is hearing loss?

Physiologically, hearing loss can be caused by any disruption of a part along the auditory pathway, i.e. from the outer ear to the auditory cortex in the brain. There are two main diagnoses. Firstly, problems in the outer ear (such as blockage of the ear canal) or middle ear (such as ossicular chain discontinuity) that cause *conductive hearing loss*, i.e. when there is a problem conducting sound waves. Secondly, problems in the inner ear (such as loss of outer or inner hair cells in the cochlea) or problems in the cochlear nerve leading to the central auditory pathway (such as auditory neuropathy) that can result in *sensorineural (mixed) hearing loss* (Arlinger, 2007).

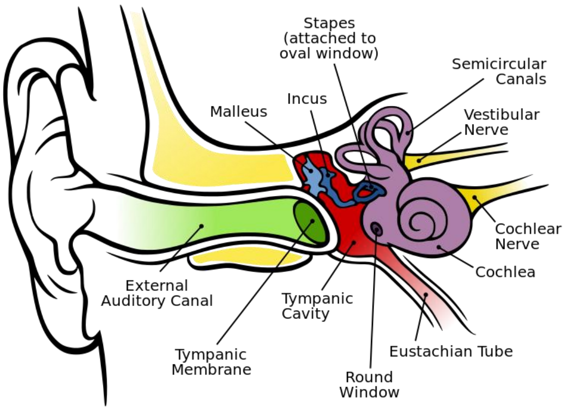

Figure 1 A diagram of the anatomy of the human ear (Chittka and Brockmann 2005)

Hearing ability is commonly assessed in a pure tone audiometry test, which tests the hearing of both ears. During the test, a machine called an audiometer produces sounds at various volumes and frequencies (pitches). The patient listens to the sounds through headphones and responds when they hear them, usually by pressing a button. A Pure Tone Average (PTA) refers to the average of hearing threshold levels at a set of specified frequencies. Test frequencies begin at 1000 Hz and include at a minimum octave steps up to 8000 Hz and down to 125 Hz. Often 750, 1500, 3000, and 6000 Hz are also included. With PTA both air and bone conduction can be tested, enabling the determination of degree, type, and configuration of hearing loss in an individual.

The degree of hearing loss is categorised according to the better ear hearing level averaged over the frequencies of 0.5, 1, 2, and 4 kHz and divided into the following categories:

- mild (PTA 26-40 dB),
- moderate (PTA 41-60 dB),
- severe (PTA 61-80 dB),
- profound (PTA > 80 dB).

Individuals with a hearing loss of PTA ≥ 95 dB are commonly referred to as deaf (Mathers et al. 2003).

How does reduced hearing affect road safety?

Hearing loss involves a loss of auditory information, which might affect behaviour in traffic and might reduce road safety. However, research regarding the effect of hearing loss on road safety and mobility is limited, and the empirical findings are somewhat inconsistent (Thorslund 2015). Perhaps due to this limited knowledge, hearing loss is not considered to reduce road safety (Englund, 2001; Glad, 1977), and therefore adequate hearing is not required for obtaining a driver's license for passenger cars.

How many people have hearing loss?

Hearing loss is one of the most frequent sensory deficits, with a prevalence of approximately 10% in the general population in the western world (Stevens et al., 2013). About 1.2% of the population in the EU aged 15-64 report that they have difficulties with hearing even when using a hearing aid (Eurostat site, accessed 16 June 2016). The share increases with age and is above 2.5% for the population aged 55-64. The prevalence of age-related hearing loss in Europe is roughly 30% for men and 20% for women at the age of 70 years, and 55% for men and 45% for women at the age of 80 years (Roth, Hanebuth and Probst, 2001). The number of road users with hearing loss will increase in the future because the prevalence of age-related hearing loss is increasing. The number can increase even further as there are indications of permanent hearing impairment in younger persons as a result of their exposure to noisy leisure time activities (Niskar et al., 2001).

Which factors influence the effect of hearing loss on road safety?

As mentioned above, reduced hearing is commonly correlated with increased age and the elderly, but the majority of studies on crash risk compensate for this in the analysis. There are however other sensory and cognitive deficits that are also associated with increased age which need to be considered (Ivers et al. 1999; Green et al. 2013).

How is the effect of hearing loss on road safety measured?

Most studies have used approaches similar to case-control. This means that the crash rates of individuals with hearing loss (cases) are compared with crash rates of individuals without hearing loss (controls). Two studies have used a retrospective cohort construction, which have more in common with occupational cohort studies and case-control studies than with prospective cohort studies (Picard et al., 2008).

1.5 MAIN CONCLUSIONS

While hearing loss is one of the most frequent sensory deficits in humans, the impact on road safety is uncertain. Research regarding the effect of hearing loss on road safety and mobility is limited, and the empirical findings are inconsistent. Studies are rare that can quantify the effect of reduced hearing on road safety in terms of crash risk. Taken together, the few studies that have been identified through the literature-search strategy cannot show a clear association between reduced hearing and increased crash risk. Study deficiencies are that the degrees of hearing loss are not measured among the participants, or that the degrees are not classified in the same way across studies. Reduced hearing is commonly correlated with increased age, but the majority of studies compensate for this in the analysis. It is possible that drivers gradually adopt compensation or adaptation strategies as the hearing becomes more and more reduced. Such strategies may reduce negative effects from hearing loss on their driving.

2 Scientific Overview

Reduced hearing is commonly correlated with increased age and elderly, but the majority of studies on crash risk compensate for this in the analysis. There are however other sensory and cognitive deficits that are also associated with increased age which need to be considered (Ivers et al. 1999; Green et al. 2013). For example, Green et al. (2013) indicated that drivers with both a hearing and vison impairment had a significantly higher rate of at fault motor-vehicle collisions (RR = 2.06, 95% CI = 1.13-3.76) in comparison with hearing impairment only (RR = 0.95, 95% 0.71-1.25). **Table 1** shows an overview of the results of the coded studies.

Table 1 Overview of results of coded studies. Key ↑ increased risk; – not significant; ↓ decreased risk

Author, Year, Country	Risk factor	Study type	Outcome variable	Effects for Road Safety	Main outcome -description
Green et al. 2013, Alabama, USA.	Reduced hearing	Retrospective cohort study. Drivers with and without hearing impairment involved in at fault crashes.	Crash involvement	–	Non-significant increase in at-fault crash risk for drivers with hearing impairment when compared with drivers with no impairment.
Dultz 2012, New York City, USA	Reduced hearing	Prospective epidemiologic study of pedestrians and cyclists struck by motor vehicles.	Injury severity (ISS)	↑	Hearing impairment is associated with higher injury severity (ISS).
Picard 2008, Quebec, Canada	Reduced hearing	Retrospective cohort study.	Crash involvement	↑	Modest but significant association between hearing loss and crash involvement.
Ivers 1999, Sydney, Australia	Reduced hearing	Self-reported accidents in population-based survey. Cross-sectional.	Crash involvement	–	Unclear relationship between hearing loss and accidents. Hearing loss is self-reported.

Beside the specific association between hearing loss and crash risk, Schmolz (1987) found that hearing loss was associated with a higher degree of inattention among road users. When it comes to attention, Hickson et al. (2012) showed that hearing loss in older drivers was associated with poorer driving performance in the presence of distraction, but not without distraction. On the other hand, Picard et al. (2008) suggested that hearing loss leads to a reduction in speeding violations, probably due to self-regulation. Similarly, Thorslund (2015) concluded that drivers with hearing loss drive more cautiously using compensatory strategies, e.g. driving at lower speeds and using a more comprehensive visual search behaviour, as well as coping strategies, e.g. engaging less in distracting activities.

3 Supporting Document

3.1 LITERATURE SEARCH STRATEGY

The literature on reduced hearing and traffic risk was searched for in the international database Scopus on April 22nd 2016.

Search no.	Search term	Hits
#1	"hearing impairment" OR "hearing disorder*"	27.179
#2 (within #1)	"road safety" OR "traffic safety" OR "road accidents"	24
#3 (within #2)	"collisions" OR "risk"	15

Limitations

- Search field: TITLE-ABS-KEY.
- Published: 1990 to current.
- Document type: "Review" and "Article".
- Language: English.
- Source type: Journal.

Final search string returning 15 hits

(TITLE-ABS-KEY ("hearing impairment" OR "hearing disorde*")) AND ("road safety" OR "traffic safety" OR "road accident") AND ("collision" OR "risk") AND (LIMIT-TO(PUBYEAR,2015) OR LIMIT-TO(PUBYEAR,2014) OR LIMIT-TO(PUBYEAR,2013) OR LIMIT-TO(PUBYEAR,2012) OR LIMIT-TO(PUBYEAR,2011) OR LIMIT-TO(PUBYEAR,2010) OR LIMIT-TO(PUBYEAR,2009) OR LIMIT-TO(PUBYEAR,2008) OR LIMIT-TO(PUBYEAR,2007) OR LIMIT-TO(PUBYEAR,2006) OR LIMIT-TO(PUBYEAR,2005) OR LIMIT-TO(PUBYEAR,2004) OR LIMIT-TO(PUBYEAR,2003) OR LIMIT-TO(PUBYEAR,2002) OR LIMIT-TO(PUBYEAR,2001) OR LIMIT-TO(PUBYEAR,2000) OR LIMIT-TO(PUBYEAR,1999) OR LIMIT-TO(PUBYEAR,1998) OR LIMIT-TO(PUBYEAR,1997) OR LIMIT-TO(PUBYEAR,1996) OR LIMIT-TO(PUBYEAR,1995) OR LIMIT-TO(PUBYEAR,1994) OR LIMIT-TO(PUBYEAR,1992) OR LIMIT-TO(PUBYEAR,1991) OR LIMIT-TO(PUBYEAR,1990)) AND (LIMIT-TO(DOCTYPE,"ar") OR LIMIT-TO(DOCTYPE,"re")) AND (LIMIT-TO(LANGUAGE,"English")) AND (LIMIT-TO(SRCTYPE,"j"))

Screening table

Total number of articles to screen	80
Exclusion due to relevance	71
Exclusion due to qualitative data	
Exclusion due to no risk data	
Exclusion due to countermeasure	2
Selected studies to obtain full-text	**7**

Eligibility table

Total number of studies to screen full-text	7
Full text could be obtained	7
Reference list examination	No
Eligible papers	**7**

Screening of the full texts

Total number of studies to screen full paper	7
-Studies with no risk estimates excluded	3
-Studies concerning measures excluded	
Remaining studies (to be coded)	**4**

3.2 ANALYSIS OF STUDY DESIGNS AND METHODS

Table 2 Characteristics of coded studies.

Author, Year, Country	Sample, method/design and analysis	Risk group/ Cases	Control group/ Controls	Research conditions/ control variables
Green and McGwin 2013, Alabama, USA.	Retrospective cohort study. Population-based sample of 2 000 licensed drivers aged 70 and older. Information of Motor-Vehicle Collisions (MVCs) collected from accident records 5 years' prior enrolment.	Drivers with hearing impairment only, At fault (crash/no crash) (n = 75)	Drivers with no impairment, At fault (crash/no crash) (n = 203)	Adjusted for age, race, sex, number of miles driven, number of medical conditions, general cognitive status, and visual processing speed.
Dultz 2012, New York City, USA	Prospective epidemiologic study of pedestrians and cyclists struck by motor vehicles, 2008-2011. Multivariate ordinal logistic regression modelling was used to isolate effects of predictor variables on the outcome of ISS categories.	Pedestrians (n = 1075), Cyclists (n = 382)	-	(Hearing impairment was defined as any current history of decreased auditory ability.)
Picard 2008, Quebec, Canada	Retrospective cohort study. Associations between occupational noise exposure levels, hearing status, and personal driving record from 1995-2001 were examined by log-binomial regression.	Drivers with hearing loss >17dB (n = 3 924)	Drivers with normal hearing (n = 7 473)	Adjusted for age, number of years and daily dose of exposure to occupational noise. (Hearing impairment was self-reported).
Ivers 1999, Sydney, Australia	Self-reported accidents in the past 12 months, 1992-1994, 2 326 drivers aged 49 and older. Cross-sectional. From population-based survey.	Drivers with mild to severe hearing loss (n= 834)	Drivers with no hearing loss (n= 1 444)	Adjusted for age and gender.

3.3 EXPLORATORY ANALYSIS OF RESULTS

Table 3: Main outcomes of coded studies

Author, Year, Country	Risk factor	Study type	Outcome variable	Effects for Road Safety	Main outcome -description
Green and McGwin 2013, Alabama, USA.	Reduced hearing	Retrospective cohort study. Drivers with and without hearing impairment involved in at fault crashes.	Crash involvement	RR=0.95; 95% CI: 0.71-1.25; p=?	Non-significant increase in at-fault crash risk for drivers with hearing impairment when compared with drivers with no impairment.
Dultz 2012, New York City, USA	Reduced hearing	Prospective epidemiologic study of pedestrians and cyclists struck by motor vehicles.	Injury severity (ISS)	Adjusted OR = 2.24; 95% CI: 1.24-4.03, p=0.01.	Hearing impairment is associated with higher injury severity (ISS).
Picard 2008, Quebec, Canada	Reduced hearing	Retrospective cohort study.	Crash involvement	Hearing loss 17-30 dB: PR = 1.06; 95%, CI: 1.01–1.11, p=0.01 Hearing loss > 50 dB: PR = 1.31; 95%, CI: 1.20–1.42, p<0.0001	Modest but significant association between hearing loss and crash involvement.
Ivers 1999, Sydney, Australia	Reduced hearing	Self-reported accidents in population-based survey. Cross-sectional.	Crash involvement	Hearing loss – mild: PR = 1.2; 95%, CI: 0.8–2.5 Hearing loss – Moderate: PR = 1.9; 95%, CI: 1.1–3.2 Hearing loss – Moderate: PR = 1.6; 95%, CI: 0.7–3.6	Unclear relationship between hearing loss and accidents. Hearing loss is self-reported.

3.4 META-ANALYSIS RESULTS

Studies associating reduced hearing with crash risk are limited. Therefore, it is not meaningful to conduct any meta-analysis, vote-count analysis or review type analysis.

3.5 REFERENCES

Coded studies

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Functional Impairment - Vision loss

Reduced sight due to a physiological cause

1 Summary

Sandin, J. and Strand, N., August 2016

1.1 COLOUR CODE: YELLOW

The current knowledge about visual impairments and crash risk suggests that visual acuity is very weakly associated with crash risk, while contrast sensitivity, visual field, and in particular cognitive aspects of vision have better evidence for their relevance to road safety.

1.2 KEYWORDS

Visual impairment, Sensory impairment, Visual field, Useful field of view, UFOV

1.3 ABSTRACT

The current knowledge about visual impairments and elevated crash risk suggests that visual acuity (generally tested during application for a driving license) is very weakly associated with crash risk, while contrast sensitivity, visual field, and cognitive aspect of vision have some, or thorough, evidence for their relevance to road safety. Impaired vision is much correlated with increased age and the elderly. Therefore, several studies focus on road users 50 years of age or older. With advanced age, other medical and functional co-morbidities follow that are potential confounders in the relationship between vision and road safety – in particular cognitive impairments. The majority of studies have used case-control approaches, usually meaning that the crash rates of individuals with vision impairments (cases) are compared with crash rates of individuals without vision impairment(s) (controls).

1.4 BACKGROUND

What is reduced vision?

Vision is an important sense that dominates other senses, so called visual dominance (Posner, Nissen, and Klein, 1976). The importance of vision in driving was noted as early as the late 1930s in a model developed by Gibson and Crooks (1938), and has since been connected to driving and other modes of transport by numerous researchers. Vision has a close link to various cognitive processes such as visual attention, memory, decision making and visuospatial ability. However, in most countries, the visual requirements to obtain a driver license rely solely on tests of visual acuity (Owsley and McGwin 2010).

How does reduced vision affect road safety?

The vision impairments that have been investigated most thoroughly in relation to road safety are visual acuity, visual field, contrast sensitivity and cognitive aspects of vision. Research on these impairments and elevated crash risk over the past decades has shown varied results. The current knowledge suggests that visual acuity is very weakly associated with crash risk, while contrast sensitivity, visual field, and cognitive aspect of vision have some, or thorough, evidence for their relevance to road safety (Owsley and McGwin 2010).

How many people have reduced vision?

There are some uncertainties regarding the prevalence of reduced vision. A report by the World Health Organization (WHO, 2007) provided an estimation suggesting that 314 million people, worldwide, suffered from impaired vision because of eye diseases or uncorrected refractive errors. Impairments and problems affecting vision often occur as a natural consequence of aging, but may also follow from different medical conditions. Additionally, visual impairments often develop gradually over a long period of time, although there is self-regulation/adaption to impairments, it is difficult for affected persons to perceive that their sense, and hence driving, has deteriorated.

Which factors influence the effect of impaired vision on road safety?

As mentioned above, impaired vision is highly correlated with increased age and the elderly. Therefore, several studies focus on road users 50 years of age or older. With advanced age, other medical and functional co-morbidities follow that are potential confounders in the relationship between vision and road safety. The most pronounced examples relate to cognitive impairments. Another example is eye disease diagnoses (e.g. glaucoma) that can lead to minor or severe visual impairments. Thus, the relationship between road safety and the visual impairment caused by the disease should be examined, and not necessarily the relationship to the disease itself. It is possible that the aforementioned self-regulation and adaptation to visual impairments modifies driving behaviour so that crash risk is moderated. However, clear empirical evidence of this moderation is scarce. Other more general methodological weaknesses are the use of self-reported crashes, small sample sizes and not accounting for driving exposure or driving habits. There are also issues across studies when it comes to different definitions of the amount of visual impairments, for example when it comes to the degree of visual field loss.

How is the effect of reduced vision on road safety measured?

The majority of studies have used case-control approaches. Usually this means that the crash rates of individuals with vision impairments (cases) are compared with crash rates of individuals without vision impairment(s) (controls). An alternative approach is to place individuals in groups based on whether or not they have had a crash, and then compare the prevalence of vision impairment(s) in the two groups.

Main conclusions

Vision is undoubtedly the most important sense for driving. Research on visual impairments and elevated crash risk over the past decades has shown varied results. The current knowledge suggests that visual acuity (generally tested during application for a driving license) is very weakly associated with crash risk, while contrast sensitivity, visual field, and cognitive aspect of vision have some, or thorough, evidence for their relevance to road safety. Impaired vision is highly correlated with increased age and the elderly. Therefore, several studies focus on road users 50 years of age or older. With advanced age, other medical and functional co-morbidities follow that are potential confounders in the relationship between vision and road safety – in particular cognitive impairments. More methodological weaknesses in studies are the use of self-reported crashes, small sample sizes and not accounting for driving exposure or driving habits.

2 Scientific Overview

Vision is an important sense that dominates other senses, so called visual dominance (Posner, Nissen, & Klein, 1976). It is thus the sense that humans rely most on. It is essential for human beings and their whereabouts in everyday life as it has evolved and adapted to our way of life through natural selection. It is thus an important sense used by humans to keep mobile in society, regardless of the mode of transport. The importance of vision in e.g. driving was noted as early as the late 1930s in a model developed by Gibson and Crooks (1938) and has since been connected to driving and other modes of transport at several occasions by numerous researchers. Since humans rely so heavily on vision it is obvious that impaired vision can be regarded as a risk factor in road safety. The link to road safety is also apparent in vision requirements that are enforced in different countries and states and which drivers have to meet in order to obtain their license. Typically, these requirements rely solely on tests of visual acuity, which has a weak association to driver safety (Owsley, 2010). Another related topic is the discussion of periodic screening of drivers, especially in the older population, with the goal of capturing at-risk drivers.

The functioning of vision enables us to see objects at varying distances under different light conditions as it is a sense that registers light, or electromagnetic radiation, with a wavelength from circa 400 nanometers up to approximately 750 nanometers. Vision has a close link to various cognitive processes such as visual attention, memory, decision making and visuospatial ability.

Vision can also be described by dividing it into the following capabilities:

- visual acuity (the resolution of the eye),
- visual field (the field of vision seen at one moment),
- contrast vision (differences in colour and brightness),
- colour vision,
- diplopia (double vision),
- adaptation (to different lightning conditions).

Tests of vision can broadly be categorised into ophthalmological tests on the one hand and tests capturing more cognitive aspects of vision on the other hand. See **Table 1** for examples of tests measuring aspects of vision capabilities and cognitive aspects, as well as example of factors influencing these capabilities. In general, most of the visual and related cognitive capabilities are affected negatively as we age.

Table 1: Overview of tests in relation to vision capabilities and examples of factors influencing each capability negatively.

Capability	Tests	Negatively influencing factors
Visual acuity	Logmar, ETDRS, Snellen	Cataracts
Visual field	Integrated visual field, Esterman visual field test, Dynamic visual field, Peripheral motion processing	Disease affecting optic nerve caused by stroke, glaucoma, retinal disorder, cataracts
Contrast vision	Pelli-Robson eye chart, Functional acuity contrast test	Cataracts

Color vision	Farnsworth, Farnsworth-Munsell, Nagel	Colour blindness, deutan colour deficiency, protan colour deficiency
Diplopia	Binocular single vision scores	Cataracts
Adaptation	Contrast sensitivity, Motion sensitivity	Night myopia
Cognitive aspects of vision	Useful field of view, Change blindness, Motor free visual perceptual test, Clock drawing test, Trail making test	Parkinson's disease, Alzheimer's disease, Multiple sclerosis

The vision impairments that have been investigated most thoroughly in relation to road safety are visual acuity, visual field, contrast sensitivity and cognitive aspects of vision. Research on these impairments and elevated crash risk over the past decades has shown varied results. The current knowledge suggests that visual acuity is very weakly associated with crash risk, while contrast sensitivity, visual field, and cognitive aspect of vision have some, or thorough, evidence for their relevance to road safety. **Table 2** shows an overview of the results of the coded studies.

Table 2: Overview of results of coded studies. Key ↑ increased risk; – not significant; ↓ decreased risk

Author, Year, Country	**Risk factor**	**Study type**	**Outcome variable**	**Effects for Road Safety**	**Main outcome - description**
Ivers 1999, Sydney, Australia	Reduced vision; Visual acuity	Self-reported accidents in population-based survey. Cross-sectional.	Crash involvement	↑	Visual deficiencies associated with crash involvement were visual acuity worse than 20/60 in the right eye, and difference in acuity between the eyes >= 10 letters, but not visual field impairment.
Owsley et al. 1998, Alabama, USA	Reduced vision; UFOV	Case-control study with drivers involved in injurious and non-injurious vehicle crashes (two case groups) and drivers not involved in vehicle crashes (controls)	Crash involvement (injury and non-injury)	↑	Only restricted useful field of view (UFOV) and glaucoma were the significant independent predictors of injurious crash involvement. The study implies that impaired visual processing and glaucoma may play a role in the aetiology of older driver crashes which result in injury.
Gresset and Meyer 1994, Quebec, Canada	Reduced vision; Visual acuity	Case-control study with male drivers involved vs not involved in a road accident.	Crash involvement	–	The study suggests that drivers with minimal visual acuity do not have a higher risk of road accidents, and a small elevated risk if combined with lack of binocularity.

3 Supporting Document

3.1 LITERATURE SEARCH STRATEGY

The literature on reduced hearing and traffic risk was searched for in the international database Scopus on April 22nd 2016.

Search no.	Search term	Hits
#1	"Vision impairment" OR "Vision disorder*" OR "Visual disord*"	22,315
#2 (within #1)	"Road safety" OR "Traffic safety" OR "road accident"	109
#3 (within #2)	"Collision" OR "Risk"	85

Limitations

- Search field: TITLE-ABS-KEY
- Published: 1990 to current
- Document type: "Review" and "Article"
- Language: English
- Source type: Journal

Final search string returning 85 hits

(TITLE-ABS-KEY ("vision impairment" OR "Vision disorde*" OR "Visual disorde*")) AND ("road safety" OR "traffic safety" OR "road accident") AND ("collision" OR "risk") AND (LIMIT-TO (PUBYEAR , 2015) OR LIMIT-TO (PUBYEAR , 2014) OR LIMIT-TO (PUBYEAR , 2013) OR LIMIT-TO (PUBYEAR , 2012) OR LIMIT-TO (PUBYEAR , 2011) OR LIMIT-TO (PUBYEAR , 2010) OR LIMIT-TO (PUBYEAR , 2009) OR LIMIT-TO (PUBYEAR , 2008) OR LIMIT-TO (PUBYEAR , 2007) OR LIMIT-TO (PUBYEAR , 2006) OR LIMIT-TO (PUBYEAR , 2005) OR LIMIT-TO (PUBYEAR , 2004) OR LIMIT-TO (PUBYEAR , 2003) OR LIMIT-TO (PUBYEAR , 2002) OR LIMIT-TO (PUBYEAR , 2001) OR LIMIT-TO (PUBYEAR , 2000) OR LIMIT-TO (PUBYEAR , 1999) OR LIMIT-TO (PUBYEAR , 1998) OR LIMIT-TO (PUBYEAR , 1997) OR LIMIT-TO (PUBYEAR , 1996) OR LIMIT-TO (PUBYEAR , 1995) OR LIMIT-TO (PUBYEAR , 1994) OR LIMIT-TO (PUBYEAR , 1992) OR LIMIT-TO (PUBYEAR , 1991) OR LIMIT-TO (PUBYEAR , 1990)) AND (LIMIT-TO (DOCTYPE , "ar") OR LIMIT-TO (DOCTYPE , "re")) AND (LIMIT-TO (LANGUAGE , "English")) AND (LIMIT-TO (SRCTYPE , "j"))

Screening table

Total nr of articles to screen	85
Exclusion due to relevance	36
Exclusion due to qualitative data	7
Exclusion due to no risk data	18
Exclusion due to countermeasure	10
Selected studies to obtain full-text	**14**

Eligibility table

Total number of studies to screen full-text	14
Full text could be obtained	14
Reference list examination	14
Eligible papers	**7**

Screening of the full texts

Total number of studies to screen full paper	7
Studies with no risk estimates excluded	4
Studies concerning measures excluded	
Remaining studies (to be coded)	**3**

3.2 ANALYSIS OF STUDY DESIGNS AND METHODS

Table 3: Characteristics of coded studies

Author, Year, Country	Sample, method/design and analysis	Risk group/ Cases	Control group/ Controls	Research conditions/ control variables
Ivers 1999, Sydney, Australia	Self-reported accidents in the past 12 months, 1992-1994, 2,326 drivers aged 49 and older. Cross-sectional. From population-based survey.	Drivers without visual impairments.	Drivers with a visual impairment, e.g. visual acuity.	Adjusted for age and gender.
Owsley et al. 1998, Alabama, USA	Case-control study based on health records from between 1985 and 1990. Association between visual risk factors and injurious vehicle crashes. Elderly drivers 55-87 years of age in case and control groups. Associations examined through a multivariable logistic regression model.	Case group 1: drivers who had incurred at least one vehicle crash resulting in an injury to at least one occupant (n = 78). Case group 2: drivers involved in non-injury crashes (n = 101).	Drivers not involved in crashes (n = 115).	Small sample. Not controlled for medication and driving exposure patterns. Visual function measured on average 3 years after crash involvement.
Gresset and Meyer 1994, Quebec, Canada	Case-control study. Association between road accidents and minimal visual acuity as well as lack of binocularity. Male drivers involved in a road accident were compared with male drivers who had not during their 70th year in 1988 or 1989. Odds ratios obtained through multiple logistic regression.	Male drivers involved in a road accident (n = 1400).	Male drivers not involved in a road accident (n = 2636, randomly selected).	Adjusted for traffic convictions, mileage, time spent and frequency of driving during rush hours.

3.3 EXPLORATORY ANALYSIS OF RESULTS

Table 4: Main outcomes of coded studies

Author, Year, Country	Risk factor	Study type	Outcome variable	Effects for Road Safety	Main outcome -description
Ivers 1999, Sydney, Australia	Reduced vision	Self-reported accidents in population-based survey. Cross-sectional.	Crash involvement.	Visual acuity, Right eye <20/60: PR = 2.2; 95%, CI: 1.3–3.5, p=0.01 Visual acuity, difference between eyes >=10 letters: PR = 1.6; 95%, CI: 1.0–2.3, p=0.02.	Visual deficiencies associated with crash involvement were visual acuity worse than 20/60 in the right eye, and difference in acuity between the eyes >= 10 letters, but not visual field impairment.
Owsley et al. 1998, Alabama, USA	Reduced vision	Case-control study with drivers involved in injurious and non-injurious vehicle crashes (two case groups) and drivers not involved in vehicle crashes (controls).	Crash involvement (injury and non-injury).	ORs for reductions in the useful field of view of 23-40%, 41-60% and greater than 60% were 4.2 (95% CI, 1.5-11.8), 13.6 (95% CI, 5.8-39.7), and 17.2 (95% CI, 5.3-55.6), respectively, compared to reductions of less than 23% (p for trend <0.001). The OR for glaucoma was 3.6 (95% CI, 1.0-12.6).	Only restricted useful field of view and glaucoma were the significant independent predictors of injurious crash involvement. The study implies that impaired visual processing and glaucoma may play a role in the aetiology of older driver crashes which result in injury.
Gresset and Meyer 1994, Quebec, Canada	Reduced vision	Case-control study with male drivers involved vs not involved in a road accident.	Crash involvement.	Visual acuity alone (6/12 or 6/15): OR= 0.97; CI 95%: 0.68–1.38 Both minimal visual acuity and lack of binocularity: OR= 1.23; CI 95%: 0.88–1.72.	The study suggests that drivers with minimal visual acuity do not have a higher risk of road accidents, and a small elevated risk if combined with lack of binocularity.

Meta-analysis results

Studies associating vision impairments with crash risk are limited. Therefore, it may not be meaningful to conduct any meta-analysis, vote-count analysis or review type analysis.

3.4 REFERENCES

Coded studies

Gresset, J. A. & Meyer, F. M. (1994). Risk of accidents among elderly car drivers with visual acuity equal to 6/12 or 6/15 and lack of binocular vision. *Ophthalmic and Physiological Optics, 14*(1), 33-37.

Ivers, R. Q., Mitchell, P., & Cumming, R. G. (1999). Sensory impairment and driving: The blue mountains eye study. *American Journal of Public Health, 89*(1), 85-87.

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Gibson, J. J., & Crooks, L. E. (1938). A theoretical field-analysis of automobile-driving. *The American Journal of Psychology, 51*(3), 453-471.

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Diseases and Disorders – Diabetes

The effect of having the condition 'diabetes' on road safety

1 Summary

Goldenbeld, C. & van Schagen, I., SWOV Institute for Road Safety Research, The Hague, Netherlands, August

1.1 COLOUR CODE: YELLOW

Studies generally show a (small) elevated crash risk. However, effects are not always statistically significant. Many studies have low quality, e.g. because they did not adjust for exposure or mileage. Furthermore, the results are possibly compromised by national countermeasures, e.g., some countries impose driving restrictions on drivers with insulin-treated diabetes. When the higher risk diabetes drivers are not allowed to participate in traffic, this will affect the overall risk of diabetes identified in that country.

1.2 KEYWORDS

diseases and disorders, diabetes, crash risk, car drivers

1.3 ABSTRACT

This chapter discusses the effect of diabetes on road safety. Diabetes mellitus is a group of metabolic diseases characterised by defects in insulin secretion, insulin action, or both. Studies generally show a (slightly) higher risk for drivers with diabetes, although differences are often not statistically significant. Two main approaches have been used to study the relationship between diabetes and crash risk. The most common approach compares crash rates of individuals with diabetes with crash rates of individuals without diabetes. The less common approach first distinguishes between drivers who have and who have not been involved in a crash, and then compares the prevalence of diabetes in these two groups. Most research has been done in the USA, Canada, and Europe. Most of the research is on private drivers; very few studies are on commercial drivers.

1.4 BACKGROUND

What is diabetes?

Diabetes mellitus (or diabetes) is a chronic condition that affects the body's ability to use glucose in food for energy. For this the hormone insulin is needed. With diabetes the body either does not make sufficient insulin or it cannot use the insulin, or both. The two main types of diabetes are type 1 and type 2. Type 1 diabetes, often called insulin-dependent diabetes or juvenile-onset diabetes, accounts for 5 to 10 percent of all diagnosed cases of diabetes; type 2 diabetes, often called non-insulin-dependent diabetes or adult-onset diabetes, accounts for 90 to 95 percent (Bieber-Tregear et al., 2011). Risk factors for developing type 2 diabetes include older age, obesity, family history of diabetes, history of gestational diabetes, impaired glucose tolerance, physical inactivity, and race/ethnicity (Bieber-Tregear et al., 2011). Treatments for diabetes aim to maintain blood glucose levels near normal (euglycemia) at all times. Exact treatment differs for type 1 and type 2 diabetes but generally includes diet control, physical activity, home blood glucose testing several times a day, and regular insulin injections or oral medication.

How does diabetes affect road safety?

The most important acute threat of diabetes for road safety is hypoglycaemia (Bieber-Tregear et al., 2011; Graveling & Frier, 2015). Hypoglycemia is a clinical syndrome that results from abnormally low levels of blood glucose which can arise as a result of treatments for diabetes. The body's biochemical response to hypoglycemia usually starts when blood sugar levels fall below 65 to 70 mg/dl (3.6 to 3.9 mmol/L). If the blood glucose level falls below 60 mg/dl (3.3 mmol/L), physical symptoms begin to become apparent: sweating, tremor, hunger, anxiety, and palpitations.

Experimental laboratory studies have demonstrated that cognitive functions critical to driving (such as attention, reaction times and hand-eye coordination) are impaired during hypoglycaemia (Graveling & Frier, 2015). Hypoglycemia also affects the visual information processing and visual perception, and hence driving performance. This is most apparent under conditions of limited perceptual time and low visual contrast (poor light). Driving simulator studies have shown that driving performance is already affected adversely by moderate hypoglycemia, causing problems such as inappropriate speeding or braking, ignoring road signs and traffic lights and not keeping to traffic lanes (Graveling & Frier, 2015).

Furthermore, there are a number of medical complications associated with diabetes that could affect driving competency, including cardiovascular disease, diabetic neuropathy, and diabetic retinopathy (Bieber-Tregear et al, 2011; Graveling & Frier, 2015).

How many people have diabetes?

In the European Region, there are about 60 million people with diabetes; i.e. about 10.3% of men and 9.6% of women aged 25 years and over (WHO, site accessed 2 May 2016). The prevalence of diabetes is increasing among all ages in the European region, mostly due to increases in overweight and obesity, unhealthy diet and physical inactivity (WHO site accessed 2 May 2016). The prevalence of diabetes varies widely in the 56 diverse countries in the European region, from 2.4% in Moldova to 14.9% in Turkey (Tamayo et al., 2014). In the USA around 9.3% of the population has diabetes (American Diabetes Association site accessed 2 May 2016).

Which factors influence the effect of diabetes on road safety?

In theory, the diabetes-risk relationship could be affected by personal factors (e.g. gender, age, type of driving), specific treatment factors, and national conditions (e.g. national screening and countermeasures for diabetes). However systematic comparable evidence about the influence of these factors is scarce. Diabetes risk studies that have included gender and age often use them as covariates rather than independent variables. There is no systematic evidence of the effect of specific treatment on crash risk. A meta-analysis found that insulin-treatment of diabetes was associated with non-significant 21% risk increase compared to non-treatment with insulin. Concerning national conditions, a meta-analysis found that the increased risk of drivers with diabetes was significant in the USA, but not in other countries (Canada, Norway, Northern Ireland, Scotland, Sweden). This difference was attributed to stricter diabetes checks and regulations for drivers in Europe and Canada.

How is the effect of diabetes on road safety measured?

Two main approaches have been used to study the relationship between diabetes and crash risk. The most common approach is the case-control study. Such a study compares the crash rates of individuals with diabetes (cases) with crash rates of individuals without diabetes (controls). The less common approach first distinguishes between drivers who have and who have not been involved in a crash, and then compares the prevalence of diabetes in these two groups. Most research has been done in the USA, Canada, and Europe. Most of the research is on private drivers; very few studies are on commercial drivers. Most studies included both type 1 and type 2 diabetes.

The studies generally look at one of the following measures of road safety:
- Actual/police-registered crash involvement,
- Actual/police-registered at fault (culpable) crash involvement,
- Self-reported crash involvement,
- Self-reported at fault crash involvement.

1.5 OVERVIEW RESULTS

Studies generally show that drivers with diabetes have a slightly increased crash risk compared to drivers without diabetes. However, effects are often statistically non-significant. Hence we cannot exclude the possibility that the observed difference in crash risk is not a real difference but based on chance and accidental fluctuations. In theory, factors that could influence the effect of diabetes on crash risk are personal factors (e.g. gender, age), medical treatment factors, or national conditions (e.g. screening and counter-measures for diabetes). However, the evidence concerning these types of modifying conditions is scarce and indirect. Most of the research is on private drivers; very few studies are on commercial drivers. There has been no systematic research on differences between type 1 and type 2 diabetes on crash risk.

1.6 NOTES ON RESEARCH AND ANALYSIS METHOD

Most studies that aim to assess the risk of diabetes compare the accident risk of diabetes patients with the accident risk of people without diabetes. It is also possible to compare the prevalence of diabetes in people who have and who have not been involved in an accident. This is a less common method.

2 Scientific Details

2.1 DESCRIPTION OF CODED STUDIES

Table 1 provides further description of the background characteristics of the coded studies on diabetes and crash risk.

Table 1: Characteristics of coded studies on diabetes and driving risk

Author, Year, Country	Method and analysis	Risk group/ Cases	Control group/ Controls	Modifying conditions/ control variables
Bieber-Tregear et al. 2011 International	Meta-analysis. Random effects. 15 studies comparing crash involvement between diabetic and non-diabetic drivers	Diabetic drivers (crash/no crash)	Non-diabetic drivers (crash/no crash)	Comparison US and non-US studies
Bieber-Tregear et al. 2011 International	Meta-analysis. Random effects. 6 studies comparing crash involvement between insulin treated diabetic drivers and otherwise treated diabetic drivers	Insulin treated diabetic drivers	Oral medication or diet treated diabetic drivers	Comparison US and non-US studies
Bieber-Tregear et al. 2011 International	Meta-analysis. Random effects. 4 studies comparing prevalence of diabetes between crash-involved and non-crash involved drivers	Crash-involved drivers (diabetes/no diabetes)	Non-crash involved drivers (diabetes/no diabetes)	4 studies also reported on conditions of diabetes treatment (insulin, pharma-cotherapy, controlled diet alone).
Bieber-Tregear et al. 2011 International	Meta-analysis. Fixed effects. 4 studies comparing prevalence of insulin-treated diabetic drivers among crash-involved and non-crash-involved drivers	Crash-involved drivers (insulin/ no insulin)	Non-crash involved drivers (insulin/no insulin)	Comparison US and non-US studies
Sagberg, 2006, Norway	Self-report questionnaires from 4448 crash-involved drivers. Odds ratio calculated.	Cases: At fault (n = 2226)	Controls: Not at fault (n = 1840)	Analysis adjusted for age and annual driving distance.
Redelmeier et al. 2009, Canada	In 2-y study interval 795 diabetic patients who had HbA1c values documented were reported to licensing authorities. Logistic regression.	Cases: 57 patients were involved in a crash	Controls: 738 were not involved in a crash	Analyses controlled for age, gender, medical complication, history severe hypoglycemia, age diabetes diagnosed
Signorovitch et al. 2012 USA	Diabetes-2 people (not insulin treated) identified from a claims database (1998–2010). Crash occurrence leading to hospital visits was com-pared between people with, and without claims for hypoglycaemia. Analysis by multivariate Cox proportional hazard models.	n=5.582 people with claims for hypoglycaemia	n=27.910 with no such claims were	Analysis adjusted for demo-graphics, comorbidities, prior treatments and prior medical service use

Vingilis & Wilk 2012 Canada	Population-based large-scale panel research (N = 12.387). 524 (4.2%) reporting an motor vehicle injury MVI 1996- 2007. Path analyses examined the odds of subsequent MVI.	Diabetes reporting MVI, n =14	Diabetic drivers not reporting MVI, n = 346	Analysis controlled for age, gender and independent effects of medication use.
Orriols et al. 2014 France	69.630 drivers involved in an injurious crash in France 2005-2008. Logistic regression analysis ; outcome = odds of being responsible for crash	Cases: drivers who were deemed responsible for the crash (n =33.200)	Controls: drivers who were not responsible for crash (n = 36.450).	Analysis adjusted for age, gender, socio-economic category, month, time of day, vehicle type, alcohol level, injury severity, exposure to medicines and other long-term diseases.

Description of main research methods

In the coded studies two main approaches were used for investigating crash risk in individuals with diabetes (**Figure 1**, taken from Bieber-Tregear et al. 2011). On the one hand, cohorts can be identified based on whether or not they have diabetes. In this scenario, crash rates among a group of individuals with diabetes (i.e., cases) are compared with crash rates among a group of individuals without diabetes. An alternative less used approach is to identify cohorts on the basis of whether or not they have had a crash, and then compare the prevalence of diabetes in the two groups.

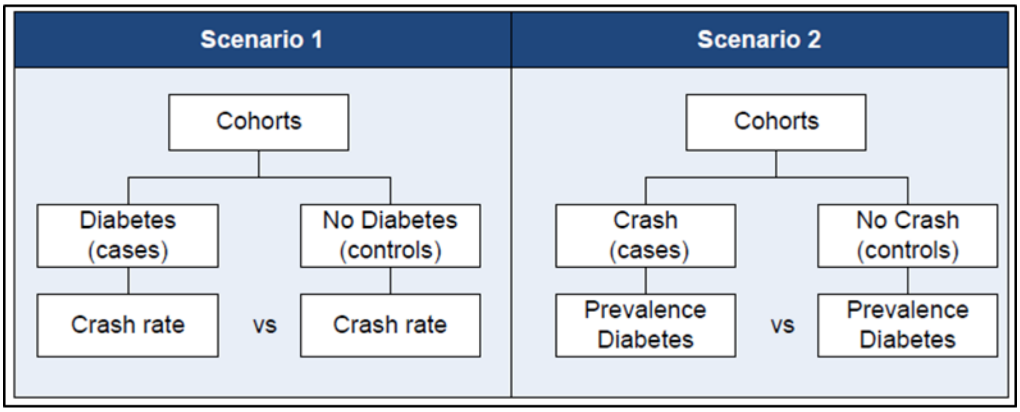

Figure 1: Scenarios for investigating risk of crash in diabetes (from: Bieber-Tregear et al., 2011)

According to Bieber-Tregear et al. (2011) 15 studies on diabetes-crash risk relationship can be classified under scenario 1, and 4 studies under scenario 2.

Most research has been done in the USA, Canada, and Europe. All of the coded studies were on private drivers. Most of the coded studies included both type 1 and type 2 diabetes. The coded studies generally looked at one of the following measures of road safety:

- Actual/police-registered crash involvement,
- Actual/police-registered at fault (culpable) crash involvement,
- Self-reported crash involvement,
- Self-reported at fault crash involvement.

Besides these basic approaches the coded studies on diabetes and risk varied on:

- Matching of cases and controls,

- Recorded crashes versus self-reported crashes,
- Inclusion of independent variables (e.g. several treatment conditions),
- Inclusion of statistical control variables (e.g. gender, age, mileage, treatment, other diseases).
-

2.2 RESULTS

Literature review

Diabetes mellitus (or diabetes) is a chronic condition that affects the body's ability to use the glucose in food for energy. For this the hormone insulin is needed. With diabetes the body either does not make sufficient insulin or it cannot use the insulin, or both. The two main types of diabetes are type 1 and type 2. Type 1 diabetes, often called insulin-dependent diabetes or juvenile-onset diabetes, accounts for 5 to 10 percent of all diagnosed cases of diabetes; type 2 diabetes, often called non-insulin-dependent diabetes or adult-onset diabetes, accounts for 90 to 95 percent (Bieber-Tregear et al., 2011). Risk factors for developing type 2 diabetes include older age, obesity, family history of diabetes, history of gestational diabetes, impaired glucose tolerance, physical inactivity, and race/ethnicity (Bieber-Tregear et al., 2011). Treatments for diabetes aim to maintain blood glucose levels near normal (euglycemia) at all times. Exact treatment differs for type 1 and type 2 diabetes but generally includes diet control, physical activity, home blood glucose testing several times a day, and regular insulin injections or oral medication.

In the European Region, there are about 60 million people with diabetes; i.e. about 10.3% of men and 9.6% of women aged 25 years and over (WHO, site accessed 2 May 2016). The prevalence of diabetes is increasing among all ages in the European region, mostly due to increases in overweight and obesity, unhealthy diet and physical inactivity (WHO site accessed 2 May 2016). The prevalence of diabetes varies widely in the 56 diverse countries in the European region from 2.4% in Moldova to 14.9% in Turkey (Tamayo et al., 2014). In the USA around 9.3% of the population have diabetes (American Diabetes Association site accessed 2 May 2016).

The most important acute threat of diabetes for road safety is hypoglycaemia (Bieber-Tregear et al., 2011; Graveling & Frier, 2015). Hypoglycemia is a clinical syndrome that results from abnormally low levels of blood glucose which can arise as a result of treatments for diabetes. The body’s biochemical response to hypo-glycemia usually starts when blood sugar levels fall below 65 to 70 mg/dl (3.6 to 3.9 mmol/L). If the blood glucose level falls below 60 mg/dl (3.3 mmol/L), physical symptoms begin to become apparent: sweating, tremor, hunger, anxiety, and palpitations.

Experimental laboratory studies have demonstrated that cognitive functions critical to driving (such as attention, reaction times and hand-eye coordination) are impaired during hypoglycaemia (Graveling & Frier, 2015). Hypoglycemia also affects the visual information processing and visual perception, and hence driving performance. This is most apparent under conditions of limited perceptual time and low visual contrast (poor light). Driving simulator studies have shown that driving performance is already affected adversely by moderate hypoglycemia, causing problems such as inappropriate speeding or braking, ignoring road signs and traffic lights and not keeping to traffic lanes (Graveling & Frier, 2015).

Furthermore, there are a number of medical complications associated with diabetes that could affect driving competency, including cardiovascular disease, diabetic neuropathy, and diabetic retinopathy (Bieber-Tregear et al, 2011; Graveling & Frier, 2015).

In theory, the diabetes-risk relationship could be affected by personal factors (e.g. gender, age, type of driving), specific treatment factors, and national conditions (e.g. national screening and countermeasures for diabetes). However systematic comparable evidence about the influence of these factors is scarce. Diabetes risk studies that have included gender and age often use them as covariates rather than independent variables. There is no systematic evidence of the effect of specific treatment on crash risk. A meta-analysis found that insulin-treatment of diabetes was associated with non-significant slight 21% risk increase compared to non-treatment with insulin. Concerning national conditions, a meta-analysis found that the increased risk of drivers with diabetes was significant in the USA, but not in other countries (Canada, Sweden, Norway, Northern Ireland, Scotland, Sweden). This difference was attributed to stricter diabetes checks and regulations for drivers in Europe and Canada.

Meta-analysis

A 2011 meta-analysis of 15 case-control studies indicated that the magnitude of increased crash risk was small and not statistically significant (Risk Ratio=1.126; 95% CI: 0.847–1.497; p=0.415). These case-control studies used a scenario 1 design (as described in **Figure 1**). A subgroup meta-analysis on 6 studies compared the crash risk of insulin-treated drivers with diabetes to that of drivers with diabetes who control their condition with pharmacotherapy or diet alone. The result of this analysis was not significant: OR = 1.537 (95% CI: 0.603–3.915, p=0.368).

A random-effects meta-analysis on 4 studies (with a design according to scenario 2 in **Figure 1**) found that drivers with diabetes are not over-represented among samples of drivers who have experienced a crash (OR = 1.052, 95% CI: 0.970–1.141; p=0.220). A fixed effects analysis on the same 4 studies found that drivers with diabetes who controlled diabetes using insulin had a non-significant higher crash rate when compared with those who do not use insulin to control their diabetes (OR = 1.212; 95% CI: 0.939–1.563, p=0.139).

Additional studies

The studies not included in the meta-analysis and/or appearing after the meta-analysis also showed mixed results (Sagberg, 2006; Redelmeier et al., 2009; Orriols et al., 2014; Vingilis & Wilk, 2012; Signorovitch et al., 2012). In a Norwegian study Sagberg analysed questionnaire data from 4448 crash-involved drivers. For drivers with untreated diabetes (diabetes type 2), he found a significant odds ratio indicating increased risk for being at fault for a crash (OR=3.08, p = 0.05). No effect was found for treated or medicated diabetes. A strong point of the study was that the researcher corrected for age and mileage; at the same time the questionnaire response was low and the method (induced-exposure method) does not allow one to determine crash risk of diabetics when compared with rest of population. A large, nationally representative, longitudinal, self-report only study of Canadians indicated a non-significant crash risk of diabetes after controlling for age and gender (OR = 1.479, 95% CI: 0.743 - 2.944; p = 0.266; Vingilis & Wilk, 2012). A large scale longitudinal French study (combining information from the national healthcare insurance database, police reports and the national police database of injury crashes) found a significant effect of type 1 diabetes on being responsible for a crash (OR = 1.47, CL=1.12–1.92; p = 0.0047; Orriols et al., 2014). This estimate was corrected for various covariates (age, gender, socioeconomic category, month, time of day, vehicle type, alcohol level, injury severity, exposure to medicines affecting driving abilities and other long-term diseases).

In large scale prospective database study, Signorovitch et al. (2012) compared the occurrence of accidents resulting in hospital visits between people with, and without, claims for hypoglycaemia after the initiation of a non-insulin antidiabetic drug. These researchers adjusted the risk estimates for demographics, comorbidities, prior treatments and prior medical service use, and they also conducted analyses stratified by age (< 65; 65 years or older). After adjusting for baseline characteristics, hypoglycaemia was associated with significantly increased risks for motor vehicle accidents (Hazard Ratio = 1.82, 95% CI 1.18–2.80, p=0.007).

Modifying conditions

In theory, conditions that might modify the diabetes-risk relationship could be personal factors (e.g. gender, age), specific treatment factors, or national conditions (e.g. screening and countermeasures for diabetes).

- Age and gender

Several studies have used age and/or gender as statistical control variables (Sagberg, 2006; Orriols et al., 2014; Vingilis & Wilk, 2012) but very few have used them as independent variables. It seems that diabetes driving risk does not increase with age. Skurtveit (2009; included in the Bieber-Tregear et al. meta-analysis) found that highest crash involvement was among 18-34 yrs. Signorovitch et al. (2012) found that hypoglycemia was associated with greater hazards of driving-related accidents in people younger than 65. Hypoglycaemia was associated with greater hazards of driving-related accidents in people younger than 65. Among the younger people, hypoglycemia was significantly associated with a greater than 130% increase in the risk of motor vehicle accidents (adjusted HR: 2.31; 95% CI: 1.44–3.70).

- National differences

Subgroup analysis indicated that the relative risk effect was significant in the USA (RR = 1.284; 95% CI=1.124-1.466; p <0.0001), but not in non-USA countries (1.035; 95%, CI: 0.720-1.487; p=0.854) (Bieber-Tregear et al., 2011). This difference in findings has been attributed to stricter diabetes checks and regulations for EU-drivers (Bieber-Tregear et al., 2011).

- Specific treatment factors

Although insulin treatment is a risk factor for hypoglycemia and hypoglycemia is considered to be a vital mechanism explaining the increased risk for diabetes, there is no evidence that insulin-treated persons are over-represented in crashes. A fixed effects meta-analysis on 4 studies (method 2, **Figure 1**) found that drivers with insulin controlled diabetes tend to be over-represented among samples of drivers who have experienced a crash: this result was not statistically significant (odds ratio =1.212; 95% CI: 0.939–1.563, p=0.139) (Bieber-Tregear et al., 2011).

Conclusions

There is some evidence that drivers with diabetes have a slight increased crash risk compared to drivers without diabetes. Most studies indicate a slightly elevated risk estimate, but results are not always significant (see **Table 2** below).

Table 2: Overview of studies and their (simplified) main outcomes (↑ = statistical significant increase in crash involvement; ↑ n.s. = statistical not significant increase; = = no effect).

Study	Simplified summary of main outcomes	
Bieber-Tregear et al. 2011, intern.	Crash involvement	↑ n.s.
Bieber-Tregear et al. 2011, intern.	Crash involvement insulin-treated vs. oral or diet treatment	↑ n.s.
Bieber-Tregear et al. 2011, intern.	Crash involvement	=
Bieber-Tregear et al. 2011, intern.	Crash involvement insulin-treated vs. oral or diet treatment	↑ n.s.
Sagberg, 2006, Norway	Self-reported crash culpability non-treated	↑

Sagberg, 2006, Norway	Self-reported crash culpability treated	=
Redelmeier et al. 2009, Canada	Crash involvement	↑
Signorovitch et al., 2012, USA	Crash involvement (resulting in hospital visit)	↑
Vingilis & Wilk, 2012, Canada	Motor vehicle injury	↑ n.s.
Orriols et al., 2014, France	Crash culpability	↑

The 2011 meta-analysis was based on a comprehensive literature search, review guiding decision rules and clearly defined quality assessment criteria. Most of the 15 case-control studies included in the meta-analysis were rated as low in quality; for example 9 of 15 case-control studies did not adjust for exposure (mileage).

The five studies after the meta-analysis or not included in the meta-analyses have used different designs and different outcome measures, and thus are not homogeneous, and their results cannot be pooled. Other complications are that over time studies are difficult to compare since the effects of treatments/medicine for diabetes may change over time. Comparison between countries is difficult since countries may differ in regulations concerning diabetes and driving. One reason why studies may fail to show a significant difference in crash rates at a population level between people at risk of hypoglycemia (mainly those with insulin-treated diabetes) and the general population with driving licenses is that countries impose restrictions on drivers with insulin-treated diabetes and remove those who are at high risk of having an accident.

Studies generally show that drivers with diabetes have a slightly increased crash risk compared to drivers without diabetes. However, effects are often statistically non-significant. Hence we cannot exclude the possibility that the observed difference in crash risk is not a real difference but based on chance and accidental fluctuations.

The main studies and their outcomes are:

- A 2011 meta-analysis of 15 case-control studies indicated a non-significant increase of the crash risk (actual crashes) of 13% (Bieber-Tregear et al., 2011).
- A large-scale Canadian longitudinal study indicated a non-significant increase in the crash risk (self-reports) of 48% (Vingilis & Wilk, 2012).
- A large-scale longitudinal French study, based on information from the national health insurance database and the national police injury crash database, reported a significant increase in crash risk (actual at fault crashes) of 47% (Orriols et al., 2014).

In theory, factors that could influence the effect of diabetes on crash risk are personal factors (e.g. gender, age), medical treatment factors, or national conditions (e.g. screening and countermeasures for diabetes). However, the evidence concerning these types of modifying conditions is scarce and indirect. Most of the research is on private drivers; very few studies are on commercial drivers. There has been no systematic research on differences between type 1 and type 2 diabetes on crash risk.

3 Supporting documents

3.1 LITERATURE SEARCH STRATEGY

The literature on diabetes and traffic risk was searched for in the international database Scopus on 23 March 2016. Scopus is the largest international peer-reviewed database. The literature was searched over the period 1999-2016; the search terms (**Table 3**) were searched in title, abstract and keywords. Also references were looked at in very recent review like texts. This search produced 164 hits.

Database: Scopus, Date: 23 March 2016

Table 3: Used search terms and logical operators

	Search terms/logical operators/combined queries	hits
	History Search Terms (TITLE-ABS-KEY (diabetes OR hypoglycemia OR hypoglycaemia OR hyperglycemia OR hyperglyceamia) AND TITLE-ABS-KEY ("road accident" OR "traffic accident" OR "accident risk" OR "crash risk" OR "road risk" OR "risky driving" OR "road safety" OR crash OR collision) AND TITLE-ABS-KEY (driving OR driver)) AND SUBJAREA (mult OR agri OR bioc OR immu OR neur OR phar OR mult OR medi OR nurs OR vete OR dent OR heal OR mult OR arts OR busi OR deci OR econ OR psyc OR soci) AND PUBYEAR > 1999	164

In a first screening round these 164 references were screened on potential relevance for coding based on title and abstract information. Criteria A to E describe reasons for not selecting publications in the first round (**Table 4**).

A = Not selected because paper refers to measure/intervention.
B = Not selected because diabetes is side subject (and not itself investigated in relationship to traffic risk).
C = Not selected because written in non-English.
D = Not selected because better or more complete results were published earlier or later in another publication (duplication).
E = Not selected because general review-like text.

Table 4: Initial screening of studies on diabetes and crash risk

Exclusion criterion	Not selected first round	Selected first round
A. Measure/intervention	21	
B. Side subject (not itself directly investigated)	59	
C .Non-English	20	
D. Duplication	4	
E. General review-like text	33	

Initially selected		**27**

The 27 studies selected in this initial screening were further screened on relevance for coding in a second round. In the second round the same criteria were used but were checked on full-text copies of the papers. **Table 5** presents the results of the second screening round and describes the final decisions concerning coding of the studies. In the end, 12 studies were coded. Of these 12 studies 6 were eventually analysed. 5 had been included in a recent meta-analysis, and consequently, were not analysed separately. One was an older meta-analysis which was replaced by a more recent meta-analysis.

Table 5: Selection of studies after the second screening round

	Reference	Relevant	Coded	Analysed
1	Abu Dabrh A.M. , Firwana B., Cowl C.T., Steinkraus L.W. , Prokop L.J. , & Murad M.H.(2014). Health assessment of commercial drivers: A meta-narrative systematic review (2014) BMJ Open, 4 (3), art. no. e003434	Review can point to specific studies, not relevant for coding but potentially relevant for review chapter	No	
2	Avalos, M. et al., 2014. Variable selection on large case-crossover data: application to a registry-based study of prescription drugs and road traffic crashes. Pharmacoepidemiology and drug safety, 23, 140–151.	Likely not relevant for coding: this article is about the problem how to screen hypotheses using probabilistic reasoning, selecting drug classes or individual drugs that most warrant further hypothesis testing.	No	
3	Bieber-Tregear, M., Funmilayo, D., Amana, A., Connor, D., & Tregear, S. (2011). Diabetes and commercial motor vehicle safety. Washington: Department of Transportation's Federal Motor Carrier Safety Administration.	Yes. Meta-analysis	Yes	Yes
4	Bloomfield, H.E., Greer, N., Newman, D., MacDonald, R., Carlyle, M., Fitzgerald, P., & Rutks, I. (2012). Predictors and Consequences of Severe Hypoglycemia in Adults with Diabetes - A Systematic Review of the Evidence. Department of Veterans Affairs, Washington.	Review not relevant for coding	No	
5	Burki, T.K.(2013). Diabetes and driving. The lancet. Diabetes & endocrinology, 1, e7–8	Not relevant for coding since this article discusses new European legislation.	No	
6	Campbell, L.K. et al. (2010). Neurocognitive Differences Between Drivers with Type 1 Diabetes with and without a Recent History of Recurrent Driving Mishaps. International journal of diabetes mellitus, 2, 73–77.	Likely not relevant for coding since the study deals with neurocognitive differences	No	
7	Cox, D.J., Gonder- Frederick, L.A., Kovatchev, B. P., Julian, D.M., Clarke, W.L. (2000). Progressive hypoglycemia 's impact on driving simulation performance: occurrence, awareness, and correction. Diabetes Care 23, 163–170.	Yes	Yes	No
8	Cox D.J., Ford D., Gonder-Frederick L., Clarke W., Mazze R., & Weinger K. (2009). Driving mishaps among individuals with type 1 diabetes. Diabetes Care, 32, 2177-2180.	Yes	Yes	No

9	Cox, D.J., Singh, H. & Lorber, D.(2013). Diabetes and driving safety: science, ethics, legality and practice. The American journal of the medical sciences, 345, 263–5	Review, not relevant for coding, but relevant for final review chapter	No	
10	Harsch, I.A., Stocker, S., Radespiel-Tröger, M., Hahn, E.G., Konturek, P.C., Ficker, J.H., & Lohmann, T. (2002). Traffic hypoglycaemias and accidents in patients with diabetes mellitus treated with different antidiabetic regimens. Journal of Internal Medicine, 252, 352-360.	Yes	Yes	No
11	Hassoun, A.A.K. et al., 2015. Driving and diabetes mellitus in the Gulf Cooperation Council countries: Call for action. Diabetes research and clinical practice, 110(1), 91–4.	Likely not relevant for coding since this paper seems more about extent of problem in Gulf countries and possible countermeasures.	No	
12	Hemmelgarn, B., Levesque, L.E., Suissa, S. (2006). Anti-diabetic drug use and the risk of motor vehicle crash in the elderly. Canadian Journal Clinical Pharmacology, 13, e112–20.	Yes	Yes	No
13	Hitosugi, M. et al., 2015. Main factors causing health-related vehicle collisions and incidents in Japanese taxi drivers. Romanian Journal of Legal Medicine, 23, 83–86	Likely not relevant since study concentrates on prevalence of several diseases (diabetes) among taxi drivers)	No	
14	Kagan A. , Hashemi G. , Korner-Bitensky N. (2010). Diabetes and fitness to drive: A systematic review of the evidence with a focus on older drivers. Canadian Journal of Diabetes, 34, 233-242.	Review can point to specific studies; at least relevant for review chapter but not for coding.	No	
15	Laberge-Nadeau, C., Dionne, G., Ekoe, J.M., Hamet, P., Desjardins, D., Messier S., & Maag, U (2000). Impact of diabetes on crash risks of truck-permit holders and commercial drivers. Diabetes Care, 23, 612-617.	Yes	Yes	No
16	Lonnen, K.F., Powell, R.J., Taylor, D., et al. (2008). Road traffic accidents and diabetes: insulin use does not determine risk. Diabetes Medicine,25, 578–84.	Yes	Yes	No
17	Marrero, D. & Edelman, S.(2000). Hypoglycemia and driving performance: A flashing yellow light? Diabetes Care, 23, 146–147.	Not suited for coding since this article mainly reviews some of earlier research in particular also a study by Cox et al. 2000	No	
18	Matsumura, M. et al. (2014). Hypoglycemic attacks in diabetic patients while driving an automobile. Journal of the Japan Diabetes Society, 57(5), 329–336.	In Japanese language	No	
19	Orriols L. , Avalos-Fernandez M., Moore N. , Philip P. , Delorme B. , Laumon B. , Gadegbeku B. , Salmi L.-R., Lagarde E. (2014). Long-term chronic diseases and crash responsibility: A record linkage study. Accident Analysis & Prevention, 71, 137-143	Yes	Yes	Yes
20	Parmentier, G. et al., (2005). Road mobility and the risk of road traffic accident as a driver. The impact of medical conditions and life events. Accident Analysis & Prevention, 37, 1121–1134	Not relevant, this study only mentions diabetes as a factor for road mobility mot as a risk factor	No	
21	Raubenheimer, P. (2012). Diabetes mellitus and	Not relevant for coding, review-like	No	

	driving. Journal of Endocrinology, Metabolism and Diabetes of South Africa, 17(2 SUPPL. 1).	paper, giving guidelines		
22	Raubenheimer, P.(2012). Diabetes mellitus and driving. Journal of Endocrinology, Metabolism and Diabetes of South Africa, 17(1).	Not relevant for coding, review-like paper, giving guidelines	No	
23	Redelmeier, D.A., Kenshole A.B., Ray J.G. (2009)., Motor vehicle crashes in diabetic patients with tight glycemic control: A population-based case control analysis. PLoS Med, 6, e1000192	Yes	Yes	Yes
24	Sagberg F. (2006). Driver Health and Crash Involvement: A Case-Control Study. Accident. Analysis & Prevention, 38, 28-34.	Yes	Yes	Yes
25	Signorovitch, J.E., Macaulay, D., Diener, M., Yan, Y., Wu, E.Q., Gruenberger, J.-B.& Frier,B.M. (2012). Hypoglycaemia and accident risk in people with type 2 diabetes mellitus treated with non-insulin antidiabetes drugs. Diabetes, Obesity and Metabolism, 15, 335–341.	Yes	Yes	Yes
26	Vaa, T. (2003) Impairment, Diseases, Age and Their Relative Risks of Accident Involvement: Results from Meta-Analysis. Oslo: TØI Report 690 for the Institute of Transport Economics..	Yes	Yes	No
27	Vingilis, E., & Wilk, P. (2012). Medical conditions, medication use, and their relationship with subsequent motor vehicle injuries: examination of the Canadian National Population Health Survey. Traffic Injury Prevention, 13, 327-36.	Yes	Yes	Yes

3.2 BACKGROUND CHARACTERISTICS OF THE ANALYSED STUDIES

Table 6 provides a detailed description of the background characteristics of the analysed studies. It should be noted that the meta-analysis of Bieber-Tregear et al. (2011) consisted of 4 separate analyses each of which is included in **Table 6**.

Table 6: Characteristics of analysed studies

Author, Year, Country	Sample, method/design and analysis	Risk group/ Cases	Control group/ Controls	Research conditions/ control variables
Bieber-Tregear et al. 2011 International	Meta-analysis. Random effects. 15 studies comparing crash involvement between diabetic and non-diabetic drivers	Diabetic drivers (crash/no crash)	Non-diabetic drivers (crash/no crash)	Comparison US and non-US studies
Bieber-Tregear et al. 2011 International	Meta-analysis. Random effects. 6 studies comparing crash involvement between insulin treated diabetic drivers and otherwise treated diabetic drivers	Insulin treated diabetic drivers	Oral medication or diet treated diabetic drivers	Comparison US and non-US studies

Bieber-Tregear et al. 2011 International	Meta-analysis. Random effects. 4 studies comparing prevalence of diabetes between crash-involved and not crash-involved drivers	Crash-involved drivers (diabetes/no diabetes)	Non-crash involved drivers (diabetes/no diabetes)	4 studies also reported on conditions of diabetes treatment (insulin, pharma-cotherapy, controlled diet alone).
Bieber-Tregear et al. 2011 International	Meta-analysis. Fixed effects. 4 studies comparing prevalence of insulin-treated diabetic drivers among crash-involved and non-crash-involved drivers	Crash-involved drivers (insulin/ no insulin)	Non-crash involved drivers (insulin/no insulin)	Comparison US and non-US studies
Sagberg, 2006, Norway	Self-report questionnaires from 4448 crash-involved drivers. Odds ratio calculated.	Cases: At fault (n = 2226)	Controls: Not at fault (n = 1840)	Analysis adjusted for age and annual driving distance.
Redelmeier et al. 2009, Canada	In 2-y study interval 795 diabetic patients who had HbA1c values documented were reported to licensing authorities. Logistic regression.	Cases: 57 patients were involved in a crash	Controls: 738 were not involved in a crash	Analyses controlled for age, gender, medical complication, history severe hypoglycemia, age diabetes diagnosed
Signorovitch et al. 2012 USA	Diabetes-2 people (not insulin treated) identified from a claims database (1998–2010). Crash occurrence leading to hospital visits was com-pared between people with, and without claims for hypo-glycaemia. Analysis by multivariate Cox proportional hazard models.	n=5.582 people with claims for hypoglycaemia	n=27.910 with no such claims were	Analysis adjusted for demo-graphics, comorbidities, prior treatments and prior medical service use
Vingilis & Wilk 2012 Canada	Population-based large-scale panel research (N = 12.387). 524 (4.2%) reporting an motor vehicle injury MVI 1996- 2007. Path analyses examined the odds of subsequent MVI.	Diabetes reporting MVI, n =14	Diabetic drivers not reporting MVI, n = 346	Analysis controlled for age, gender and independent effects of medication use.
Orriols et al. 2014 France	69.630 drivers involved in an injurious crash in France 2005-2008. Logistic regression analysis ; outcome = odds of being responsible for crash	Cases: drivers who were deemed responsible for the crash (n =33.200)	Controls: drivers who were not responsible for crash (n = 36.450).	Analysis adjusted for age, gender, socio-economic category, month, time of day, vehicle type, alcohol level, injury severity, exposure to medicines and other long-term diseases.

The meta-analysis was based on a comprehensive literature search, review guiding decision rules and clearly defined quality assessment criteria. Most of the 15 case-control studies included in the meta-analysis were rated as low in quality; for example 9 of 15 case-control studies did not adjust for exposure (mileage).

The five studies after meta-analysis or not included in the meta-analysis used different designs and different outcome measures, and thus are not homogeneous, and their results cannot be pooled. Other complications are that over time studies are difficult to compare since the effects of treatments/medicine for diabetes may change over time. Comparison between countries is difficult since countries may differ in regulations concerning diabetes and driving. One reason why studies may fail to show a significant difference in crash rates at a population level between people at risk of hypoglycemia (mainly those with insulin-treated diabetes) and the general population with driving licenses is that countries impose restrictions on drivers with insulin-treated diabetes and remove those who are at high risk of having an accident.

3.3 OVERVIEW OF THE RESULTS OF THE ANALYSED STUDIES

An overview of the main results of the analysed studies is presented in **Table 7**.

Author, Year, Country	Risk factor	Study type	Outcome variable	Effects for Road Safety	Main outcome -description
Bieber-Tregear et al. 2011 International	Diabetes 1 and 2	Meta-analysis Random effects 15 studies	Crash involvement	RR=1.126; 95% CI: 0.847–1.497; p=0.415	Increased crash risk was small and not statistically significant
Bieber-Tregear et al. 2011 International	Insulin-treated diabetes	Meta-analysis. Random effects. 6 studies	Crash involvement	OR = 1.537; 95% CI: 0.603–3.915, p=0.368).	Non-significant increase in crash risk for insulin-treated drivers when compared with drivers treated with oral medication and/or diet alone.
Bieber-Tregear et al.2011 International	Diabetes 1 and 2	Meta-analysis Random effect 4 studies	Crash involvement	OR = 1.052; 95%, CI: 0.970–1.141; p=0.220	Drivers with diabetes are not over-represented among samples of drivers who have experienced a crash
Bieber-Tregear et al.2011 International	Insulin-treated diabetes	Meta-analysis Fixed effects 4 studies	Crash involvement	OR=1.212; 95% CI: 0.939–1.563, p=0.139	Drivers with insulin controlled diabetes tend to be over-represented among samples of drivers who have experienced a crash; not statistically significant
Sagberg 2006 Norway	Diabetes 1 and 2	Questionnaire study. Induced exposure: at fault crash-involved drivers compared not at fault.	Self-reported crash culpability	Non-medicated diabetic drivers: (Diabetes Type II) OR=3.08, p = 0.05	The adjusted odds ratio was significant for non-medicated diabetic drivers For diabetic drivers on medication (Diabetes 1) the OR was non-significant.
Redelmeier et al. 2009 Canada	Glycemic control	A population-based case control analysis	Crash involvement	OR= 1.26, 95% Cl:1.03–1.54)	Crash risk increases 26% for each 1% reduction in HbA1c (finding robust after control for confounders)
Signorovitch et al 2012 USA	Hypo-glycemia (Diabetes 2)	Case-control comparing diabetes 2 patients with and without evidence hypoglycemia	Crash involvement (resulting in hospital visit)	Hazard ratio (HR) = 1.82 (95% CL: 1.18, 2.80) People < 65 years; HR = 2.31 (95% CL: 1.44, 3.70)	After adjusting for baseline characteristics, hypoglycaemia significantly increased hazard
Vingilis & Wilk 2012 Canada	Diabetes 1 and 2	Population-based large-scale panel research	Motor vehicle injury	OR = 1.479, 95% CI: 0.743 - 2.944; p = 0.266 (NS).	No significantly increased odds of subsequent MVI was found for diabetes
Orriols et al. 2014 France	Diabetes 1 and 2	Case-control analysis comparing responsible vs. non responsible crash-involved drivers.	Crash culpability (estimated by standard method)	Diabetes type 1: OR = 1.47; 95% CI 1.12–1.92; p = 0.0047	Significantly increased risk of being responsible for a crash found for drivers with type 1 diabetes. Type 2 diabetes not selected in final risk model.

Table 7: Main results of analysed studies

3.4 REFERENCES

Analysed studies

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Personal Factors - Sensation Seeking

A personality trait that leads individuals to seek novel and exciting feelings and experiences and is associated with risk taking

1 Summary

Goldenbeld, C. & van Schagen, I., August 2016

1.1 COLOUR CODE: YELLOW

Studies generally show an association between sensation seeking and self-reported risky driving and self-reported crashes. In a number of studies the association remains significant after statistical control for various demographic and other related personality variables. This suggests that sensation seeking has an independent effect on risky driving behaviour. However, the independent effect of sensation seeking is generally small, and the causal relationship is not always clear. Moreover, in nearly all studies the association may be inflated by research biases and, hence, overestimated.

1.2 KEYWORDS

personal factors, sensation seeking, driver behaviour, road crash

1.3 ABSTRACT

Sensation seeking is a personality trait that steers people at "varied, novel, complex, and intense sensations and experiences" and at accepting the physical, social, legal, and financial risks for the sake of such experiences. Sensation seeking can have an immediate, direct effect on driving behaviour and crashes because sensation seekers are more inclined to look for new, exciting and intense sensations of, for example, driving fast and recklessly. Generally, the results show that sensation seeking is associated with self-reported risky driving behaviours such as speeding, risky driving, alcohol-impaired driving, driving with multiple passengers and self-reported crash-involvement. Various studies show that this effect is robust after control for demographic and other personality variables. However, the independent effect of sensation seeking is generally small, its causal interpretation is not always clear, and in nearly all survey research the reported association may be inflated or exaggerated by research biases. In summary, although there is fairly consistent evidence that sensation seeking is linked to risky driving behaviour and road crashes, the independent, direct effect of sensation seeking is rather small and may be overestimated.

1.4 BACKGROUND

What is sensation seeking?

As defined by Zuckerman (2007), sensation seeking is the need for "varied, novel, complex, and intense sensations and experiences, and the willingness to take physical, social, legal, and financial risks for the sake of such experiences" (p. 49). Traditionally, sensation seeking is conceptualized as having four distinct components: experience seeking, thrill and adventure seeking, disinhibition, and boredom susceptibility (Zuckerman 2007). Sensation seeking is often confused with impulsivity. Although impulsivity and sensation seeking each affect risk-taking, they do not reflect the same process. Impulsivity refers to a lack of self-control or deficiencies in response inhibition; it leads to hasty, unplanned behaviour. Sensation seeking, in contrast, refers to the tendency to seek out novel, varied, and highly stimulating experiences, and the willingness to take risks in order to attain them (Zuckerman, 1979; Steinberg et al., 2008).

How does sensation seeking affect road safety?

Sensation seeking may affect safe driving and road safety in several ways (Jonah, 1997; Fernandes et al., 2010; Mirman et al., 2012):

- Persons high in sensation seeking may perceive less risk in driving situations.
- Persons high in sensation seeking may directly seek out new experiences of fast or reckless driving.
- Persons high in sensation seeking may seek out situations or conditions such as alcohol or drug impairment, driving with multiple peers, driving while fatigued, that are detrimental to safe driving.

How many people are high sensation seekers?

The level of sensation seeking is a sliding scale: some people are more; some people are less sensation seeking. Sensation seeking is about normally distributed in the population (Zuckerman, 1994). Who can be qualified as a high sensation seeker depends upon what cut-off point in the sensation seeking scale/score is applied. Some researchers use a median split which would create a fairly large group of high sensation seekers. In a somewhat more conservative approach high sensation seekers are defined as those who have a score of one standard deviation above the mean score. Such a cut-off point would identify about 16% of the total population as high sensation seeking (Sargent et al., 2010).

Which factors influence the effect of sensation seeking on road safety?

The expression of sensation seeking is influenced via socialisation, and hence, socialisation processes could be targeted directly for the prevention of reckless or risky behaviours during adolescence (Arnett, 1995). As research among young male drivers has shown, the possible risk increasing predispositions resulting from sensation seeking and other personality traits may be counteracted by the young driver's parents. The parent's attitudes and conduct in respect to safe driving may serve to temper their offspring's predispositions, counteracting their tendency for risky driving (Taubman et al., 2016; Smorti and Guarnieri, 2014). Another factor that affects sensation seeking is age. Sensation seeking has been found to increase between childhood and early adolescence, and thereafter steadily declines into adulthood.

How is the effect of sensation seeking on road safety measured?

Nearly all studies on the effect of sensation seeking are survey studies that have analysed the association between sensation seeking and self-reported risky driving, speeding, impaired driving or crash involvement by way of correlation, regression analysis, or structural equation modelling. In more recent years, a few studies have also linked sensation seeking to simulated or real driving behaviour.

Overview results

- Most research on sensation seeking concerns young drivers and self-reports of risky driving.
- Sensation seeking is associated with self-reported risky driving. Most correlations rank between 0.20-0.40.
- A few studies also found an association between sensation seeking and risky driving in real traffic.
- Sensation seeking has its own, independent effect on self-reported or risky driving after control for various other personality variables.
- In general sensation seeking predicts only a small portion of variance in driving behaviour (a few percent).

Notes on research and analysis method

Most studies are cross-sectional survey studies that have measured both sensation seeking and self-reported risky driving and that use correlation or regression analysis to study the relationship between sensation seeking and risky driving. A few studies have also investigated the association between sensation seeking and real driving.

2 Scientific Details

2.1 DESCRIPTION OF CODED STUDIES

Table 1: Description of study characteristics of coded studies

Author, Year, Country	Study type	Analysis	Measurement sensation seeking variable
Greene et al., 2000, USA	survey	correlation / ANOVA / regression	40-item Form V of Zuckerman' s (1994) SS scale
Jonah et al., 2001, Canada	survey	correlation/ANOVA	40-item Zuckerman SS Scale
Iversen & Rundmo, 2002, Norway	survey	SE modelling	6 new items measuring SS were developed
Sümer, 2003, Turkey	survey	partial / structural correlations / SE	The 20 items Arnett Inventory (AISS) (Arnett, 1994) including 2 SS dimensions (novelty + intensity
Dahlen et al., 2005, USA	survey	correlation / regression	the 20-item AISS (Arnett, 1994)
Schwebel et al., 2006, USA	survey + simulated riding test	partial correlations / regression	40-item SS Scale-Form V (Zuckerman, 1994)
Oltedal & Rundmo, 2006, Norway	survey	correlation / regression	8 items excitement seeking on NEO Personality Inventory (Costa and McCrae, 1992)
Goldenbeld & Van Schagen, 2007, Netherlands	survey	correlation	20-items shortened version of the SS scale (Zuckerman, 1994).
Machin & Sankey, 2008, Australia	survey	correlation / regression / SE model	Excitement-Seeking from the International Personality Item Pool (IPIP; Goldberg, 1999).
Zakletskaia et al., 2009, USA	survey	logistic regression	the brief 8-item SS- scale (BSSS) (Hoyle et al., 2002)
Cestac et al., 2010, France	survey	correlation / regression	Driving-related sensation seeking (DRSS)
Eensoo et al., 2010, Estonia	survey	correlation / regression	Adaptive and Mal-adaptive Impulsivity Scale AMIS (Eensoo, 2007)
Fernandes et al. 2010, Australia	survey	correlation / regression	The SS Scale-Form V (Zuckerman, 1980).
Lucidi et al., 2010, Italy	survey	correlation / cluster analysis	Excitement seeking scale from NEO-Personality Inventory-Revised (Costa and McCrae, 1992)
Miller & Taubman,	survey	correlation / regression	10-item thrill and adventure seeking subscale of

Author, Year, Country	Study type	Analysis	Measurement sensation seeking variable
2010,			Zuckerman's (1994) Sensation Seeking Scale (SSS-V
Prato et al., 2010, Israel	survey + driver behaviour monitoring	negative binomial model	10-item thrill and adventure seeking sub-scale of the SS Scale (SSS-V; Zuckerman, 1994)
Delhomme et al. 2012, France	survey	regression	Driving Related Sensation Seeking (DRSS)
Marengo et al., 2012, Italy	survey + simulated riding test	correlation / cluster analysis	Dangerous Thrill Seeking scale of the SS Facets measure (International Personality Item Pool)
Mirman et al., 2012, USA	survey	correlation / hierarchical regression / mediation	3 items from Zuckerman SS Scale
Bachoo et al., 2013, South Africa	survey	correlation / regression	45 item UPPS Impulsive Behaviour Scale
Pearson et al. , 2013	survey	Correlation / path analysis	12 item SS scale from 45-item UPPS
Scott-Parker et al., 2013, Australia	2 online surveys at a 6-month interval	correlation / SE model	8-item Brief SS Scale (BSSS) (Hoyle et al., 2002)
Yang et al., 2013, China	survey	correlation / regression	10-item SS (extraversion) scale from International Personality Item Pool (Goldberg, 1999)
Ge et al., 2014, China	survey	correlation / hierarchical regression	10 item scale
Nordfjærn et al., 2014, Turkey	survey	correlation / SE model	9-item SS-scale on the Revised NEO Personality Inventory.
Smorti & Guarnieri, 2014, Italy	survey	correlation / hierarchical regression / mediation	20-item Italian version of Arnett Inventory of SS (AISS) (Arnett, 1994)
Taubman-BenAri et al., 2016, Israel	survey + driving data	Poisson-model	10-item thrill/adventure scale (Zuckerman, 1994)

The coded survey studies - like survey studies in general - may typically suffer from biases such as common method variance, and uncertainty regarding causal interpretation of associations. In more recent years, a few studies have also linked sensation seeking to simulated or real driving behaviour (Marengo et al, 2012; Prato et al., 2010; Taubman et al., 2016).

Description of main research methods

As can be seen in **Table 1**, the most commonly used approach to study the association between sensation seeking and road safety is a cross-sectional survey design, using a convenience sample of students or young drivers who answer questions on several personality traits and driving variables. All of the 23 coded studies used some type of survey design. Only a few of the coded studies have linked sensation seeking to driving in a simulator or real-life driving (Marengo et al., 2012; Prato et al., 2010; Schwebel et al., 2006; Taubman et al., 2016). **Table 1** further shows that the coded studies used correlations, regression or structural equation models for the analysis of the relationship between sensation seeking and unsafe driving.

Although the coded studies seem fairly similar in study type, they differ from one another in the measurement of sensation seeking, the type and the measurement of risky driving that is under study, the pathways in the assumed theoretical model, and the measurement of statistical control or other model variables.

Results

Self-report only studies
The self-report only studies, mostly conducted on a convenience sample of college or university students, indicate that sensation seeking is correlated with or a significant predictor for risky driving. Most correlations range between r = 0.20 and 0.40. In these survey studies, risky driving has been measured in different ways, by questions on speeding, traffic violations, and impaired driving. Also sensation seeking has been measured in different ways.

Correlations between sensation seeking and risky driving may be influenced by other variables such as age, gender, driving experience and other personality variables. Therefore it is important to know that sensation seeking may have an independent effect on risky driving after control for demographic and personality variables. Several studies have found an independent effect of sensation seeking after control for demographic and personality variables (Fernandes et al., 2010; Ge et al., 2014; Iversen et al. 2002; Machin et al., 2008; Mirman et al., 2012; Scott-Parker et al., 2013; Schwebel et al., 2006; Yang et al., 2013; Zakletskaia et al., 2009). It should be kept in mind that although sensation seeking was a significant predictor in these studies, it only explained a small amount of variance (a few percent) in the outcome variable.

However, not all studies indicate an effect of sensation seeking after control for other variables. In the study by Fernandes et al. (2010), sensation seeking was not a significant predictor in the regression models on drinking and driving, fatigued driving, and seat belt wearing. Bachoo et al. (2013) concluded that sensation seeking was not a significant predictor of risky driving. Yang et al. (2013) found that sensation seeking did not predict crashes. Nordfjærn et al. (2014) found no significant associations between sensation seeking and driving behaviour and risk perception. These differential study outcomes may have to do with differences in the samples, differences in the measurements of sensation seeking and risky driving, and differences in the included statistical control variables.

Field studies
There is evidence that sensation seeking is related to actual risky driving behaviour. In two studies that monitored real driving data from young Israeli drivers by way of an in-vehicle data recorder system, sensation seeking appeared to be linked with risky driving (Prato et al., 2010; Taubman et al., 2016). Prato et al. (2010) reported a risk increase of 43% (incidence rate ratio = 1.43); Taubman et al. (2016) a risk increase of 55% (parameter Poisson-gamma model 1.55).

Modifying conditions
The coded studies provide information on variables that may interact with sensation seeking and modify its impact on risk taking: gender, other personality variables, and parental behaviour and guidance (Fernandes et al., 2010; Cestac et al., 2010; Delhomme et al., 2012; Ge et al., 2014; Iversen et al. 2002; Machin et al., 2008; Mirman et al., 2012; Nordfjærn, 2014; Scott-Parker et al., 2013; Schwebel et al, 2006; Yang, 2013; Zakletskaia, 2009).

- Gender

Cestac et al. (2010) found that sensation seeking was significantly linked to speeding intention among young male drivers, but not among young female drivers. According to these researchers, this may be due to the fact that thrill is the main sensation associated with speeding and is precisely the kind of sensation on which men and women differ the most.

- Other personality factors

Several of the coded studies have investigated the role of sensation seeking next to other personality variables such as driving anger, trait anger, locus of control, normlessness, impulsivity, and reward sensitivity (Fernandes et al., 2010; Delhomme et al., 2012; Ge et al., 2014; Iversen et al. 2002; Machin et al., 2008; Mirman et al., 2012; Nordfjærn et al., 2014; Scott-Parker et al., 2013; Schwebel et al., 2006; Yang et al., 2013; Zakletskaia et al., 2009). These studies have rather consistently found that after control for other personality variables sensation seeking has its own, independent effect on self-reported or real risky driving. This means that the specific mechanisms through which sensation seeking leads to more risky driving cannot be modified or reduced by treatment of other problematic personality traits such as tendency to experience anger, tendency to act impulsively, or low experienced self-control. In a study that directly investigated possible interactions between sensation seeking and other personality variables, Schwebel et al. (2006) found no strong evidence for a multiplicative effect between sensation seeking and other traits. These researchers conclude: "In other words, an individual who is high on sensation-seeking may not drive in a particularly more risky manner if he or she also scores high on anger/hostility".

- Parental role

Several studies have investigated whether young driver risk taking, heightened by high levels of sensation seeking, may be reduced by a supportive parental role (Prato et al., 2010; Smorti and Guarnieri, 2014; Taubman et al., 2016). Smorti and Guarnieri (2014) predicted that parental guidance may facilitate the transmission of positive values and attitudes as well as of those social skills, which allow adolescents to develop the ability to self-control and to resist situational temptations. The researchers hypothesised that parents would shape adolescents' risky driving indirectly via a temperamental predisposition such as sensation seeking. The study by Smorti and Guarnieri (2014) finds evidence that a supportive bond between an adolescent female and her parents is a significant deterrent for risky driving and that sensation seeking mediates this process, i.e. through lowering sensation seeking a good parental bond decreases risk taking. At the same time such a supportive bond appears to have no effect on adolescent male risk behaviour. One reason for this gender difference is that parental socialisation processes operate differently for male and female adolescents. Compared to males, females are more ''family oriented'' and base decision-making on a capacity to maintain interpersonal connections (Smorti and Guarnieri, 2014).

In other studies on parental involvement with driving of young family members, Prato et al. (2010) and Taubman et al. (2016) used data on real driving. These researchers found that sensation seeking increased the actual driving risk, whereas positive parental involvement (parental driving, parental attitudes and monitoring) decreased risky driving, thus counterbalancing the propensity to drive recklessly. The study by Taubman et al. (2016) used a sample of male drivers. This study provides evidence also that for young males, supportive parental involvement in the driving of their offspring positively impacts their driving safety. In contrast to Smorti and Guarnieri (2014), Taubman et al. (2016) have not tested the mediation between positive parental supportive bond, sensation seeking, and risky driving. All studies indicate that supportive role of parents may counteract risky driving among adolescents, but only Smorti and Guarnieri provide direct evidence that - at least for females - this effect is mediated by a reduction of sensation seeking tendency.

Conclusions

In conclusion (see **Table 2**), most survey studies find that sensation seeking is significantly associated with various self-reported risky driving acts or risky driving conditions (speeding, impaired driving). Correlations typically range between 0.20 and 0.40. In addition, studies that control for the effects of demographic and personality variables most often find that sensation seeking is an independent significant predictor of risky driving. The amount of extra variance in risky driving explained by sensation seeking is typically small (a few percent).

One problem with the literature is the emphasis on cross-sectional analyses, which limits a causal interpretation. Also, in the various self-report only studies the associations between sensation seeking and risky driving may be overestimated due to "common method bias". In contrast with most survey studies, some studies have found no significant association between sensation seeking and risky driving. The precise reason for this (small) divergence is not clear. Presumably differences in samples, measurements of constructs and statistical control variables, are involved. There is no evidence that sensation seeking strongly interacts with other personality variables to result in more extreme levels of risky driving. For young drivers, a supportive parental bond and parental monitoring of driving may counteract risk increasing tendencies as result of sensation seeking.

Table 2: Overview of studies and their (simplified) main outcomes (↑ = statistical significant relation between sensation seeking and factors that negatively affect road safety; ↑/ = some statistical significant relations, but not for all groups or conditions or risk outcomes; ↓ = no statistical significant relations).

Study	Simplified summary of main outcomes	
Greene et al., 2000, USA	↑	Correlated with risky driving and drink driving
Jonah et al., 2001, Canada	↑	Correlated with speeding, drink-driving and aggressive driving
Iversen & Rundmo, 2002, Norway	↑	Correlated with risky driving and accident involvement
Sümer, 2003, Turkey	↑	Correlated with aggression, aberrant driving behaviour, dysfunctional drinking, speed and accident involvement; affected speeding
Dahlen et al., 2005, USA	↑	Correlated with anger expression, aggressive driving, risky driving
Schwebel et al., 2006, USA	↑/	Correlated with risky driving and accidents with damages, not with injury accidents
Oltedal & Rundmo, 2006, Norway	↑/	Predicted risky behaviour and violations in some analyses
Goldenbeld & Van Schagen, 2007, Netherlands	↑	Correlated with speed, judgement of safe speed, speed violations, accidents
Machin & Sankey, 2008, Australia	↑	Correlated with speeding, risk taking, efficacy; directly affected speeding, affected risk taking
Zakletskaia et al., 2009, USA	↑	Predicted drink-driving
Cestac et al., 2010, France	↑/	Correlated with traffic violations, speeding and intention to speed, predicted intention to speed for men, *not* for women
Eensoo et al., 2010,	↑/	Correlated with speeding of women

Estonia		
Fernandes et al., 2010, Australia	↑/	Predicted speeding, not drink-driving, fatigued driving and seat belt wearing
Lucidi et al., 2010, Italy	↑	Correlated with violations, lapses, errors
Miller & Taubman, 2010, Israël	↑/	Correlated with reckless driving and angry driving for men, *not* for women. Predicted angry driving of men, predicted *less* angry driving for women
Prato et al., 2010, Israel	↑	Affected reckless driving
Delhomme et al., 2012, France	↑	Affected speeding
Marengo et al., 2012, Italy	↑	Correlated with drink-driving, traffic violations, risky driving and accidents
Mirman et al., 2012, USA	↑	Correlated with and affected risky driving
Bachoo et al.,2013, South Africa	↑/	Correlated with risky driving; did *not* predict risky driving
Pearson et al., 2013	↑/	Correlated with driving violations and cell phone driving. Did not predict driving errors, lapses, violations, cell phone driving, traffic citations and traffic collisions when correcting for gender and age
Scott-Parker et al.,2013, Australia	↑	Correlated with and predicted risky driving
Yang et al.,2013, China	↑/	Correlated with aggressive violations and ordinary violations, *not* with accidents Predicted ordinary violations, *not* aggressive violations nor accidents
Ge et al., 2014, China	↑	Correlated with dangerous driving, aggressive driving, risky driving, drink-driving
Nordfjærn et al., 2014, Turkey	↑/	Correlated with negative road safety attitudes, *not* with risk perception or driving behaviour
Smorti & Guarnieri, 2014, Italy	↑	Correlated with risky driving
Taubman et al., 2016, Israel	↑	Affected reckless driving

3 Supporting Documents

3.1 LITERATURE SEARCH STRATEGY

The literature on sensation seeking and traffic risk was searched for in the international database Scopus on 23 March 2016. Scopus is the largest international peer-reviewed database. The literature was searched over the period 1999-2016; the search terms were searched in title, abstract and keywords. This search (**Table 3**) produced 103 hits. In addition, references of the identified studies were studied in order to obtain crucial studies before 1999.

Database: Scopus Date: 23 March 2016

Table 3: Used search terms, and logical operators

Search terms/logical operators/combined queries	hits
(TITLE-ABS-KEY ("sensation seeking" OR "excitement seeking") AND TITLE-ABS-KEY ("road accident" OR "traffic accident" OR "accident risk" OR "crash risk" OR "road risk" OR "risky driving" OR "road safety" OR crash OR collision) AND TITLE-ABS-KEY (driving OR driver)) AND SUBJAREA (mult OR agri OR bioc OR immu OR neur OR phar OR mult OR medi OR nurs OR vete OR dent OR heal OR mult OR arts OR busi OR deci OR econ OR psyc OR soci) AND PUBYEAR > 1999	103

In a first screening round the 103 references were screened on potential relevance for coding based on title, and abstract information. Criteria A to E describe reasons for not selecting publications in the first round.

A = Not selected because paper refers to measure/intervention.
B = Not selected because sensation seeking is side subject (and not itself investigated in relationship to traffic risk).
C = Not selected because written in non-English.
D = Not selected because better or more complete results were published earlier or later in another publication (duplication).
E = Not selected because general review-like text.

Table 4: Initial selection of studies after the first screening round

Exclusion criterion	Not selected first round	Selected first round
A. Measure/intervention	5	
B. Side subject (not itself directly investigated)	41	
C. Non-English	6	
D. Duplication	3	
E. General review-like text	4	

Selected after initial screening		44

The 44 selected studies were further screened on relevance for coding in a second screening round. In the second round the same criteria were used but were checked on full-text copies of the papers. **Table 5** presents the results of this second screening round and describes the final decisions concerning coding of the studies. After the second screening round 27 papers were assessed to be relevant for our purposes and were coded.

Table 5: Selection of studies to be coded in second screening round

	Reference	Relevant	Coded
1	Bachoo, S., Bhagwanjee, A., & Govender, K. (2013). The influence of anger, impulsivity, sensation seeking and driver attitudes on risky driving behavior among post-graduate university students in Durban, South Africa. Accident Analysis & Prevention, 55, 67-76.	Yes	Yes
2	Bina, M. et al., (2009). Psychological functions of driving and risky driving and involvement in risky driving in adolescence. Accident Analysis & Prevention.	Book chapter; possibly relevant for general review but not for coding	No
3	Cestac, J., Paran, F., Delhomme, P. (2010). Young drivers' sensation seeking, subjective norms, and perceived behavioral control and their roles in predicting speeding intention: How risk-taking motivations evolve with gender and driving experience. Safety Science, 49, 424-432	Yes	Yes
4	Dahlen, E.R., Martin, R.C., Ragan, K., Kuhlman, M.M.(2005). Driving anger, sensation seeking, impulsiveness, and boredom proneness in the prediction of unsafe driving. Accident Analysis & Prevention, 37, 341-348	Yes	Yes
5	Dahlen, E.R., White, R.P. (2006). The Big Five factors, sensation seeking, and driving anger in the prediction of unsafe driving. Personality and Individual Differences, 41 (5), 903-915	Relationship between Dahlen 2005 and 2006 has to be looked at for further decision	No
6	Delhomme, P., Chaurand, N., & Paran, F. (2012). Personality predictors of speeding in young drivers: Anger vs. sensation seeking. Transportation Research Part F, 15, 654-666.	Yes	Yes
7	Dotta-Panichi, R.M., Wagner, A. & Sarriera, J.C. (2013). Discriminant profile of young adulthood driving behaviour among Brazilian drivers. The Spanish journal of psychology, 16,	Likely not relevant since the paper is about identifying driver profiles based on self-reported traffic behaviours. The link between sensation seeking and traffic behaviour is not studied.	No
8	Eensoo, D., Paaver, M. & Harro, J. (2010). Factors associated with speeding penalties in novice drivers. Annals Advances Automotive Medicine, 2010; 54, 287-94.	Yes	Yes
9	Fernandes, R., Hatfield, J. & Job, R.F.S. (2010). A systematic investigation of the differential predictors for speeding, drink-driving, driving while fatigued, and not wearing a seat belt, among young drivers. Transportation Research Part F, 13, 179–196.	Yes	Yes
10	Ge, Y. et al. (2014). The effect of stress and personality on dangerous driving behavior among Chinese drivers. Accident Analysis & Prevention, 73, 34–40.	Yes	Yes
11	Goldenbeld, C. & van Schagen, I. (2007). The credibility of speed limits on 80 km/h rural roads: The effects of road and person(ality)	Yes	Yes

	characteristics. Accident; analysis and prevention, 39(6), 1121–30.		
12	Greene, K. et al. (2000). Targeting adolescent risk-taking behaviors: the contributions of egocentrism and sensation-seeking. Journal of Adolescence, 23(4), 439–61	Yes	Yes
13	Hatfield, J., Fernandes, R. & Job, R.F.S. (2014). Thrill and adventure seeking as a modifier of the relationship of perceived risk with risky driving among young drivers. Accident Analysis & Prevention, 62, 223–9.	Relationship between this study and Fernandes et al 2010 has to be looked at. Low priority.	No
14	Iversen, R.Q. et al. (2006). A cohort study of 20,822 young drivers: the DRIVE study methods and population. Injury prevention: journal of the International Society for Child and Adolescent Injury Prevention	Although this study has measured sensation seeking it does not relate this trait directly to risky driving or crashes. Therefore not relevant for coding.	No
15	Iversen, H., Rundmo, T. (2002) Personality, risky driving and accident involvement among Norwegian drivers. Personality and Individual Differences, 33 (8), 1251-1263.	Yes	Yes
16	Jonah, B.A. (1997) Sensation seeking and risky driving: a review and synthesis of the literature. Accident Analysis & Prevention, 29, 651-665.	Literature review	No
17	Jonah, B.A., Thiessen, R., Au-Yeung, E. (2001). Sensation seeking, risky driving and behavioral adaptation. Accident Analysis & Prevention, 33 (5), 679-684	Yes	Yes
18	Kim, J.-H. & Kim, K.S. (2012). The role of sensation seeking, perceived peer pressure, and harmful alcohol use in riding with an alcohol-impaired driver. Accident Analysis & Prevention, 48, 326–34	Likely not relevant because outcome variable is not risky driving or crashes	No
19	Li, Y.Z. et al. (2005). Association of personality with driving behaviors and accident involvement in motorcyclists. Chinese Journal of Clinical Rehabilitation, 9(48), 12–14	This article is in Chinese language http://www.chinastm.net/JournalSearch/5630474	No
20	Lucidi, F. et al. (2010). Young novice driver subtypes: relationship to driving violations, errors and lapses. Accident Analysis & Prevention, 42(6), 1689–96	Yes	Yes
21	Machin, M.A., Sankey, K.S. (2008). Relationships between young drivers' personality characteristics, risk perceptions, and driving behaviour. Accident Analysis & Prevention, 40, 541–547.	Yes	Yes
22	Marengo, D., Settanni, M., & Vidotto, G. (2012). Drivers' subtypes in a sample of Italian adolescents: Relationship between personality measures and driving behaviors. Transportation Research Part F, 15 (5), 480–490.	Yes	Yes
23	Miller, G. & Taubman-Ben-Ari, O. (2010). Driving styles among young novice drivers--the contribution of parental driving styles and personal characteristics. Accident Analysis & Prevention, 42(2), 558–70	Yes	Yes
24	Mirman, J.H., Albert, D., Jacobsohn, L.S., Winston, F.K. (2012). Factors Associated With Adolescents' Propensity to Drive With Multiple Passengers and to Engage in Risky Driving Behaviors. Journal of Adolescent Health, 50, 634–640	Yes	Yes
25	Nordfjærn, T. et al. (2014). Social cognition and personality traits related to risky driving in a Turkish sample. Journal of Risk Research, 18(4), 452–466.	Yes	Yes

26	Nordfjærn, T. & Rundmo, T. (2013). Road traffic safety beliefs and driver behaviors among personality subtypes of drivers in the Norwegian population. Traffic Injury Prevention, 14(7), 690–6.	Sensation seeking is part of several variables that identify clusters of drivers. Direct data on relationships between sensation seeking and risky driving/crashes are not given. So the study seems not relevant for coding but it could be relevant for the more general review.	No
27	Oltedal, S., Rundmo, T. (2006). The effects of personality and gender on risky driving behaviour and accident involvement. Safety Science, 44, . 621-628.	Yes	Yes
28	Pearson, M.R., Murphy, E.M. & Doane, A.N. (2013). Impulsivity-like traits and risky driving behaviors among college students. Accident Analysis & Prevention, 53, 142–8	Yes	Yes
29	Prato, C.G. et al. (2010). Modeling the behavior of novice young drivers during the first year after licensure. Accident Analysis & Prevention, 42(2), 480–6.	Yes	Yes
30	Prato, C.G. & Kaplan, S. (2013). Driving on the edge: The motivational factors of risk-taking among teen drivers. In Psychology of Risk-Taking.	Book chapter not relevant for coding, but maybe relevant for general review.	No
31	Rudin-Brown, C.M., Edquist, J. & Lenné, M.G.(2014). Effects of driving experience and sensation-seeking on drivers' adaptation to road environment complexity. Safety Science, 62, 121–129.	This study looks at effect of sensation seeking on aspects of driving performance, but is not directly concerned with risk taking or crashes.	No
32	Schwebel, D.C., Severson, J., Ball, K.K., Rizzo, M., (2006). Individual difference factors in risky driving: the role of anger/hostility, conscientiousness, and sensation seeking. Accident Analysis & Prevention, 38, 801-810.	Yes	Yes
33	Scott-Parker, B., Watson, B., King, M.J., Hyde, M.K. (2012). The influence of sensitivity to reward and punishment, propensity for sensation seeking, depression and anxiety on the risky behaviour of novice drivers: A path model. British Journal of Psychology, 103, 248-267.	Relationship between Scott-Parker 2012 and 2013 further to be looked at. Low priority.	No
34	Scott-Parker, B. , Watson, B., King, M.J., Hyde, M.K. (2013). A further exploration of sensation seeking propensity, reward sensitivity, depression, anxiety, and the risky behaviour of young novice drivers in a structural equation model. Accident Analysis & Prevention, 50, 465-471.	Yes	Yes
35	Smorti, M., & Guarnieri, S. (2014). Sensation seeking, parental bond, and risky driving in adolescence: Some relationships, matter more to girls than boys. Safety Science, 70, 172-179.	Yes	Yes
36	Sümer, N. (2003). Personality and behavioral predictors of traffic accidents: Testing a contextual mediated model. Accident Analysis & Prevention, 35 (6), 949-964.	Yes	Yes
37	Taubman – Ben-Ari, O. et al. (2016). The combined contribution of personality, family traits, and reckless driving intentions to young men's risky driving: What role does anger play? Transportation Research Part F,	Yes	Yes
38	Theofilatos, A. & Yannis, G. (2014). Relationship between motorcyclists' attitudes, behavior, and other attributes with declared	These authors used a somewhat non-standard operationalization of	No

	accident involvement in Europe. Traffic Injury Prevention, 15(2),156–64.	sensation seeking based on available SARTRE-items which raises some doubts about whether to include this study.	
39	Ulleberg, P. (2001). Personality subtypes of young drivers. Relationship to risk-taking preferences, accident involvement, and response to a traffic safety campaign. Transportation Research Part F, 4(4), 279–297	This study is not relevant since sensation seeking is but one of several traits that are used to identify clusters of young drivers. The study is not about the separate effect of sensation seeking.	No
40	Wong, J.-T., Chung, Y.-S. & Huang, S.-H. (2010). Determinants behind young motorcyclists' risky riding behavior. Accident Analysis & Prevention, 42(1), 275–81	In this study sensation seeking was not directly linked to risky driving behaviour, but rather to attitudes, risk perception and utility perception. Therefore it was decided not to code.	No
41	Yang, J. et al. (2013). Effects of personality on risky driving behavior and accident involvement for Chinese drivers. Traffic Injury Prevention, 14(6), 565–71	Yes	Yes
42	Yıldırım-Yenier, Z. et al. (2016). Relationships between thrill seeking, speeding attitudes, and driving violations among a sample of motorsports spectators and drivers. Accident Analysis & Prevention, 86, 16–22	Perhaps not so relevant to code since the sample concerns a very specific group of drivers, i.e. 408 members and visitors of car club and racing websites!	No
43	Zakletskaia, L.I. et al. (2009). Alcohol-impaired driving behavior and sensation-seeking disposition in a college population receiving routine care at campus health services centers. Accident Analysis & Prevention, 41(3), 380–386	Yes	Yes
44	Zuckerman, M. (2007). Sensation seeking and risky behaviour. American Psychological Association, Washington.	General review. Likely not useful for coding, perhaps relevant for general review chapter.	No

Background characteristics of the coded studies

Table 6: Background characteristics of coded studies

Author, Year, Country	Study type	Analysis	Measurement risk variable	Measurement risk outcome
Greene et al., 2000, USA	cross-sectional survey design	correlation/ ANOVA/ regression	40-item Form V of Zuckerman' s (1994) SS scale	Risky driving measured by 3 Likert-type items: 'How often have you driven over 80 mph?', 'How often have you driven more than 20 mph over the speed limit?' and 'How often have you passed in a no passing zone while driving?' 'never' (1) - 'very often'' (5). Drinking and driving was measured by 2 items 'In the past year, how often have you driven a car while under the influence of alcohol?' and 'In the past year, how often have you ridden with a driver who was under the influence of alcohol?' 'never' (1) - '6 or more times' (5).
Jonah et al., 2001,	cross-sectional	correlation/ ANOVA	40-items Zuckermann SS Scale	Highway speed, seat belt use, drink driving, aggressive driving.

Author, Year, Country	Study type	Analysis	Measurement risk variable	Measurement risk outcome
Canada	survey design			
Iversen & Rundmo, 2002, Norway	cross-sectional survey design	structural equation modelling	6 new items measuring SS were developed; these items were related to fascination regarding situations with uncertain out-comes, yearning for excitement, enjoying gambling and bets, etc.	1. Risk behaviour comprised 5 items related to breaking the speed limit on particular roads (50 mph, 80-90 mph), risky overtaking and ignorance of traffic rules; 2. Accident involvement included injury crashes, damage only crashes and near-accidents.
Sümer, 2003, Turkey	cross-sectional survey design	partial/ structural correlations /structural equations	The Arnett Inventory of SS (AISS) (Arnett, 1994) including 20 items was used to measure the two dimensions of sensation seeking, each having 10 items: novelty (e.g. I like to travel to places that are strange and far away) and intensity (e.g. when I listen to music, I like it to be loud).	1. 20 items from the Driver Behavior Questionnaire (DBQ) tapped 2 types of aberrant driver behaviors, namely violations (e.g. Disregard the speed limit on a residential road) and errors (e.g. Brake too quickly on a slippery road). Items measuring lapses in the original scale were excluded. 9 new items representing typical violations and errors observed among Turkish drivers (e.g. warning the car in front by honking to cross a junction as soon as the traffic lights turn to yellow) were also included, totalling 28 items. 2. The speed latent variable was measured by 3 indicators: overtaking tendency, speed within and intercity road. 3. Self-reported accidents past 3 years.
Dahlen et al., 2005, USA	cross-sectional survey design	correlation/ regression	The 20-item AISS (Arnett, 1994).	Crash-related conditions; aggressive driving; risky driving.
Schwebel et al., 2006, USA	survey + simulated riding test	partial correlations /regression	40-item SS Scale-Form V (Zuckerman, 1994).	1. 24-item, short version of the Driving Behavior Questionnaire (DBQ; Parker et al., 1995); 2. 12-item Driving Habits Questionnaire (DHQ); 5 driving indices in simulator: Slowing open gates, Hitting closed gates, Course time, Speed to depart closed gates, Bumping curbs.
Oltedal & Rundmo, 2006, Norway	cross-sectional survey	correlation/ regression	Excitement seeking measured by 8 items on NEO Personality Inventory (Costa and McCrae, 1992).	An index based on 3 dimensions of risky driving (speeding, rule violations and self-assertiveness) previously developed by Rundmo and Ulleberg (2000); accident involvement was measured by asking people if they had ever been involved in accidents with either material damage or personal injury.
Goldenbeld & Van Schagen, 2007, Netherlands	cross-sectional survey design	correlation	20-items shortened version of the SS scale (Zuckerman, 1994).	Self-reported speed, safe speed limit, speed tickets, crashes.
Machin & Sankey,	cross-sectional	correlation/ regression/	Excitement-Seeking (Extraversion); items were	6- item Speeding scale (Ulleberg and Rundmo, 2003) measured how often

Author, Year, Country	Study type	Analysis	Measurement risk variable	Measurement risk outcome
2008, Australia	survey design	equation model	selected from the International Personality Item Pool (IPIP; Goldberg, 1999).	respondents engaged in various speeding behaviours (e.g., "I exceed the speed limit in built-up areas (more than 10 km/h)", "I exceed the speed limit on country roads (more than 10 km/h)", "I overtake the car in front when it is driving at the speed limit", "I drive too close to the car in front", "I bend the traffic rules in order to get ahead in traffic", and "I ignore traffic rules in order to get ahead in traffic").
Zakletskaia et al., 2009, USA	Cross-sectional survey design	logistic regression	SS disposition was evaluated with the brief 8-item SS- scale (BSSS) (Hoyle et al., 2002), suitable for evaluating SS among young adults. It has the same basic content as the SSS-V (Zuckerman, 1978, 1994) with a Likert-type response format.	Alcohol-impaired driving behaviour was defined as a Yes response to either or both of the following questions: (1) "In the last 6 months, did you ever ride in a car or other vehicle with a driver who had been drinking alcohol?"; and (2) "In the last 6 months, did you ever drive in a car or other vehicle after drinking any alcohol?" A No response to both questions is taken as an indicator of driving conduct without alcohol influence.
Cestac et al., 2010, France	cross-sectional survey design	Correlation/ regression	Driving-related sensation seeking (DRSS) was measured using the French adaptation (Cronbach's alpha = 0.68) of Taubman et al.'s (1996) scale (Cronbach's alpha = 0.84).	Four items were used to measure the behavioural intention to speed. These four items were aggregated in order to obtain an overall intention score (alpha = .87).
Eensoo et al., 2010, Estonia	cross-sectional survey design	correlation/ regression	Adaptive and Mal-adaptive Impulsivity Scale AMIS (Eensoo, 2007).	Odds of being speed limit exceeder.
Fernandes et al. 2010 Australia	Cross-sectional survey design	correlation/ regression	SS measured by the SS Scale-Form V (Zuckerman, 1980).	Self-reported intention speeding, intention drink-driving, intention fatigued driving, intention not wearing seat belt.
Lucidi et al., 2010, Italy	cross-sectional survey design	correlation/ cluster analysis	Excitement seeking scale from NEO-Personality Inventory-Revised (Costa and McCrae, 1992).	28-item Driver Behaviour Questionnaire (DBQ).
Miller & Taubman, 2010,	Cross-sectional survey design		10 items in the thrill and adventure seeking subscale of Zuckerman's (1994) Sensation Seeking Scale (SSS-V).	The Multidimensional Driving Style Inventory (Taubman - Ben-Ari et al., 2004a) - a validated and reliable 44-item scale - assessed four broad driving styles: Reckless and careless, Anxious, Angry and hostile, Patient and careful.
Prato et al., 2010, Israel	survey + driver behaviour monitoring	negative binomial model	10-item thrill and adventure seeking sub-scale of the SS Scale (SSS-V; Zuckerman, 1994).	Driving behaviour data over 12 month period.
Delhomme et al. 2012, France	survey	Correlation/ regression	7-item Driving Related Sensation Seeking scale (DRSS; Delhomme, 2002; Taubman,	Four speeding intentions, four speeding past behaviour and one speeding present behaviour represented one single factor,

Author, Year, Country	Study type	Analysis	Measurement risk variable	Measurement risk outcome
			Mikulincer, & Iram, 1996.	speeding score; speeding items referred to driving over 110 km/hr at 90km/hr road.
Marengo et al., 2012, Italy	survey + simulated riding test	correlation/ cluster analysis	Dangerous Thrill Seeking subscale part of the SS Facets measure from the International Personality Item Pool.	Self-reported driving under influence substances and traffic violations; safe driving and crashes in simulator test.
Mirman et al., 2012, USA	cross-sectional survey design	correlation/ hierarchical regression/ mediation	3 items from Zuckerman SS Scale were rated on a scale from (1) Strongly Disagree to (5) Strongly Agree: (1) I like to take risks; (2) I would like to explore strange places; and (3) I like to do frightening things.	6 items assessed risky driving including the following: 1. I have road rage when I drive; 2. I talk on the cell phone while I drive; 3. I am speeding when I drive; 4. I am in a hurry when I drive; 5. I drink alcohol and then drive; and 6. I smoke pot and then I drive. Driving with multiple passengers assessed as the frequency with which participants reported that "I drive with many teen passengers (i.e., piling)".
Bachoo et al., 2013, South Africa	cross-sectional survey design	correlation/ regression	45 item UPPS Impulsive Behaviour Scale.	Risky driving.
Pearson et al., 2013	Cross-sectional survey design	Correlation/ path analysis	12 item SS scale from 45-item UPPS scale	Driving errors, lapses and violations from adapted 24-item DBQ questionnaire, separate questions for cell phone driving, traffic citations and traffic collisions.
Scott-Parker et al., 2013, Australia	2 online surveys at a 6-month interval	correlation/ structural equation model	8-item Brief SS Scale (BSSS) (Hoyle et al., 2002).	The 44-item Behaviour of Young Novice Drivers Scale (BYNDS).
Yang et al., 2013, China	cross-sectional survey design	correlation/ regression	10-item SS (extraversion) scale was taken from International Personality Item Pool (Goldberg, 1999).	Self-reported aggressive violations, ordinary violations, all accidents past 3 yrs., serious accidents past 3 yrs., at-fault accidents past 3 yrs.
Ge et al., 2014, China	cross-sectional survey design	correlation/ hierarchical regression	10 item scale.	Dula Dangerous Driving Index.
Nordfjærn et al., 2014, Turkey	cross-sectional survey design	correlation/ structural equation modelling	9-item measure of SS obtained from the Revised NEO Personality Inventory.	Attitudes towards traffic safety were measured by a 25-item revised version of the Iversen and Rundmo (2004) scale. Information about self-reported driver behaviour was obtained by a 17-item revised version of the validated Ulleberg and Rundmo (2003) Instrument of Driver Behaviour. Traffic risk perception measured by a 12-item version of the Rundmo and Fuglem (2000) instrument.
Smorti & Guarnieri, 2014, Italy	cross-sectional survey design	correlation/ hierarchical regression/ mediation	20-item Italian version of Arnett Inventory of SS (AISS) (Arnett, 1994).	Risky driving was assessed by considering the frequency of 13 traffic offences over the last 6 months (examples: "Driving after you've used marijuana"; "Driving after you've had

Author, Year, Country	Study type	Analysis	Measurement risk variable	Measurement risk outcome
				three or more glasses of wine or cans of beer''; "Exceeding the speed limit by over 30 km/h''). For each item adolescents answered on a 4-point Likert scale (1 = Never; 4=Always). Total score was derived by the sum of all items and could range from 13 to 52.
Taubman-BenAri et al., 2016, Israel	survey and actual driver data	Poisson-model	The 10-item thrill and adventure scale of the SS Scale (Zuckerman, 1994).	In-vehicle data recorders (IVDRs) were installed on the vehicle usually driven by the young male driver. The driving behaviour recorded during the 3-month period starting 9 months after licensure. 3 levels of risk identified (i.e., low, medium, high).

Overview of the results of the coded studies

Studies that look at the effects of sensation seeking on driving behaviour or crash involvement usually calculate correlations or apply regression analyses or structural equation models. **Table 7** presents information on the study sample characteristics and the main outcomes of coded studies.

Table 7: Sample characteristics and main outcomes (related to sensation seeking) of coded studies

Author, Year, Country	Sample characteristics	Main outcomes
Greene et al., 2000, USA	Convenience sample; junior high school and high school students (n=381) and college students (n=343) were sampled; M high school = 15.1; M college = 20.7; 42% male; 57% female.	- Significant correlations ranging from 0.17 to 0.48 between the 4 SS-scales and risky driving and drinking and driving. - The SS disinhibition scale had the highest correlations with risky driving ($r = 0.48$; $p < 0.001$) and drinking and driving ($r = 0.48$; $p < 0.001$). - ANOVA-analyses found a significant main effect of the total SS (low vs high) on both self-reported risky driving and drinking and driving.
Jonah et al., 2001, Canada	Convenience sample; students in psychology, design, marketing, or dental assistant courses at two colleges in Montreal and Ottawa; M=25.0; 120 male, 159 female.	- Sign correlations SS with highway speeding (0.28), drive within 2 hrs drinking (0.27), aggressive driving (0.37; 0.21). - Correlations slightly higher for subscale disinhibition.
Iversen & Rundmo, 2002, Norway	Random sample; Norwegian drivers randomly selected from the driver's licence register; M=45; 48% male; 52% female.	SS was the strongest predictor for risky driving (beta coefficient=0.31) and also predicted accident involvement (beta=0.20) in a model that also included driver anger, locus control, and normlessness as explanatory variables.
Sümer, 2003, Turkey	The initial sample consisted of 321 professional and amateur drivers working in Ankara in Turkey; 29 drivers with less than 3 years of driving experience were excluded from the sample, leaving 295 participants for the analyses.	Only 7% of the number of accidents that drivers were involved in the last 3 years was directly accounted for by proximal variables, and indirect effects of the psychological symptoms added some to this portion. Structural correlations among latent variables indicated that SS was significantly correlated with: aggression ($r = 0.61$), aberrant driving behaviours ($r = 0.28$), dysfunctional drinking ($r = 0.40$), speed ($r = 0.50$) and self-reported accidents ($r = 0.15$). In the structural equations model, SS displayed a significant effect on speed (path coefficient = 0.60). In the structural equations model, there were no significant effect of SS

		on dysfunctional drinking (path coefficient = 0.14) or aberrant driving behaviour (path coefficient = 0.10).
Dahlen et al., 2005, USA	Convenience sample, undergraduate students; 70% female.	sign. correlations with driver anger expression (0.23-0.25); aggressive driving (0.20); risky driving (0.33);. Predictor crash-related conditions and risky driving.
Schwebel et al., 2006, USA	Respondents were randomly selected from high school classes within 2 counties where a road safety campaign was performed (n= 4397 adolescents, 632 (46.6%) men and 724 (53.4%) women). The majority were 18 or 19 years of age.	Excitement-seeking (ES) was related to risky driving (r = .30, p < 0.01) and accidents with damages (r = .12, p < 0.01), but not accidents with personal injury (r = .03, ns). Risky driving behaviour correlated with both accidents with damages (r = .21, p < 0.01) and accidents with personal injury (r = .14, p < 0.01). ES (β=0.103; t = 4.188) explained 9% raw variance and 3% unique variance in risky driving. Normlessness was the strongest predictor of risky driving explaining 20% raw variance and 12% unique variance.
Oltedal & Rundmo, 2006, Norway	Convenience sample, college students; M=27.8; 41% male, 55% female, 4% unknown sex.	After control for gender, yrs. driving experience, anger/ hostility, conscientiousness, SS was a predictor of DBQ and DHQ violations (beta= 0.42; 0.39). After control for gender and years of driving experience in stepwise regression, SS was not a significant predictor of risky driving in simulator. The effect of individual differences on risky driving was not strongly multiplicative.
Goldenbeld & Van Schagen, 2007, Netherlands	Panel sample; representative age and gender; 54% male; 46% female.	Sign. Correlations with speed (0.28), safe speed limit (0.24), speed tickets (0.21), crashes (0.11).
Machin & Sankey, 2008, Australia	Convenience sample; students drawn from all faculties of the University of Southern Queensland; M=18.7; 46 male, 112 female.	Higher excitement seeking (ES) was significantly correlated with: - stronger self-reported speeding (r = 0.33; p < 0.010), - higher self-reported efficacy (r = 0.25; p < 0.010), - less self-reported aversion to risk taking (r = -0.37; p < 0.010). In hierarchical regression, ES explained 2% variance speeding after control for other variables. In structural modelling, ES had a direct effect on self-reported speeding (coeff. 0.20) and an indirect effect by way of aversion to risk taking. A greater level of ES was associated with a lower aversion to risk taking which in turn negatively predicted speeding.
Zakletskaia et al., 2009, USA	Convenience sample of 1587 college students over the age of 18 who completed a health screening survey while presenting for routine, non-urgent care at campus health services centres.	The full regression model included SS, heavy episodic drinking, gender, age, race, university site, freshman status, graduate student status, and adding residence, living arrangement, and drinking location; even with all the predictors in the model, SS remained a statistically significant independent predictor of alcohol-impaired driving behaviour (OR = 1.52, p < .001).
Cestac et al., 2010, France	Participants in the MARC (Mobility, Attitudes, Risk and Behavior) survey were 3002 young drivers (52% men) who averaged 22.3 years of age (SD = 2.0, range 18–25).	Sensation seeking correlated positively with number of times ticketed last year (r = .19; p < 0.01), past speeding behaviour (r = 0.44; p < 0.010) and intention to speed (r = 0.42; p < 0.010). General model regression: The third step of the regression revealed a significant contribution (ΔR2 = .14) of sensation seeking to intention to drive over the speed limit (β = 0.05; p < 0.01) (and self-descriptions, typical-deviant descriptions, perceived similarity to the typical deviant, and comparative judgments of penalty risk). Regressions by gender: On the third regression step sensation seeking contributed to explaining the intention variance for men (β = 0.057; p < 0.010) but not for women (ns).
Eensoo et al., 2010,	2-stage sample; novice drivers; M=24.7 yrs.; 372 men; 537 female.	After adjustment age only one subscale (Disinhibition) predictor odds among women of being speed limit exceeder; OR= 1.16 (1.01-1.32).

Estonia		
Fernandes et al. 2010 Australia	Convenience sample: first-year psychology students (N = 215) from the University of NSW participated in a study on "driving and road safety" for course credit; participants were required to be ≤ 25 yrs., and have held a NSW drivers' license for at least 1 year; the sample for speeding and drink-driving behaviours included 108 participants (60.2% females; M = 19.0 yrs.); the sample for driving while fatigued and not wearing seat belts behaviours included 107 participants (60.7% females; M = 19.0 yrs.).	The full regression model included: Gender, Age, Authority–rebellion, Time urgency, SS, Driver anger, Road-unrelated perceived relative risk, Road-related general perceived relative risk, Road-related specific perceived relative risk, General perceived severity, Specific perceived severity, General perceived susceptibility, Specific perceived susceptibility, Perceived benefits, Perceived costs, Peer influence. Seeding was significantly predicted by SS after adjustment for other predictors. SS was not a significant predictor in the regression models on drinking and driving, fatigued driving and seat belt wearing.
Lucidi et al., 2010, Italy	Convenience sample; Italian high school students; M=18.3 yrs.; 57% male.	Sign. correlations with violations (0.37), lapses (0.10), errors (0.21) .
Miller & Taubman, 2010, Israël	Convenience sample of young drivers; 130 participants who were sent the questionnaires (50 males and 80 females, aged 16.5–24;M= 17.74, SD = 1.36) returned completed forms and were included in the analysis	Sensation seeking was not significantly correlated with 4 driving styles in total sample (N = 130) and female sample (N = 80). For male young drivers (N = 50), sensation seeking was positively correlated with both reckless driving ($r = 0.27$; $p < 0.05$) and angry driving ($r = 0.27$; $p < 0.05$). In hierarchical regression analysis (Step 2), sensation seeking was a significant predictor of angry driving style. In a hierarchical regression analysis, a gender x sensation seeking interaction on reckless driving was found (Step 5). Subsequent separate regression analyses showed that sensation seeking was significantly associated with a decreased tendency for the reckless driving style among women, $\beta = -.12$, $p < .05$, but was related to increased reckless driving among men, $\beta = .15$, $p < .05$.
Prato et al., 2010, Israel	Convenience sample; volunteer families of newly licensed drivers were recruited by direct contact through licensing agencies, professional driving schools and advertisements in a dedicated web-site; M=17 yrs.; 36 males (58.1%); 26 females (41.9%).	The personality traits of SS and trait anger increased the risk of reckless driving by 55% (sensation seeking: effect size = 1.547) to 38% (anger: effect size 1.381), but the safety climate dimensions decreased it by 14%-38%, thus counterbalancing the propensity to drive recklessly. The findings show that parental involvement in the driving of their adolescent offspring positively impacts their safety.
Delhomme et al., 2012, France	Sample of 2038 young drivers, 19-28 years old, based on randomly chosen phone numbers between January and April 2004, and screening question whether they were less than 26 and had a driving license. Out of the 2286 persons who matched these criteria, 201 refused to participate and 47 only participated first round study.	Driving sensation seeking was a significant predictor of speeding: the higher the participant's score on the driving sensation seeking scale, the higher their speeding score ($F(1,2029) = 126.901$, $p < .001$, g2 = .051). Driving anger also had an effect ($F(1,2029) = 25.754$; $p < .001$, $\eta 2 = 0.010$): the higher the participant's anger, the higher their speeding score. The effect size for sensation seeking was higher than for anger (in contrast to other studies). When using separately the six factors of the DAS in the regression analysis, the effect of driving sensation seeking remains ($F(1,2029) = 68.453$, $p < .001$, $\eta 2 = .0.025$). Driving related sensation seeking was weakly correlated with driving anger (0.081; $p < 0.01$). All driving anger subfactors had a significant effect on speeding.
Marengo et al., 2012,	Convenience sample; high school students; mean age 14-15 yrs.; 98 males, 108 females.	Sign. correlations with self-reported driving under influence substances (0.30), traffic violations (0.40), safe driving in simulator (-0.24) and crashes in simulator (0.19).

Italy		
Mirman et al., 2012, USA	Convenience sample; junior license holders, i.e. youth who answered yes to the following question: "I passed my driver test but my license puts some restrictions on my driving." M = 17.3 yrs.; 87 male; 111 female.	Sign. correlations with risky driving (0.26) and driving with multiple passengers (0.36). After adjustment for age, gender, state, driving hours per week, and grades, SS sign. predictor for DWMP (stand. beta= 0.31), risky driving (stand. beta = 0.23) and risky driving controlled for DWMP (st. beta = 0.15). DWMP partially mediates the predictive effects of SS (CI .008, .050) on risky driving.
Bachoo et al., 2013, South Africa	Convenience sample; post-graduate university students; M=27.2; 165 male, 141 female.	r = -0.22 SS and risky driving; SS non-significant in regression.
Pearson et al., 2013	Convenience sample; 266 college students (60.5% female).	Sensation seeking was not significantly correlated with driving errors (r = 0.06) or with driving lapses, (r = 0.01), traffic citations (r = 0.08) and traffic collisions (r = 0.04). Sensation seeking correlated significantly with: driving violations (r = 0.17), cell phone driving (r = 0.17). In path analyses controlling for gender and age, sensation seeking was not a significant predictor for driving errors, driving lapses, driving violations, cell phone driving, traffic citation, traffic collision.
Scott-Parker et al., 2013, Australia	Total population sample; every learner driver in Queensland, Australia, who passed their practical driving assessment 1 April through 30 June 2010 were invited to participate; M=17.9 yrs.; 113 males; 277 female.	Sign. correlations between SS and self-reported risky driving (survey 1: 0.37, survey 2: 0.40, both p < 0.001). General model: risky driving was predicted by the Time 2 driver's SS, reward sensitivity, and anxiety, with greater SS propensity, reward sensitivity and anxiety associated with more risky driving.
Yang et al., 2013, China	Convenience sample; 160 graduate students and 64 drivers recruited near train station; 82 males, 142 females.	Sign. correlations with aggressive violations (0.15), ordinary violations (0.21), and sign. regression predictor ordinary violations. After adjustment for gender, age, mileage; no correlation/predictor crashes.
Ge et al., 2014, China	Convenience sample; participants recruited from residential communities, train stations, shopping centre, psychology school; M=35.7 yrs.; 119 males, 123 females.	Sign. correlations with dangerous driving (0.35), aggressive driving (0.24), risky driving (0.41), drunk driving (0.15) after adjustment for age, gender and years driving.
Nordfjærn et al., 2014, Turkey	Convenience sample of Turkish drivers based on snowballing method among students at the Izmir University of Economics and friends/ relatives. 350 questionnaires were distributed and 213 were returned (61%); 129 (61%) females and 82 (39%) males; the respondents' age ranged from 19 to 66 years (M= 33.00 yrs.).	SS was significantly, negatively correlated with (positive) attitude towards traffic safety (r = .22; p < 0.001), but not significantly correlated with risk perception (r = -0.09) or with driver behaviour (r = -0.01). In the fitted model, SS and normlessness together formed the personality construct, personality and risk perception influenced attitudes towards traffic safety which in turn influenced driver behaviour. In total 24% of driver behaviour was explained by the model.
Smorti & Guarnieri, 2014, Italy	Convenience sample; adolescents aged from 16 to 20 years, living in Bolzano's province (northeast Italy) and attending different high schools and universities; all participants came from families of middle or high socioeconomic status and more than 75% of adolescents reported that both their parents had a high school diploma or university degree; M =	1. sign. Correlations between novelty (0.11), intensity (0.47) and total SS (0.42) with risky driving. 2. Intensity and total SS score partially mediated the link between parental bond and risky driving. Thus, parents may exert also an indirect influence on their daughters' risky driving by shaping their children's SS, which in turn predict the adolescents' risky driving. 3. No mediational effect was found for novelty. 4. Mediational models were only supported among females.

	18.7; 143 males, 196 females.	
Taubman-BenAri et al., 2016, Israel	The sample was drawn from 242 families who participated in a larger longitudinal study of young male drivers and their families in Israel. N = 163 young male drivers aged 17-21.5 yrs. (M = 17.6) whose driving behaviour was monitored by an IVDR over a period of 12 months.	Whereas the personality traits of SS and trait anger increased the risk of reckless driving by an average of 55% to 38%, the safety climate dimensions decreased it by an average of 14–38%, thus counterbalancing the propensity to drive recklessly; parental involvement in the driving of their adolescent offspring positively impacts their safety.

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Personal Factors - Attention Deficit Hyperactivity Disorder (ADHD)

A behaviour disorder characterised by inattention, hyperactivity and impulsivity

1 Summary

Hay, M., Etienne, V., Gabaude, C., Paire-Ficout, L., August 2016

1.1 COLOUR CODE: YELLOW

Even though few studies investigated the crash risk related to ADHD (only six reviewed studies), a consensus on its negative effect on road safety has arisen. More precisely, ADHD appears to significantly increase the risk of crash and near-crash involvement, and the risk of traffic violations. However, results about the negative effect of ADHD on the risk of injury and crash responsibility were inconsistent. Additional studies have to be conducted to further explore this issue.

1.2 KEYWORDS

Attentional deficit hyperactivity disorder, ADHD, attention disorder, hyperactivity, crash risk, traffic safety

1.3 ABSTRACT

Attention deficit hyperactivity disorder (ADHD) is a behavioural disorder characterized by inattention, hyperactivity, and impulsivity. A review of the literature was conducted to investigate the crash risk related to ADHD. Six studies were included in this literature review, one meta-analysis, three cross-sectional studies, one longitudinal study and one case-control study. Most of the reviewed studies have been carried out in the United States and in the European Union, and have been conducted on car drivers. The effect of ADHD on road safety has been measured by the analysis of self-reported crashes, patient registry, or by simulated driving performances. Most of the reviewed studies showed a negative effect of ADHD on road safety, with an increased risk of crash involvement and traffic violations. Inconsistent results have been found regarding the risk of crash responsibility and injuries. The main limitation of the reviewed studies concerns the diagnosis of ADHD, often based on subjective evaluation instead of based clinically.

1.4 BACKGROUND

What is the attentional deficit hyperactivity disorder (ADHD)?

According to the fifth edition of the Diagnostic and Statistical Manual of Mental Disorders (DSM-V), ADHD is characterized by inattention, hyperactivity, and impulsivity. More precisely, individuals who are suffering from ADHD fail to pay close attention to details, have difficulties organising their activities, are excessive talkers, move restlessly, and are unable to remain seated in particular situations (American Psychiatric Association, 2013). This disorder begins in childhood and can continue through adulthood for some people.

How does ADHD affect road safety?

It has been shown that inattention and distractibility are the most common reasons for road crashes (Lam, 2002). As the inattention is one of the characteristics of the ADHD, many studies have been conducted to document the association between ADHD and road crashes (Barkley & Cox, 2007; Cox, Cox, & Cox, 2011; Cox, Madaan, & Cox, 2011; Jerome, Habinski, & Segal, 2006; Redelmeier, Chan, &

Lu, 2010). Moreover, it has been suggested that visual inattentiveness and impulsiveness are the largest contributors to the risk of transport accidents in patients with ADHD (Jerome et al., 2006).

How often does the ADHD occur? (Prevalence)

Among the neurobehavioral disorders that could affect children, ADHD is the most common one. Regarding gender, boys are six times more often diagnosed with ADHD in childhood than girls and three times more often in adolescence (Steinau, 2013).The worldwide-pooled prevalence of ADHD was estimated at 5.3% (Polanczyk, de Lima, Horta, Biederman, & Rohde, 2007). More specifically, the prevalence of ADHD reached 2.5% in the adult population aged 19 and older (Simon, Czobor, Bálint, Mészáros, & Bitter, 2009).

How is the effect of ADHD on road safety measured?

The effect of ADHD on road safety can be measured using crashes (reported either by the drivers themselves, by the police, or recorded in patient registry). These reports give information regarding crash involvement, crash responsibility, crash-related injuries and traffic violations. Another way to measure the effect of ADHD on road safety is to conduct driving experiments, in which the driving performance is assessed either on-road or on a driving simulator. Hence driving performances, such as the number of errors or the type of errors, are used as indicators of road safety.

Which factors influence the effect of ADHD on road safety?

Excessive risk taking, poor control of aggression and substance use were identified as factors that could negatively affect road safety (Barkley & Cox, 2007; Barkley, Fischer, Smallish, & Fletcher, 2004). Moreover, as men are more affected by ADHD than women (Polanczyk et al., 2007) and as there is a gender difference of persons involved in transport accidents (Massie, Campbell, & Williams, 1995), the gender can influence the effect of ADHD on road safety.

1.5 OVERVIEW OF THE RESULTS

Few studies have been eligible for this literature review on the effect of ADHD on road safety. Among the six coded studies, one was a recent meta-analysis, three were cross-sectional studies, one was a case-control and one was a longitudinal study. Most studies focused on the impact of ADHD on drivers' safety. Regarding the data type, of these six studies, five were based on crash or injury data, coming from self-reports or patient registry, and one study was based on simulated driving performances. Overall, the review-type analysis revealed that ADHD increased the relative risk of crash involvement, traffic violations, and entailed degraded simulator driving performances. Moreover, the risk of injury and crash responsibility seems to be increased by ADHD, although the results are inconsistent.

1.6 NOTES ON ANALYSIS METHODS

The method chosen to investigate the risk associated with ADHD was a review-type analysis, because of the heterogeneity of the study designs, methods, and the small number of eligible studies (only six). Even though the sample size was relatively large, some participants suffered from comorbidities and others had medication, both of which could have affected road safety, in addition to ADHD. Moreover, the effect of ADHD on drivers' road safety have been investigated through analyses performed on crash data and on simulated driving data. Further studies are needed to better understand the effect of ADHD on driving performances assessed objectively.

2 Scientific Overview

2.1 LITERATURE REVIEW

According to the International Classification of Diseases (10th revision), ADHD belongs to the mental and behavioural disorder category and is characterized by a disturbance of activity and attention. More precisely, individuals who suffer from ADHD have problems paying attention (i.e. inattention), are excessively active (i.e. hyperactivity), and have difficulties controlling their behaviour (i.e. impulsivity, American Psychiatric Association, 2013). Although this syndrome mainly affects children, adults can also suffer from it. It has been shown that adults with ADHD had impaired attentional abilities (such as selective, divided or sustained attention), and executive functioning (flexibility, working memory, planning, problem solving, decision making, see Fuermaier et al., 2015 for a review).

Cognitive, social, and emotional impairments caused by ADHD can have negative consequences on everyday life activities, such as driving (or, more generally, travelling). Driving is a complex activity which requires cognitive, physical, perceptual and psychomotor abilities. As attention and executive functions are fundamental cognitive functions for driving safety, adults with ADHD may be at higher risk of being involved in road crashes.

2.2 DESCRIPTION OF THE AVAILABLE STUDIES

Among the six coded studies, one was a meta-analysis, three were cross-sectional, one was a case-control, and one was a longitudinal study (Table 1). The crash risk related to ADHD was investigated either using self-reported crashes, patient registry, or driving simulator performances. Different types of analyses have been conducted to study this topic, such as regression (given the odds ratio or relative risk) or ANOVAs (given the absolute difference).

Socio-demographic factors (such as age, gender, marital status, level of education, socio-professional category, work type, income), lifestyle or environmental factors (such as alcohol consumption), medical factors (such as comorbidities) and driving-related factors (such as the number of years of having a driving license or the annual number of kilometres driven) were used as controlled variables.

Table 1. Description of the main characteristics of the coded studies dealing with ADHD (sorted by year of publication)

Author, Year, Country	Sample, method/ design and analysis type	Risk / Control groups	Data type / Outcomes	Control variables
Aduen et al., 2015, United States	Observational, cross-sectional study Odds ratio	ADHD group: n = 275 / Healthy control group: n = 1828	Crash (self-report): Crash involvement, moving violations, injuries, crash responsibility	Age, gender, education, income, marital status, average annual miles driven
Philip et al.,	Observational,	ADHD group:	Crash (self-report):	Age, gender, marital status, socio-

Author, Year, Country	Sample, method/ design and analysis type	Risk / Control groups	Data type / Outcomes	Control variables
2015, France	cross-sectional study Odds ratio	n = 1543 / Healthy control group: n = 34597	near-miss crash and crash involvement	professional category, work type, sleepiness, alcohol consumption, anxiety, depression, sleep disorders, years of driving license, kilometres driven per year
El Farouki et al., 2014, France	Observational, case-control study Odds ratio	Cases: n = 358 / Controls: n = 419	Crash (self-report): Crash responsibility	
Vaa, 2014, International	Meta-analysis (random-effects)	32 results collected from 16 studies	Relative risk for crash	Publication bias, mileage, comorbidity
Chang et al., 2014, Sweden	Longitudinal study Hazard ratio	ADHD groups: n = 41793 men + 27399 women / non-ADHD groups: n = 415662 men + 271866 women	Injury (patient register and cause of death register)	Sociodemographic factors, previous psychiatric diagnosis, other psychotropic medications, and criminal convictions
Classen et al, 2013 United States	Observational, cross-sectional study Absolute difference	ADHD group: n = 9 / Healthy control group: n = 22	Driving simulator assessment: number and type of errors	

2.3 DESCRIPTION OF THE ANALYSIS CARRIED OUT

Results of the meta-analysis

A meta-analysis of 16 studies published in 2014 showed an increased relative risk of crash involvement for ADHD drivers (Vaa, 2014). Even after correction for publication bias and after controlling for the mileage, the increased relative crash risk was still significant. The authors also considered the comorbidities of the drivers, such as Oppositional Defiant Disorder (ODD), Conduct Disorder (CD), disturbed social conduct, or conduct problems. Overall, results indicated that the relative crash risk of ADHD-drivers with comorbidities was higher than that of ADHD-drivers without these comorbidities.

Additional studies on ADHD

Although some effects of ADHD on road safety outcomes were not significant (for example, effect on crash responsibility or injury), results of the five additional studies seem to indicate an overall negative effect of ADHD on road safety (see

Table 2).

Table 2. Main outcomes of coded articles according to types of indicators of road safety

Indicators of road safety	Effect on road safety	Main outcomes
Crash involvement	↗	Significant increase of the crash risk (Aduen, Kofler, Cox, Sarver, & Lunsford, 2015; Philip et al., 2015, p. 2015; Vaa, 2014)
Crash responsibility	NS or ↗	Inconsistent results - Significant increase of the risk for crash responsibility (El Farouki et al., 2014) - Non-significant effect of ADHD (Aduen et al., 2015)
Traffic violations	↗	Significant increase of the risk for traffic violations (Aduen et al., 2015)
Injuries	NS or ↗	Inconsistent results: - Significant increase of the risk for injury (Chang, Lichtenstein, D'Onofrio, Sjolander, & Larsson, 2014; Vaa, 2014) - Non-significant effect of ADHD (Aduen et al., 2015)
Driving errors	↗	- ADHD drivers committed significantly more driving errors recorded during a driving simulator experiment than controls (Classen, Monahan, Brown, & Hernandez, 2013) - Error types: visual attention and anticipation

Key: ↗ Increased risk; NS result not statistically significant

Modifying conditions

As ADHD affects more men than women, gender might modify the ADHD-risk relationship. One coded study investigated the influence of gender on this relationship. Results showed that both ADHD-men and ADHD-women were at higher risk of crash than the non-ADHD men and women, respectively (Chang et al., 2014). Moreover, as shown by Chang et al.(2014) and Vaa (2014), comorbidities (such as ODD, CD, antisocial personality disorder, personality trait disorder, disturbed social conduct, and conduct problems), and medication could also influence the crash risk.

Conclusion

Reviewed studies showed an increased risk of crash involvement and traffic violations for ADHD drivers. Moreover, inconsistent results regarding crash responsibility or injuries have been found, with still a negative effect of ADHD on these road safety outcomes.

Only one study investigated the effect of ADHD on driving performances. This study was conducted with a driving simulator. Results showed that ADHD drivers committed more errors than controls. These driving errors reflected visual attentional and anticipation impairment. This result has to be confirmed in ecological conditions, using on-road driving assessment.

Bias and transferability

Comorbidities and medication have to be controlled and taken into account in the ADHD-risk relationship.

3 Supporting Documents

3.1 METHODOLOGY

Below we describe first the method of the literature search, and subsequently the main research methods used for investigating the ADHD-risk relationship.

Literature search strategy

Three international databases had been explored for the identification of the relevant studies about ADHD and traffic risk:

- **Sciencedirect** (part of Elsevier databases), which hosts over 12 million pieces of content from 3,500 academic journals.
- **Web of science** (previously known as ISI Web of Knowledge), which hosts over 37 million from 9,000 sources.
- **Pubmed**, a free search engine accessing primarily the MEDLINE database of references and abstracts on life sciences and biomedical topics.

In the tables below are described the combination of search terms in each of these three databases and the number of articles found in each case (see Table 3,
Table 4, and
Table 5).

Table 3. Results from Sciencedirect database (date: 6th April 2016)

search no.	search terms / operators / combined queries	hits
#1	"attention disorder" OR "attention deficit" OR "hyperactivity" OR "ADHD"	77,370
#2	"road casualties" OR "road fatalities" OR "traffic accident" OR "road crash"	17,881
#3	("road safety" OR "traffic safety") AND ("collision" OR "risk")	55,319
#4	#1 AND #2 AND #3	**168**

Limitations/ Exclusions:

- Search field: TITLE-ABS-KEY
- published: 1990 to current
- Source Type: "Journal"

Table 4. Results from Web of Science database (date: 6th April 2016)

search no.	search terms / operators / combined queries	hits
#1	"attention disorder" OR "attention deficit" OR "hyperactivity" OR "ADHD"	89,973
#2	"road casualties" OR "road fatalities" OR "traffic accident" OR "road crash"	7,484
#3	("road safety" OR "traffic safety") AND ("collision" OR "risk")	2,598

#4	#1 AND #2 AND #3	**228**

Limitations/ Exclusions:
- Search field: TS = Topic (title, abstract, key words, authors keywords)
- published: 1990 to current
- Source Type: "Journal"
- Language : English

Table 5.Results from Pubmed database (date: 6th April 2016)

search no.	search terms / operators / combined queries	hits
#1	"attention disorder" OR "attention deficit" OR "hyperactivity" OR "ADHD"	46,046
#2	"road casualties" OR "road fatalities" OR "traffic accident" OR "road crash"	3,818
#3	("road safety" OR "traffic safety") AND ("collision" OR "risk")	1,357
#4	#1 AND #2 AND #3	**7**

Limitations/ Exclusions:
- Search field: TS = Topic (title, abstract, key words, authors keywords)
- published: 1990 to current
- Source Type: "Journal"
- Language : English

This search strategy resulted in **243 studies to screen** (Table 6).

Table 6. Results of the literature search

Database	Hits
Scopus (after exclusions of non-relevant papers)*	99
Web of Science (after exclusions of non-relevant papers) *	141
Pubmed (after exclusions of non-relevant papers) *	3
Total number of studies to screen title/ abstract	**243**

* : not in English or French or not in a peer reviewed journal

Among these 243 studies, 224 have been excluded. The exclusion criteria are presented below in Table 7.

Table 7. Results from the first screening

Total number of studies to screen title / abstract	243
-De-duplication	161 (remaining 82)
-exclusion criteria : no risk factor	53 (remaining 29)
-exclusion criteria B : part of a meta-analysis	7 (remaining 22)

-exclusion criteria C : research not conducted in OECD countries	3 (remaining 19)
Remaining studies	19
Not clear (full-text is needed)	8
Studies to obtain full-texts	19

Among the 19 remaining studies, 10 full texts have been obtained and were eligible to be coded (Table 8).

Table 8. Eligibility

Total number of studies to screen full-text	**19**
Full-text could be obtained	10
Reference list examined Y/N	Yes
Eligible papers	6

The 10 references were screened on potential relevance for coding (Table 9). The inspection of abstracts and/or full texts provided further information on whether the article was relevant for coding. Among the 10 references, 4 were not selected because articles were part of a meta-analysis (three articles) or duplicate (one article). Then, the six remaining articles were coded.
The prioritizing coding steps were:

- Prioritizing Step A (meta-analysis first);
- Prioritizing Step B (best fitting in coding scheme);
- Prioritizing Step C (published more recently);
- Prioritizing Step D (Central-European countries before others).

Table 9. Screening of the full texts

Total number of eligible papers	**10**
exclusion criteria "duplicate"	1
exclusion criteria "part of a meta-analysis"	3
Remaining studies	6

The detailed list of the eligible papers and the reasons why the articles have been included or excluded on the global analysis are presented in Table 10.

Table 10. List of references resulting from search strategy (sorted by year of publication and meta-analysis first)

No.	**Publication**	**Coded Y/N**	**Reason**
1.	Aduen, P. A., Kofler, M. J., Cox, D. J., Sarver, D. E., & Lunsford, E. (2015). Motor vehicle driving in high incidence psychiatric disability: Comparison of drivers with ADHD, depression, and no known psychopathology. Journal of Psychiatric Research, 64, 59–66.	Y	Prioritizing step B

2.	Philip, P., Micoulaud-Franchi, J.-A., Lagarde, E., Taillard, J., Canel, A., Sagaspe, P., & Bioulac, S. (2015). Attention Deficit Hyperactivity Disorder Symptoms, Sleepiness and Accidental Risk in 36140 Regularly Registered Highway Drivers. Plos One, 10(9), e0138004.	Y	Prioritizing step B
3.	Vaa, T. (2014). ADHD and relative risk of accidents in road traffic: A meta-analysis. Accident Analysis & Prevention, 62, 415–425.	Y	Prioritising step A (meta-analysis)
4.	Chang, Z., Lichtenstein, P., D'Onofrio, B. M., Sjolander, A., & Larsson, H. (2014). Serious Transport Accidents in Adults With Attention-Deficit/Hyperactivity Disorder and the Effect of Medication A Population-Based Study. Jama Psychiatry, 71(3), 319–325.	Y	Prioritizing step B
5.	El Farouki, K., Lagarde, E., Orriols, L., Bouvard, M.-P., Contrand, B., & Galera, C. (2014). The Increased Risk of Road Crashes in Attention Deficit Hyperactivity Disorder (ADHD) Adult Drivers: Driven by Distraction? Results from a Responsibility Case-Control Study. Plos One, 9(12), e115002.	Y	Prioritizing step B
6.	Classen, S., Monahan, M., Brown, K. E., & Hernandez, S. (2013). Driving indicators in teens with attention deficit hyperactivity and/or autism spectrum disorder. Canadian Journal of Occupational Therapy-Revue Canadienne D Ergotherapie, 80(5), 274–283.	Y	Prioritizing step B
7.	Classen, S., Monahan, M., & Wang, Y. (2013). Driving Characteristics of Teens With Attention Deficit Hyperactivity and Autism Spectrum Disorder. American Journal of Occupational Therapy, 67(6), 664–673.	N	Mixed risk factor: ADHD and autism spectrum disorder
8.	Fried, R., Petty, C. R., Surman, C. B., Reimer, B., Aleardi, M., Martin, J. M., ... Biederman, J. (2006). Characterizing impaired driving in adults with attention-deficit/hyperactivity disorder: A controlled study. Journal of Clinical Psychiatry, 67(4), 567–574.	N	Included in Vaa , 2014 meta-analysis
9.	Woodward, L. J., Fergusson, D. M., & Horwood, L. J. (2000). Driving Outcomes of Young People With Attentional Difficulties in Adolescence. Journal of the American Academy of Child & Adolescent Psychiatry, 39(5), 627–634.	N	Included in Vaa , 2014 meta-analysis
10.	Barkley, R., Guevremont, D., Anastopoulos, A., Dupaul, G., & Shelton, T. (1993). Driving-related risks and outcomes of attention-deficit hyperactivity disorder in adolescents and young-adults - a 3-year to 5-year follow-up survey. Pediatrics, 92(2), 212–218.	N	Included in Vaa , 2014 meta-analysis

Detailed analysis of study designs and methods

Table 11. Characteristics of coded studies

Author, Year, Country	**Sample, method/design and analysis type**	**Risk group**	**Control group**	**Research conditions**	**Control variables**
Aduen et al., 2015, United States	Observational, cross-sectional study Odds ratio	ADHD group: n = 275	Healthy control group: n = 1,828	Investigation of the risk for traffic collisions, moving violations, collision-related injuries, and collision fault, related to ADHD	Age, gender education, income, marital status, average annual miles driven
Philip et al., 2015, France	Observational, cross-sectional study Odds ratio	ADHD group: n = 1,543	Healthy control group: n = 34,597	Investigation of the risk of accidents and near-miss accidents for drivers with ADHD symptoms	Age, gender, marital status, socio-professional category, work type, sleepiness, alcohol consumption, anxiety, depression, sleep disorders, years of driving license, km driven per year
Vaa, 2014, international	Meta-analysis, 16 studies (random-effects)	ADHD drivers	Healthy control group : non-ADHD drivers	Estimation of the relative risk of crash for ADHD drivers	Age, gender, education, years of driving, IQ, ethnicity, socioeconomic status
Chang et al., 2014, Sweden	Longitudinal study Hazard ratio	ADHD groups: n_men = 41,793, n_women = 27,399	Healthy control groups: n_men = 415,662; n_women = 271,866	Investigation of the risk of serious transport accident for men and women suffering from ADHD (aged 18-46 years)	Civil status, employment, education status, place of residence, income, previous psychiatric diagnosis, other psychotropic medications, and criminal convictions
El Farouki et al., 2014, France	Observational, case-control study Odds ratio	Cases, ADHD drivers responsible for crash: n = 358	Healthy controls, not responsible for crash: n = 419	Investigation for the risk for crash responsibility related to ADHD	
Classen et al, 2013, United States	Observational, cross-sectional study Absolute difference	ADHD group: n = 9	Healthy control group: n = 22	Examination of the between-group simulated driving differences in ADHD-teens, compared to healthy controls	

3.2 EXPLORATORY ANALYSIS OF RESULTS

Table 12. Effects of cognitive impairment on road safety (sorted by year of publication, and meta-analysis first)

Author, year, country	Risk factor	Outcome variable	Effects on Road Safety		Main outcome – description
Aduen et al., 2015, United States	ADHD	1 violation (last 3 years)	–	OR = 1.33 CI 95% = 0.91 – 1.93 p = NS	Non-significant effect on road safety
		2 or more violations (last 3 years)	↗	OR = 2.27 CI 95% = 1.48 – 3.49 p <0.05	ADHD drivers experienced a 127% increased risk for multiple violations relative to controls
		1 collision (last 3 years)	–	OR = 1.25 CI 95% = 0.87 – 1.78 p = NS	Non-significant effect on road safety
		2 or more collisions (last 3 years)	↗	OR = 2.21 CI 95% = 1.31 – 3.74 p<0.05	ADHD drivers experienced a 121% increased risk for multiple collisions relative to controls
		Injury from collisions (n = 91 ADHD drivers + 416 healthy controls)	–	OR = 1.67 CI 95% = 0.81 – 3.48 p = NS	Non-significant effect on road safety
		At-fault collisions (n = 91 ADHD drivers + 416 healthy controls)	–	OR = 1.65 CI 95% = 0.98 – 2.78 p = NS	Non-significant effect on road safety
Philip et al., 2015, France	ADHD	All near-miss accidents	↗	OR = 1.84 CI 95% = 1.65 – 2.06 p <0.0001	Drivers with ADHD symptoms were significantly at higher risk for near-miss accidents than drivers without ADHD symptoms
		Sleepy near-miss accidents	↗	OR = 1.4 CI 95% = 1.21 – 1.60 p <0.0001	Drivers with ADHD symptoms reported significantly more sleep-related near misses than drivers without ADHD symptoms
		Inattention near-miss accidents	↗	OR = 1.9 CI 95% = 1.71 – 2.14 p <0.0001	Drivers with ADHD symptoms reported significantly more inattention-related near misses than drivers without ADHD symptoms
		All accidents	↗	OR = 1.24 CI 95% = 1.03 – 1.51 p <0.021	Drivers with ADHD symptoms were more likely to report accidents than drivers without ADHD symptoms
		Sleepy accidents	–	OR = 1.45 CI 95% = 1.07 – 1.95 p <0.015	Non-significant effect on road safety
		Inattention accidents	–	OR = 1.45 CI 95% = 1.07 – 1.95 p <0.015	Non-significant effect on road safety
Vaa, 2014,	ADHD	Accident (from all	↗	RR = 1.36	ADHD-drivers have a 36% increased

Author, year, country	Risk factor	Outcome variable	Effects on Road Safety		Main outcome – description
international		results)		CI 95% = 1.18 – 1.57 p <0.05	risk of being involved in an accident compared to drivers without ADHD
		Accidents (with correction from publication bias, "trim-and-fill method")	↗	RR = 1.29 CI 95% = 1.12 – 1.49 p <0.05	After correction from publication bias, ADHD-drivers have a 29% increased risk of being involved in an accident compared to drivers without ADHD.
		Accident (for studies with controlled mileage)	↗	RR = 1.23 CI 95% = 1.04 – 1.46 p <0.05	ADHD drivers have a 23% increased risk of being involved in an accident compared to non-ADHD drivers, after controlling for mileage
		Property-damage accident only	–	RR = 1.07 CI 95% = 0.87 – 1.31 p = NS	Non-significant effect on road safety
		Personal injury accident	↗	RR = 1.80 CI 95 % = 1.41 – 2.30 p <0.05	ADHD-drivers have a 80% increased risk of personal injury accident compared to drivers without ADHD
		Accident (comorbidity stated = ODD, CD, disturbed social conduct, and conduct problems)	↗	RR = 1.43 CI 95% = 1.20 – 1.70 p <0.05	Significant negative effect on road safety
		Accident (comorbidity not stated)	↗	RR = 1.40 CI 95% = 1.02 – 1.91 p <0.05	Significant negative effect on road safety
		Accident (comorbidity excluded)	–	RR = 1.31 CI 95% = 0.96 – 1.81 p >0.05	Non-significant effect on road safety
		Accident (in studies where more than 50% of ADHD-drivers have comorbid problems)	↗	RR = 1.86 CI 95% = 1.27 – 2.75 p <0.05	ADHD-drivers with comorbid disorders have a higher relative risk of crash than ADHD-drivers without these comorbidities
Chang et al., 2014	ADHD men	Serious transport accident	↗	HR = 1.47 CI 95% = 1.32 – 1.63 p<0.05	ADHD-men have a significantly higher relative risk of serious transport accident than men without ADHD
	ADHD women	Serious transport accident	↗	HR = 1.45 CI 95% = 1.24 – 1.71 p<0.05	ADHD-women have a significantly higher relative risk of serious transport accident than women without ADHD
El Farouki et al., 2014, France	ADHD	Crash responsibility	↗	OR = 2.18 CI 95% = 1.22 – 3.88 p < 0.01	ADHD drivers were significantly at higher risk for being responsible for a crash than controls

Author, year, country	Risk factor	Outcome variable	Effects on Road Safety		Main outcome – description
Classen et al, 2013	ADHD	Visual scanning	↗	U = 52.50 p = 0.041	ADHD drivers made significantly more visual scanning errors than HC
		Speed regulation	↗	U = 28.00 p = 0.001	ADHD drivers made significantly more speed regulation errors than HC
		Lane maintenance	–	U =60.50 p = 0.094	Non-significant effect on road safety
		Signalling	–	U = 63.00 p = 0.124	Non-significant effect on road safety
		Vehicle positioning	–	U = 80.00 p = 0.428	Non-significant effect on road safety
		Adjustment to stimuli	–	U = 74.00 p = 0.292	Non-significant effect on road safety
		Gap acceptance	–	U = 73.50 p = 0.273	Non-significant effect on road safety
		Total number of errors	↗	U = 32.50 p = 0.003	ADHD drivers made significantly more errors than HC
		Off-road crashes	–	U = 94.50 p = 0.848	Non-significant effect on road safety
		Collisions	–	U = 72.00 p = 0.254	Non-significant effect on road safety
		Pedestrians hit	–	U = 86.00 p = 0.593	Non-significant effect on road safety
		Stops at traffic lights	–	U = 83.00 p = 0.507	Non-significant effect on road safety
		Centreline crossings	–	U = 56.00 p = 0.064	Non-significant effect on road safety
		Road edge excursions	–	U = 68.00 p = 0.188	Non-significant effect on road safety
		Correct divided attention responses	–	U = 56.50 p = 0.086	Non-significant effect on road safety
		Divided attention response time	–	U = 59.00 p = 0.114	Non-significant effect on road safety
		Divided attention with no response	–	U = 56.50 p = 0.064	Non-significant effect on road safety

3.3 SUMMARISING THE RESULTS

A review-type analysis was conducted to investigate the effect of ADHD on road safety. The main effects are summarised in

Table 2.

Table 2. Main outcomes of coded articles according to types of indicators of road safety

Indicators of road safety	Main outcomes
Crash involvement	Significant increase of the crash risk (Aduen et al., 2015; Philip et al., 2015, p. 2015; Vaa, 2014)
Crash responsibility	Inconsistent results - Significant increase of the risk for crash responsibility (El Farouki et al., 2014) - Non-significant effect of ADHD (Aduen et al., 2015)
Traffic violations	Significant increase of the risk for traffic violations (Aduen et al., 2015)
Injuries	Inconsistent results: - Significant increase of the risk for injury (Chang et al., 2014; Vaa, 2014) - Non-significant effect of ADHD (Aduen et al., 2015)
Driving errors	- ADHD drivers committed significantly more driving errors recorded during a driving simulator experiment than controls (Classen et al., 2013) - Error types: visual attention and anticipation

3.4 FULL LIST OF STUDIES

Table 13. List of the coded studies (sorted by year of publication)

Reference	Study summary	Bias
Aduen, P. A., Kofler, M. J., Cox, D. J., Sarver, D. E., & Lunsford, E. (2015). Motor vehicle driving in high incidence psychiatric disability: Comparison of drivers with ADHD, depression, and no known psychopathology. Journal of Psychiatric Research, 64, 59–66.	This study investigated the risk factor for traffic violations or collisions related to depression and ADHD. The authors conducted an observational, cross-sectional study. The outcomes were retrospective self-reported traffic collisions, moving violations, collision-related injuries, and collision fault for the last three years. The exposure variables were depression and ADHD (three groups: drivers with depressive symptoms, drivers with ADHD, and healthy controls, HC). To predict the relative risk for collisions, violations, injuries, and collision fault for drivers with depression or ADHD relative to HC, a multinomial logistic regression was performed. The results showed that Depression was uniquely associated with self-reported injury following a collision. More precisely, the depressed drivers experienced a 125% increased risk for self-reported injuries from collisions relative to HC drivers. Moreover, ADHD but not Depression was a unique risk factor for multiple motor vehicle violations and collisions. This increased risk was remarkable, such that drivers with ADHD were 2.3 and 2.2 times more likely to report multiple violations and multiple collisions relative to HC drivers, respectively.	This study relied exclusively on retrospective self-report data, and diagnostic status was based on self-report and responses to a well validated measure. Thus, the extent to which the findings generalize to adults with clearly defined ADHD, or correspond to official police, hospital, and/or Department of Motor Vehicles records is unknown.
Philip, P., Micoulaud-Franchi, J.-A., Lagarde, E., Taillard, J., Canel, A., Sagaspe, P., & Bioulac, S. (2015). Attention Deficit Hyperactivity Disorder Symptoms, Sleepiness and Accidental Risk in 36140 Regularly Registered	This study investigated the risk of accidents and near-miss accidents in drivers with ADHD symptoms. The authors conducted an observational, cross sectional study. The outcomes were the number of accidents and near-miss accidents. The exposure variable was ADHD symptoms (absence or presence). To test the relationship between the ADHD symptoms and the accident variables (i.e. accident, sleepy accident, inattention accident, near-miss accident, sleepy near-miss accident, inattention near-miss accident), multivariate logistic regression analyses were performed. The odds ratios were adjusted for	The groups were defined on the basis of ADHD symptoms and not on an ADHD diagnosis based on the DSM criteria and a clinical interview. The results of this study need to be confirmed with a population of ADHD patients diagnosed with

Reference	Study summary	Bias
Highway Drivers. Plos One, 10(9), e0138004.	socio-demographical, driving and clinical variables. The results showed that drivers with ADHD symptoms were also significantly at higher risk of accidents than driver without ADHD symptoms. They were also significantly at higher risk of near-miss accidents. More precisely, ADHD drivers reported significantly more sleepiness- and inattention-related near-misses than controls.	a standardized face-to-face clinical interview performed by experienced clinicians according DSM-5 ADHD diagnostic criteria. Sleep disorders were assessed on the basis of drivers' testimonials but there was no clinical interview to confirm the disease or treatment.
Chang, Z., Lichtenstein, P., D'Onofrio, B. M., Sjolander, A., & Larsson, H. (2014). Serious Transport Accidents in Adults With Attention-Deficit/Hyperactivity Disorder and the Effect of Medication A Population-Based Study. Jama Psychiatry, 71(3), 319–325.	This study investigated the risk of serious transport accident for men and women suffering from ADHD (aged 18-46 years). The authors conducted a longitudinal study. The outcome was the serious transport accident. The exposure variable was ADHD. To explore the association between ADHD and serious transport accidents, the rate of accidents between persons with and without ADHD was compared using Cox proportional hazard regression. Measured covariates were included into the model to control for confounding. The results showed that patients with ADHD were at increased risk for serious transport accidents. The authors found that individuals with ADHD had a 45% to 47% increased rate of serious transport accidents compared with individuals without ADHD, in both men and women.	
El Farouki, K., Lagarde, E., Orriols, L., Bouvard, M.-P., Contrand, B., & Galera, C. (2014). The Increased Risk of Road Crashes in Attention Deficit Hyperactivity Disorder (ADHD) Adult Drivers: Driven by Distraction? Results from a Responsibility Case-Control Study. Plos One, 9(12), e115002.	This study investigated the risk for crash responsibility related to ADHD. The authors conducted an observational case-control study. The outcome was the crash responsibility (two categories: responsible or not responsible for a crash). The exposure variable was ADHD. To test the relationship between responsibility for road traffic crash and ADHD, multivariate, logistic regression was performed. The results showed that ADHD significantly enhanced the crash responsibility.	The assessment of psychiatric disorders was based on subjective evaluation and not on clinical diagnosis
Vaa, T. (2014). ADHD and relative risk of accidents in road traffic: A meta-analysis. Accident Analysis & Prevention, 62, 415–425.	This study aimed to estimate the relative risk of crash for ADHD drivers. The authors conducted a meta-analysis. The outcome were the crashes (all types, personal injury and property-damage only). The exposure variables was ADHD. To perform the meta-analysis of the data collected from 16 studies, a random-effects model has been applied because it represents more conservative estimates than the fixed-effects model. The results showed that ADHD-drivers have a significant higher risk of crash than controls and that comorbidities exacerbate this risk as ADHD-drivers with comorbid disorders have a higher relative risk of crash than ADHD-drivers without these comorbidities.	
Classen, S., Monahan, M., Brown, K. E., & Hernandez, S. (2013). Driving indicators in teens with attention deficit hyperactivity	This study examined the between-group simulated driving differences in ADHD-teens, compared to healthy controls (HCs). The authors conducted an observational study. The outcome were the number and the type of driving errors recorded during a driving simulator task. The exposure variable was ADHD. To determine between-group differences, Mann-Whitney U test	Small sample size

Reference	Study summary	Bias
and/or autism spectrum disorder. Canadian Journal of Occupational Therapy-Revue Canadienne D Ergotherapie, 80(5), 274–283.	were used for non-parametric continuous data. The results showed that ADHD-drivers made significantly more driving errors than HC during the simulated driving task. The errors were mainly related to visual scanning and speed regulation.	

3.5 REFERENCES

Coded studies

Aduen, P. A., Kofler, M. J., Cox, D. J., Sarver, D. E., & Lunsford, E. (2015). Motor vehicle driving in high incidence psychiatric disability: Comparison of drivers with ADHD, depression, and no known psychopathology. *Journal of Psychiatric Research*, *64*, 59–66. http://doi.org/10.1016/j.jpsychires.2015.03.009

Chang, Z., Lichtenstein, P., D'Onofrio, B. M., Sjolander, A., & Larsson, H. (2014). Serious Transport Accidents in Adults With Attention-Deficit/Hyperactivity Disorder and the Effect of Medication A Population-Based Study. *Jama Psychiatry*, *71*(3), 319–325. http://doi.org/10.1001/jamapsychiatry.2013.4174

Classen, S., Monahan, M., Brown, K. E., & Hernandez, S. (2013). Driving indicators in teens with attention deficit hyperactivity and/or autism spectrum disorder. *Canadian Journal of Occupational Therapy-Revue Canadienne D Ergotherapie*, *80*(5), 274–283. http://doi.org/10.1177/0008417413501072

El Farouki, K., Lagarde, E., Orriols, L., Bouvard, M.-P., Contrand, B., & Galera, C. (2014). The Increased Risk of Road Crashes in Attention Deficit Hyperactivity Disorder (ADHD) Adult Drivers: Driven by Distraction? Results from a Responsibility Case-Control Study. *Plos One*, *9*(12), e115002. http://doi.org/10.1371/journal.pone.0115002

Philip, P., Micoulaud-Franchi, J.-A., Lagarde, E., Taillard, J., Canel, A., Sagaspe, P., & Bioulac, S. (2015). Attention Deficit Hyperactivity Disorder Symptoms, Sleepiness and Accidental Risk in 36140 Regularly Registered Highway Drivers. *Plos One*, *10*(9), e0138004. http://doi.org/10.1371/journal.pone.0138004

Vaa, T. (2014). ADHD and relative risk of accidents in road traffic: A meta-analysis. *Accident Analysis & Prevention*, *62*, 415–425. http://doi.org/10.1016/j.aap.2013.10.003

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Cox, D. J., Madaan, V., & Cox, B. S. (2011). Adult attention-deficit/hyperactivity disorder and driving: why and how to manage it. *Current Psychiatry Reports*, *13*(5), 345–350.

Fuermaier, A. B. M., Tucha, L., Evans, B. L., Koerts, J., de Waard, D., Brookhuis, K., … Tucha, O. (2015). Driving and attention deficit hyperactivity disorder. *Journal of Neural Transmission (Vienna, Austria: 1996)*. http://doi.org/10.1007/s00702-015-1465-6

Jerome, L., Habinski, L., & Segal, A. (2006). Attention-deficit/hyperactivity disorder (ADHD) and driving risk: a review of the literature and a methodological critique. *Current Psychiatry Reports*, *8*(5), 416–426.

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Emotions – Anger, Aggression

Experiencing emotions, particularly anger or aggression, while driving/riding

1 Summary

Eichhorn, A., Pilgerstorfer, M., July 2016

1.1 COLOUR CODE: YELLOW

The relationship between emotion and crash risk varies depending on the mode of measurement (simulator, questionnaires, different decision making tests, self-reported crashes etc.). Moreover, emotion is induced in different ways (pictures and videos, emotional recall, traffic events etc.) and its exposure can only be concluded from self-ratings. Therefore, results are inconsistent but show a tendency to an elevated crash risk, though, not always statistically significant.

1.2 KEYWORDS

Emotion, negative emotion, positive emotion, anger, aggression, angry driving, aggressive driving, stress, time pressure, anxiety, fright

1.3 ABSTRACT

There is no consensus about an unambiguous definition for emotion. However, in common speech, it is any relatively brief mental experience with intensity and a high degree of pleasure or displeasure (Cabanac, 2002). Most research in this field is based on the appraisal theory. According to appraisal theory, the particular judgments about a stimulus cause emotion (Scherer et al., 2001). Studies generally indicate a (slightly) higher risk for drivers that show emotion, typically anger or aggression, while driving, although differences are often not statistically significant. Most research has been done in Europe and USA and was conducted at universities with students as participants. Only car drivers have been investigated. There is no information on VRU. Due to the kind of study interests, studies with control groups (in the sense of "neutral" emotions) are rare.

1.4 BACKGROUND

What is emotion?

Emotions presents itself as very complex and heterogeneous and covers a wide variety of important psychological phenomena. According to different theories, they lead to physical and psychological changes that influence ones behaviour (Schacter et al., 2011). In this context, three components play a decisive role: subjective experience, physiological response, and behavioural/expressive response (Hockenbury & Hockenbury, 2007).

Scientists tried to classify emotions across the years and came to different results. In the 1970s, Paul Eckman recommended six common basic emotions for all cultures – anger, disgust, fear, surprise, happiness, and sadness – and extended them later on with the emotions of embarrassment, excitement, contempt, shame, pride, satisfaction, and amusement (Handel, 2012). One decade later, Robert Plutchik suggested eight primary emotions – joy, sadness, trust, disgust, fear, anger, surprise, and anticipation – that were grouped on positive and negative basis and could be combined in different ways. So, for instance, the combination of anticipation and happiness could become the emotion excitement (Handel, 2012; Plutchik, 2002).
As a definition of emotion proved to be difficult, often a distinction is drawn between "positive" and "negative" emotions.

The focus on this paper is on anger and aggression, as those turned out to be the best investigated constructs in road safety. Whereas anger can be defined as an emotion, aggression is a behaviour. Deffenbacher et al. (Deffenbacher, 1994; in Nesbit et al., 2007) suggested that driving anger is a situation-specific form of anger and often follows a similar pattern to that of general trait anger. Aggressive driving can be defined as a behavioural construct that includes behaviours such as tailgating, running a red light, cutting another driver off, etc. (Nesbit et al., 2007).

How does emotion affect road safety?

Several studies draw the conclusion that anger and aggression have negative effects on road safety. Questionnaire studies show a relation between the inclination to react angrily or with driver aggression, and near-misses and crashes and risky driving behaviour (SWOV Factsheet, 2012). These acts, which can be an expression of driver aggression, are known to increase the risk of crashes (e.g. Aarts & Van Schagen, 2006).

Studies by Deffenbacher et al. (1994, 2003; in Nesbit et al., 2007) show that drivers with a relatively strong tendency towards anger become angry in traffic about twice as often, and report acts of aggression in traffic about three times more than drivers without this tendency. In driving simulators they also show a greater tendency to risky driving behaviour (close following, more speeding, less steady driving behaviour), and they are found to be involved in (virtual) crashes twice as often as other drivers (SWOV, 2012).

It must be emphasised that different methods can lead to different results. Nesbit et al. (2007) found out that aggressive driving outcomes measured by a driving simulator were significantly smaller than those outcomes garnered by a self-report measure.

How frequently does emotion, especially anger and aggression, occur in traffic?

An American study estimates that aggressive driving behaviour plays a role in more than half of all fatal crashes. However, due to the poor data availability, different definitions and methodological difficulties, it is difficult to determine the frequency of emotions in traffic (AAA, 2009). Research shows that some emotions are more frequent than others. Anger, happiness, and anxiety seem to occur relatively often (Mesken et al., 2007).

A recent Naturalistic Driving (ND) study evaluated data regarding risk factors during the last seconds leading up to a crash. Results show that the risk to be involved in a crash when being "emotional" while driving (anger, sadness, crying and/or emotional agitation) is 9.8 times higher than being in neutral state. The baseline prevalence is 0.22%, which represents the percentage of time the factor was present during the normal driving condition (Dingus et al., 2016).

The method that is used to determine the prevalence of emotions in traffic has, however, been shown to influence the type and frequency of the emotions that are reported. Anxiety has been found to be reported more frequently in interviews while driving than in questionnaire studies (SWOV, 2012).

Which factors influence the effect of emotions on road safety?

In this context the frustration-aggression-theory of aggressive driving behaviour can be used as a reference. This theory includes both personal and situational aspects. Age, gender, personality, and stress are personal aspects that have found to contribute to driver aggression. E.g. young men tend to show more aggressive behaviour in traffic than women. Just as much, situational aspects like behaviour of other road users, driving environment (traffic jams, red light delays, speed, tailgaters, perspective, road space, traffic density, time pressure, anonymity, or means of communication) play a decisive role (Uhr, 2014). However, driver aggression is often said to be stronger in situations where the own interests are affected and frustration arises (SWOV, 2012).

How is the effect of emotion on road safety measured?

Two main approaches have been used to study the relationship between emotional driving and crash risk. Self-ratings mostly use the DAS scale in questionnaires in order to measure driving anger. In driving simulator studies the emotion to be investigated is induced in different ways e.g. recall, film clips or critical events.

Most research has been done in Europe and the USA and was conducted at universities with students as participants. Anger and aggression turned out to be the best investigated constructs in road safety studies. Due to the kind of study interests, studies with control groups (in the sense of "neutral" emotions) are rare.

1.5 OVERVIEW OF RESULTS ON ANGER AND AGGRESSION

Studies generally show that drivers in emotional states have a (slightly) increased crash risk compared to drivers in neutral states. However, effects sometimes are statistically non-significant. Only one coded study linked emotional driving with real crashes. Results show a 9.8 times higher risk to be involved in a crash when driving in an emotional state (Dingus et al., 2016).

Studies which assessed self-reported accidents show inconsistent results. A meta-analysis (Nesbit et al., 2007) indicated a very small relationship between aggressive driving and motor vehicle accidents as well as anger and motor vehicle accidents. Delhomme et al. (2012) reported a significant correlation between driving anger and self-reported crashes, and Chliaoutakis et al. (2002) found that irritability is a highly significant predictor of reported crashes. Simon & Corbett (1996) and Mesken et al. (2007) found no significant correlation between driver anger/aggression and self-reported accidents.

However, research based on self-reports shows that anger has significant effects on road user behaviour, particularly on speed and speeding and other traffic offences (Beck et al., 2013; Delhomme et al., 2012; Mesken et al., 2007; Simon & Corbett, 1996). Simulator studies confirm these effects on road user behaviour (Abdu et al., 2012; Jallais et al., 2014; Jeon et al., 2014; Roidl et al., 2013 a/b).

2 Scientific Details

2.1 THEORETICAL BACKGROUND

Appraisal theory currently is the main approach in order to explain formation and differentiation of emotions. Whether or not a particular event causes emotion depends on how the person interprets the event. This interpretation also determines what emotion and how intensively it occurs. Thus, cognitive assessments and positive or negative reviews of the event are essential (Reisenzein, 2000).

Most researchers agree that affect has at least two qualities: Valence is positive or negative affectivity, whereas arousal measures how calming or exciting the information is. Russell's (1980) 'Circumplex model' suggests that emotions are distributed in a two-dimensional circular space, containing arousal and valence dimensions.

2.2 METHODOLOGY

A literature search was carried out in two databases (Scopus and a KFV-internal literature database) with separate search strategies (for a detailed description see "Supporting documents"). Below is given initial information on the characteristics of coded studies, and subsequently the main research methods used for investigating anger and aggression while driving is provided.

Description of studies

Table 1 provides further description of the background characteristics of the coded studies that deal with anger and aggression (sorted by year of publication, meta-analysis first).

Author, year, country	Sample, method/design and analysis	Risk group/ Cases	Control group/ Controls	Control variables
Nesbit et al., 2007, international	Meta-analysis. 25 studies were evaluated concerning the relationship of anger and aggressive driving.	College students, community drivers		Analysis of influence of type of anger, mode of measurement
Dingus, et al., 2016, USA	Naturalistic driving data, case-control study (3 year period) Odds ratios	N= 905 Drivers with crash events	N= 3,500 Drivers with no crash events	
Abdu et al., 2012, Israel	Driving simulation with 15 drivers, 2 conditions: angry, neutral, within-subject-design, t-tests	Male students induced with anger	Male students in neutral condition	
Simon & Corbett, 1996, United Kingdom	Postal questionnaire (n=422) and personal interviews (n=66) with persons that had at least one accident in the last 3 years, 3-way ANOVA	Drivers with high accident rates High offending rates	Drivers with low accident rates Low offending rates	Gender and age were independent variables
Beck et al., 2013, United States	Questionnaire (n=769) among young drivers (18-23 years), multiple linear regression	Correlations between aggressive driving, risky driving, driving anger		Analysis controlled for age, gender, race, ethnicity

Chliaoutakis et al., 2002, Greece	Questionnaire of self-reported car crash involvement (n=356), randomly selected, young drivers (18–24 years old), principal components analysis (PCA) and multiple regression analysis	Regression-analysis of crashes and irritability		
Delhomme et al., 2012, France	Questionnaire among young drivers (n=2,038) using the Driving Related Sensation Seeking Scale (DRSS) and the Driving Anger Scale (DAS), randomly chosen phone numbers, regression analysis	Correlations between driving anger, self-reported crashes, and fines		
Jallais et al., 2014, France	Experimental design, comparing two negative emotions according to the arousal dimension, emotion (sadness, anger, neutral) induced in laboratory, 54 participants, randomly assigned in one of the three conditions, ANOVA	Participants induced with anger	Participants in neutral condition	
Jeon et al., 2014, United States	Driving simulation, 70 undergraduate participants drove under three different road conditions, induced with anger, fear, happiness, or neutral, within-subject-design, t-tests	Participants induced with anger	Participants in neutral condition	
Mesken et al., 2007, Netherlands	Questionnaire (e.g. DAS, DBQ) and test drive in instrumented car including self-reported emotion, heart rate measurement and GPS (n = 44), correlations & mean differences	Correlations between anger and self-reported accidents		
Roidl et al., 2013 a, Germany	Driving simulation, questionnaire (GEW, DAS), 74 drivers, emotion induced with short film clips, randomly assigned in one of the two conditions (emotional, neutral), correlations, multiple linear regressions and path-models	Correlations between anger and driving parameters (velocity, acceleration, speeding)		
Roidl et al., 2013 b, Germany	Driving simulation with 4 scenarios, emotion was rated after driving with questionnaires (GEW, DAS), 80 drivers, scenarios randomly assigned, correlations, multiple linear regression and path-models	Correlations between anger and driving parameters (velocity, acceleration, speeding)		
Roidl et al., 2014 Germany	Driving simulation, 17 km rural route with four critical events, 2x2 within-subject design, randomly, assigned, 79 drivers , t-tests	Participants with high emotion	Participants with low emotion	

Table 1. Characteristics of coded studies that deal with anger and aggression

Description of main research methods

Links to real crashes in studies concerning emotional driving are rare. Two main approaches have been used to study the relationship between emotional driving and crash risk. One approach is the use of self-ratings. Numerous driving anger questionnaires exist (e.g. Driving Anger Scale (DAS), Driving Behaviour Index (DBI), Dula Dangerous Driving Index). Problematically, each of these scales measures anger or emotion in a slightly different way.

Another approach uses driving simulations, in which emotions are induced in different ways e.g. recall, film clips or critical events. Anger and aggression turned out to be the best investigated constructs in road safety studies. Due to the kind of study interests, studies with control groups (in the sense of "neutral" emotions) are rare.

2.3 OVERVIEW OF RESULTS

Meta-analysis results

A 2007 meta-analysis of 25 studies using driving behaviour/anger scales indicated a significant association between anger and aggressive driving (weighted Z=0.38), regardless of the type of anger. However, aggressive driving outcomes measured by a driving simulator (mean effect size=0.14) were significantly smaller than those outcomes garnered by a self-report measure (mean effect size=0.32).

Nevertheless, the relationship between anger and accidents (weighted Z=0.09) and between aggressive driving and accidents (weighted Z=0.11) is very small. It may be that the low base rate of motor-vehicle-accidents (MVAs) and the lack of age diversity in the samples restricted the range of the correlation and thus, may not be a good estimate of the true value.

Additional studies on angry and aggressive driving

The studies not included in the meta-analysis and/or appearing after the meta-analysis show a tendency to an elevated crash risk, though this relationship was hardly measured directly. Different safety performance indicators (e.g. speed/speeding, acceleration, traffic offences) were used to draw conclusions on effects on road safety (Abdu et al., 2012; Beck et al., 2013; Chiliaoutakis et al., 2002; Delhomme et al., 2012; Jallais et al. 2014; Jeon et al., 2014; Mesken et al., 2007; Simon & Corbett, 1996; Roidl et al., 2013).

Only one study based on naturalistic driving linked emotion with real crashes. Results show a 9.8 times higher risk to be involved in a crash when driving in an emotional state (Dingus et al., 2016).

Studies which assessed self-reported accidents show inconsistent results. Delhomme et al. (2012) reported a significant correlation between driving anger and self-reported crashes, Chliaoutakis et al. (2002) found out that irritability is a highly significant predictor of reported crashes. Neither Simon & Corbett (1996) nor Mesken et al. (2007) found a significant correlation between driver anger/aggression and self-reported accidents. However, research based on self-reports shows that anger has significant effects on road user behaviour particularly on speeding and other traffic offences (Beck et al., 2013; Delhomme et al., 2012; Mesken et al., 2007; Simon & Corbett, 1996).

Simulator studies confirm these effects on road user behaviour (Abdu et al., 2012; Jallais et al., 2014; Jeon et al. 2014; Roidl et al. 2013 a/b, Roidl et al., 2014).

Table 2 presents information on the main outcomes of the coded studies on anger and aggression while driving (sorted by author, meta-analysis first).

Table 2: Main outcomes on coded studies that deal with anger and aggression

Author, Year, Country	Exposure variable	Outcome variable	Effects on Road Safety		Main outcome description
Nesbit et al., 2007, international	Anger (any)	Aggressive Driving	↗	Weighted Z=0.38, 95% CI: 0.29-0.48	There is a significant association between anger and aggressive driving
	Aggressive Driving	Self-reported Motor Vehicle Accidents (MVA)	–	Weighted Z=0.11 , 95% CI: -0.04-0.25	Very small relationship between aggressive driving and MVA
	Anger	Self-reported MVA	–	Weighted Z=0.09 , 95% CI: -0.01-0.19	Very small relationship between anger and MVA
Abdu et al., 2012, Israel	Anger	Speed	–	t=1.89, p=0.08	Non-significant effect on road safety
	Anger	Pedestrian hits	–	t=1.36, p=0.194	Non-significant effect on road safety
	Anger	Yellow light crossings	↗	t=3.58, p=0.003	In the angry state drivers crossed more of yellow-lighted-intersections than in the neutral state
	Anger	Collisions with other cars	–	t=0.87, p=0.4	Non-significant effect on road safety
Beck et al., 2013, United States	Driver anger	Tickets (lifetime)	↗		Drivers who have been ticketed were significantly more likely to report greater driver anger
	Aggressive driving	Tickets (lifetime)	↗		Drivers who have been ticketed were significantly more likely to be aggressive drivers
	Driver anger	Hurried driving	↗	r=0.377, p<0.01	Hurried driving is significantly correlated with driving anger
Chliaoutakis, et al. 2002, Greece	Irritability	Self-reported car crashes	↗	*B*=0.13, p=0.04	Irritability is a highly significant predictor of reported crashes
Delhomme et al., 2012, France	Driving anger	Self-reported car crashes	↗	r=0.47, p<0.05	Driving anger is significantly correlated with the number of self-reported crashes
	Driving anger	Self-reported fines	↗	r=0.071, <0.01	Driving anger is significantly correlated with the number of self-reported fines
	Driving anger	Speed	↗	F(1,2029)=25.754, p<0.001	The higher the anger the higher the speeding score
Jallais et al., 2014, France	Anger	Time for localization of road elements on (jumbled) pictures of intersections	↗	F(1,51)=13.31, p<0.001	Anger group was significantly slower than the control group
	Anger	Errors in localization of road elements	–	F(1,51)=2.21	No statistical difference between the sadness group and the control group
Jeon et al., 2014, United States	Anger	Confidence	–	anger (M=4.44) and neutral (M=5.22)	No significant difference between perceived confidence level among anger and neutral

Author, Year, Country	Exposure variable	Outcome variable	Effects on Road Safety		Main outcome description
	Anger	Risk	–	anger ($M=3.28$) and neutral ($M=2.61$)	No significant difference between perceived risk level among anger and neutral
	Anger	Lane Keeping Errors	↗	angry drivers ($M=4.72$) and neutral drivers ($M=2$), $p<0.01$	Angry drivers did significantly more errors in LK than neutral drivers
	Anger	Traffic Rule Violations	↗	angry drivers ($M=3.72$) and neutral ($M=2.06$), $p<0.05$	Angry drivers reported significantly more errors in TR than the neutral
	Anger	Aggressive Driving	↗	angry state ($M=15.11$) and neutral ($M=9.17$), $p<0.01$	Participants in the angry state reported significantly more errors than in the neutral
Mesken et al., 2007, Netherlands	Anger	Average speed	↗	anger ($M=90.7$) and neutral ($M=87.3$), $p<0.05$	Significant difference between average speed on roads of 100km/h among anger and neutral
	Anger	Exceeding Speed limit	↗	anger ($M=16.0$) and neutral ($M=2.4$), $p<0.01$	Significant difference between percentage of exceeding the speed limit on roads of 100km/h among anger and neutral
	Driving Anger	Average speed	↗	High driving anger ($M=52.9$) and low driving anger ($M=49.8$), $p<0.05$	Significant difference between average speed on roads of 50 km/h with high scores in driving anger and low scores in driving anger
	Anger frequency	Reported accidents	–	$r=-0.02$	No significant correlation between anger frequency and self-reported accidents
	Anger strength	Reported accidents	–	$r=-0.07$	No significant correlation between anger strength and self-reported accidents
Simon & Corbett, 1996, United Kingdom	Driver aggression	Offending rates	↗	$r=0.44$, $p=0.001$	Driver aggression is significantly correlated with offending rates (weighted sum combining serious points with frequencies)
	Driver aggression	Accident rates	–		No significant correlation between driver aggression and accident rates (number of accidents, degree of responsibility, estimate of annual mileage)
Roidl et al. a, 2013, Germany	Anger	Velocity	↗	$B=0.27$, $p=0.016$	High anger scores added a significant amount of speed to the population mean
	Anger	Acceleration	↗	$B=0.32$, $p=0.004$	High anger scores increased acceleration significantly
	Anger	Lateral Acceleration	–	$B=0.19$, $p=0.099$	No significant correlation between anger and lateral acceleration
	Anger	Speeding	–	$B=0.16$, $p=0.145$	No significant correlation between anger and speeding
Roidl et al. b, 2013, Germany	Anger	Velocity	↗	$B=0.3$, $p=0.006$	Mean driving speed was positively affected by reported anger
	Anger	Acceleration	↗	$B=0.31$, $p=0.01$	People who drove angrily accelerated more quickly

Author, Year, Country	Exposure variable	Outcome variable	Effects on Road Safety		Main outcome description
	Anger	Lateral Acceleration	↗	*B*=0.33, p= 0.003	Anger is positively influencing lateral acceleration
	Anger	Speeding	↗	*B*=0.31, p= 0.003	Anger influenced speeding
Roidl et al. , 2014, Germany	Anger	Velocity	↗	t(73)=2.71, p<0.009	Participants who experienced more anger drove faster directly after the critical event in the driving simulation.
	Anger	Acceleration	↗	t(73)=0.94, p<0.023	Higher anger leads to stronger acceleration directly after the critical event in the driving simulation.
	Anger	Lateral Acceleration	↗	t(73)=2.11, p <0.038	Lateral acceleration was positively influenced by anger intensities.
	Anger	Speeding	↗	t(73)=2.78, p<0.007	Participants with stronger anger violated the speed limit for a longer period of time.

*Significant effects on road safety are coded as: decreased risk (↘), increased risk (↗) or non-significant (–)

Additional studies on other emotions investigated

A similar picture is shown in Cœugnet et al. (2013), who investigated driving under **time pressure**. Time pressure had no significant effect on self-reported accidents, but could be linked to self-reported near accidents. Furthermore, time pressure significantly influenced SPIs like speed, overtaking, risk taking and road violations.

A study on **anxiety** (Dula et al., 2010) found that drivers with high anxiety had caused significantly more crashes and engaged in more DUI episodes than others ($p<0.05$). Moreover, anxiety was related to a variety of dangerous driving behaviours (seatbelt citations, cutting off another driver, tail gaiting). Roidl et al. (2014) found that anxiety intensities affect driving behaviours like speed, speeding, and lateral acceleration. The same applies for **fright**. A further study (Kinnear et al., 2015) shows a weak correlation between frustration and overtaking intention (r=.16).

Modifying conditions

In theory, conditions that might modify effects on anger and aggressive driving could be personal factors (e.g. gender, age) and situational factors (e.g. behaviour of other road users and driving environment). Berdoulat (2013) found a significant gender effect for aggressive driving, emotional physical aggression, instrumental physical aggression and instrumental verbal aggression. Men scored significantly higher in all variables except aggressive driving (women scored higher).

Conclusion

General – The focus on this synopsis is on anger and aggression, as those turned out to be the best investigated emotion related constructs in road safety. However, there is some literature on other emotions available. These emotions – negative as well as positive ones – may also have an effect on road safety.

Main results – Research on emotional driving is not often linked to actual crashes, but reverts to self-reports or simulator studies. Studies generally show that drivers in emotional states have a (slightly) increased crash risk compared to drivers in neutral states. A meta-analysis (Nesbit et al., 2007) indicated a very small relationship between aggressive driving and motor vehicle accidents as well as anger and motor vehicle accidents. However, emotional driving, especially angry or aggressive driving, can be linked to several SPIs (e.g. speed/speeding, risk taking, or other traffic offences).

Biases and transferability – It appears that different methods can lead to different results. Nesbit et al. (2007) found that aggressive driving outcomes measured by a driving simulator were significantly smaller than those outcomes garnered by a self-report measure. Furthermore, numerous driving anger questionnaires exist (e.g. Driving Anger Scale (DAS), Driving Behaviour Index (DBI), Dula Dangerous Driving Index). Problematically, each of these scales measures anger or emotion in a slightly different way.

In driving simulator studies emotions are induced in different ways e.g. recall, film clips or critical events, which may lead to different outcomes. Additionally, it's questionable if drivers take as much risk in real traffic as they do in a driving simulation.

Most research has been conducted at universities with (often psychology-) students as participants, often with small samples. Therefore, results may not be generalizable. Due to the kind of study interests, studies with control groups (in the sense of "neutral" emotions) are rather rare. Research on emotion is mainly on car drivers and information on VRUs is missing.

3 Supporting Documents

3.1 LITERATURE SEARCH STRATEGY

A literature search was conducted in March 2016. It was carried out in two databases with separate search strategies. The first one was performed in 'Scopus' which is a large abstract and citation database of peer-reviewed literature. The second was conducted in a KFV-internal literature database ('DOK-DAT').

Database: Scopus **Date:** 22nd of March 2016

no.	search terms / logical operators / combined queries	hits
#1	"emotion*" OR "affect*" OR "feeling*" OR "sensation" OR "stress" OR "aggressi*" OR "anger" OR "panic" OR "fear" OR "distress" OR "nervous*" OR "time pressure" OR "hurried driving"	4,826,059
#2	"speed*" OR "overtak*" OR "lane chang*" OR "lane keep*" OR "headway distance" OR "road violation" OR "traffic rule" OR "aggressive driving" OR "age" OR "road violation" OR "traffic rule"	3,498,818
#3	"road casualties" OR "road fatalities" OR "traffic accident" OR "road crash"	45,558
#4	("road safety" OR "traffic safety") AND ("risk" OR "collision")	4,620
#5	#1 AND #2 AND #3	2,404
#6	#1 AND #2 AND #4	318
#7	#5 OR #6	**2,547**

Table 3: Used search terms, logical operators, and combined queries of literature search (Scopus).

Detailed search terms, as well as their linkage with logical operators and combined queries are shown in Table 3. Using search field titles, abstract and keywords (TITLE-ABS-KEY) and a general limitation to studies which were published from 1990 to present led to a large number of studies (Table 3).

Results were limited to "article" and "review" and in a further step to the languages 'English' and 'German'. The quantity of studies was further reduced by limiting source type to "Journal" as well as excluding various countries. As on study scope we only considered European and North American countries, as well as Russia. As a last reduction step we limited remaining studies to subject area "Engineering", "Social Science" and "Psychology". This led to a final sample of 551 studies from the literature search in the Scopus database.

Database: DOK-DAT **Date:** 18th of March 2016

search no.	search terms / operators / combined queries	hits
#1	"emotion*" OR "affect*" OR "feeling*" OR "sensation" OR "stress" OR "aggressi*" OR "anger" OR "panic" OR "fear" OR "distress" OR "nervous*" OR "time pressure" OR "hurried driving"	1,945
#2 (within #1)	Limit to year: 1990 to 2016	1,560
#3 (within #2)	"speed*" OR "overtak*" OR "lane chang*" OR "lane keep*" OR "headway distance" OR "road violation" OR "traffic rule" OR "aggressive driving" OR	173

	"age" OR "road violation" OR "traffic rule"	
#4 (within #3)	"road casualties" OR "road fatalities" OR "traffic accident" OR "road crash"	7
#5 (within #3)	("road safety" OR "traffic safety") AND ("collision" OR "crash")	1
#6	#4 OR #5	**8**

Table 4: Used search terms, logical operators, and combined queries of literature search (DOK-DAT).

(German) Search fields 'Titel', 'ITRD Schlagworte' and 'freie Schlagworte' were used. Hits were only limited to the years 1990 to 2016 and got eight more potential studies (Table 4).

Results Literature Search

Database	Hits
Scopus (remaining papers after several limitations/exclusions)	551
DOK-DAT	8
Recommended literature	11
Total number of studies to screen title/ abstract	**570**

Table 5: Results of literature search

In total, this literature search lead to 570 potential studies for screening.

Screening

Total number of studies to screen title/ abstract	570
-De-duplication	3
-exclusion criteria A (not or other topic)	517
-exclusion criteria B (emotion is not the risk factor)	10
Remaining studies	40
Not clear (full-text is needed)	40
Studies to obtain full-texts	**40**

Table 6: Number of studies to obtain full-texts

Eligibility

Total number of studies to screen full-text	40
Full-text could be obtained	-3
Reference list examined Y/N	partly
Eligible papers	37

Table 7: Number of studies to screen full-texts

Screening of the full texts

Total number of studies to screen full paper	37
Emotion is not the risk factor - excluded	7
Studies with no codeable data - excluded	4
Studies concerning measures - excluded	2
Full texts not screened due to limited time resources	7

Remaining studies	17
Number of studies dealing with "anger & aggression"	11
Number of studies dealing with other emotions	6

Table 8: Screening of full texts

Prioritizing Coding
- Prioritizing Step A (meta-analysis first)
- Prioritizing Step B (best fitting in coding scheme)
- Prioritizing Step C (published more recently)
- Prioritizing Step D (Central-European countries before others)

List of references resulting from search strategy (sorted by year of publication, meta-analysis first)

	Publication	Coded Y/N	Reason
1	Nesbit, S.M., Conger, J.C., & Conger, A.J. (2007). A quantitative review of the relationship between anger and aggressive driving. *Aggression and Violent Behavior, 12*, 156–176.	Y	Meta-analysis
2	Dingus, T.A., Guo, F., Lee S., Antin, J.F., Perez, M., Buchanan-King, M., & Hankey, J. (2016). Driver crash risk factors and prevalence evaluation using naturalistic driving data. *PNAS Early Edition, 113(10)*, 2636-2641. Retrieved from http://www.pnas.org/cgi/doi/10.1073/pnas.1513271113	Y	
3	Kinnear, N., Helman, S., Wallbank, C., & Grayson, G. (2015). An experimental study of factors associated with driver frustration and overtaking intentions. *Accident Analysis and Prevention, 79*, 221-230.	Y	
4	Jeon, M., Walker, B. N., & Yim, J.-B. (2014). Effects of specific emotions on judgment, driving performance, and perceived work load. *Transportations Research Part F, 24*, 197-209.	Y	
5	Roidl, E., Frehse, B., & Höger, R. (2014). Emotional states of drivers and the impact on speed, acceleration and traffic violations – A simulator study. *Accident Analysis and Prevention, 70*, 282-292.	Y	
6	Megías, A., Di Stasi, L.L., Maldonado, A., Catena, A., & Cándido, A. (2014). Emotion-laden stimuli influence our reactions to traffic lights. *Transportations Research Part F, 22*, 96-103.	Y	
7	Jallais, C., Gabaude, C., & Paire-ficout, L. (2014). When emotions disturb the localization of road elements: Effects of anger and sadness. *Transportation Research Part F, 23*, 125–132.	Y	
8	Stephens, A.N., & Sullman, M.J.M. (2014). Development of a short form of the driving anger expression inventory. *Accident Analysis and Prevention, 72*, 169-176.	N	emotion is not the risk factor
9	Conner, K.A., & Smith, G.A. (2014). The impact of aggressive driving-related injuries in Ohio, 2004-2009. *Journal of Safety Research, 51*, 23-31.	N	no codeable data
10	Kovácsová, N., Rošková, E., & Lajunen, T. (2014). Forgivingness, anger, and hostility in aggressive driving. *Accident Analysis and Prevention, 62*, 303-308.	N	fulltext not screened
11	Berdoulat, E., Vavassori, D., & Sastre M.T. (2013). Driving anger, emotional and	Y	

	Publication	Coded Y/N	Reason
	instrumental aggressiveness, and impulsiveness in the prediction of aggressive and transgressive driving. *Accident Analysis and Prevention, 50*, 758-767.		
12	Beck, K.H., Daughters, S.B., & Ali, B. (2013). Hurried driving: Relationship to distress tolerance, driver anger, aggressive and risky driving in college students. *Accident Analysis and Prevention, 51*, 51-55.	Y	
13	Roidl, E., Siebert, F.W., Oehl, M., & Höger, R. (2013). Introducing a multivariate model for predicting driving performance: the role of driving anger and personal characteristics. *Journal of Safety Research, 47*, 47-56.	Y	
14	Coeugnet, S., Naveteur, J., Antoine, P., & Anceaux, F. (2013). Time pressure and driving: Work, emotions and risks. *Transportations Research Part F*, 20, 39-51.	Y	
15	Tapp, A., Pressley, A., Baugh, M., & White, P. (2013). Wheels, skills and thrills: A social marketing trial to reduce aggressive driving from young men in deprived areas. *Accident Analysis and Prevention, 58*, 148-157.	N	emotion is not the risk factor
16	Schmidt-Daffy, M. (2013). Fear and anxiety while driving: differential impact of task demands, speed and motivation. *Transportation Research Part F, 16*, 14-28.	N	emotion is not the risk factor
17	Stephens, A.N., Trawley, S.L., Madigan, R., & Groeger, J.A. (2013). Drivers display anger-congruent attention to potential traffic hazards. *Applied Cognitive Psychology, 27*, 178-189.	N	fulltext not screened
18	Roidl, E., Frehse, B., Oehl, M., & Höger, R. (2013). The emotional spectrum in traffic situations: Results of two online-studies. *Transportation Research Part F, 18*, 168-188.	N	emotion is not the risk factor
19	Sullman, M.J.M., Stephens, A.N., & Kuzu D. (2013). The expression of anger amongst Turkish taxi drivers. *Accident Analysis and Prevention, 56*, 42-50.	N	fulltext not screened, Prioritizing Step D
20	Delhomme, P., Chaurand, N., & Paran, F. (2012). Personality predictors of speeding in young drivers: Anger vs. sensation seeking. *Transportations Research Part F, 15*, 654–666.	Y	
21	Abdu, R., Shinar, D., & Meiran, N. (2012). Situational (state) anger and driving. *Transportation Research Part F, 15 (5)*, 575–580.	Y	
22	Lambert-Bélanger, A., Dubois, S., Weaver, B., Mullen, N., & Bédard, M. (2012). Aggressive driving behaviour in young drivers (aged 16 through 25) involved in fatal crashes. *Journal of Safety Research, 43*, 5-6.	N	emotion is not the risk factor
23	Trick, E., Brandigapola, S., & Enns, J. (2012). How fleeting emotions affect hazard perception and steering while driving: the impact of image arousal and valence. *Accident Analysis and Prevention, 45*, 222-229.	N	no codable data
24	Scott-Parker, B., Watson, B., King, M.J., & Hyde, M.K. (2012).The influence of sensitivity to reward and punishment, propensity for sensation seeking, depression, and anxiety on the risky behaviour of novice drivers: A path model. *British Journal of Psychology, 103*, 248-267.	N	fulltext not screened, emotion as risk maybe only marginally investigated
25	Dula, C.S., Adams, C.L., Miesner, M.T., & Leonard, R.L. (2010). Examining relationships between anxiety and dangerous driving. *Accident Analysis & Prevention, 42*, 2050–2056.	Y	

	Publication	Coded Y/N	Reason
26	Paleti, R.; Eluru, N., & Bhat, C.R. (2010). Examining the influence of aggressive driving behavior on driver injury severity in traffic crashes. *Accident Analysis and Prevention*, *42*, 1839-1854.	N	no codable data
27	Özkan, T., Lajunen, T., Parker, D., Sümer, N., & Summala, H. (2010). Symmetric relationship between self and others in aggressive driving across gender and countries. *Traffic Injury Prevention*, *11*, 228-239.	N	fulltext not screened, emotion as risk maybe only marginally investigated
28	AAA Foundation for Traffic Safety. (2009). Aggressive Driving: Research Update. AAA Foundation for Traffic Safety. Retrieved from https://www.aaafoundation.org/sites/default/files/AggressiveDrivingResearchUpdate2009.pdf	N	no codable data
29	Björklund, G.M. (2008). Driver irritation and aggressive behaviour. *Accident Analysis and Prevention*, *40*, 1069-1077.	N	fulltext not screened
30	Mesken, J., Hagenzieker, M.P., Rothengatter T., & de Waard, D. (2007). Frequency, determinants, and consequences of different drivers' emotions: An on-the-road study using self-reports, (observed) behaviour, and physiology. *Transportation Research Part F*, *10* (6), 458–475.	Y	
31	Asbridge, M., Smart, R.G., & Mann, R.E. (2006). Can we prevent road rage? *Trauma, Violence, and Abuse*, *7*, 109-121.	N	concerns measures
32	Beck, K.H., Wang, M.Q., & Mitchell, M.M. (2006). Concerns, dispositions and behaviors of aggressive drivers: What do self-identified aggressive drivers believe about traffic safety? *Journal of Safety Research*, *37*, 159-165.	N	emotion is not the risk factor
33	Dula, C.S., & Geller, E.S. (2003). Risky, aggressive, or emotional driving: Addressing the need for consistent communication in research. *Journal of Safety Research*, *34*, 559-566.	N	emotion is not the risk factor
34	Chliaoutakis, J.E., Demakakosb, P. Tzamaloukaa, G., Bakoub, V., Koumakib, M., & Darviribь, C. (2002). Aggressive behavior while driving as predictor of self-reported car crashes. *Journal of Safety Research*, *33*, 431–443.	Y	
35	Johnson, K. (2000). Aggressive Driving: One City's Solution. *Traffic Safety*, *4*, 17-19. National Safety Council.	N	concerns measures
36	Simon, F., & Corbett, C. (1996). Road traffic offending, stress, age, and accident history among male and female drivers. *Ergonomics*, 39 (5), 757-780.	Y	
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Table 9: List of references resulting from search strategy

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