Driver training in a simulator. Improved hazard perception.

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Driver training in a simulator

Improved hazard perception

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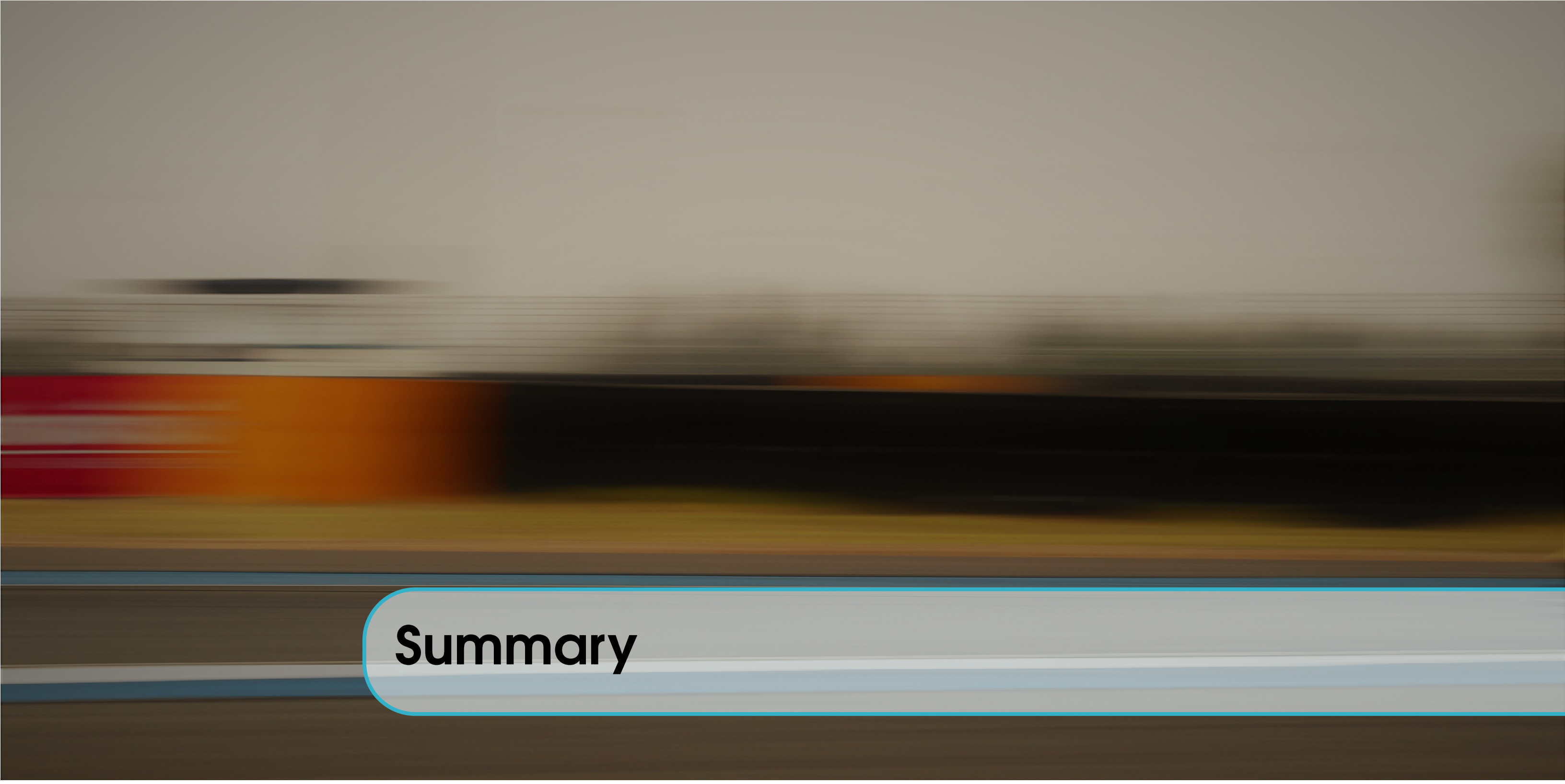


Summary

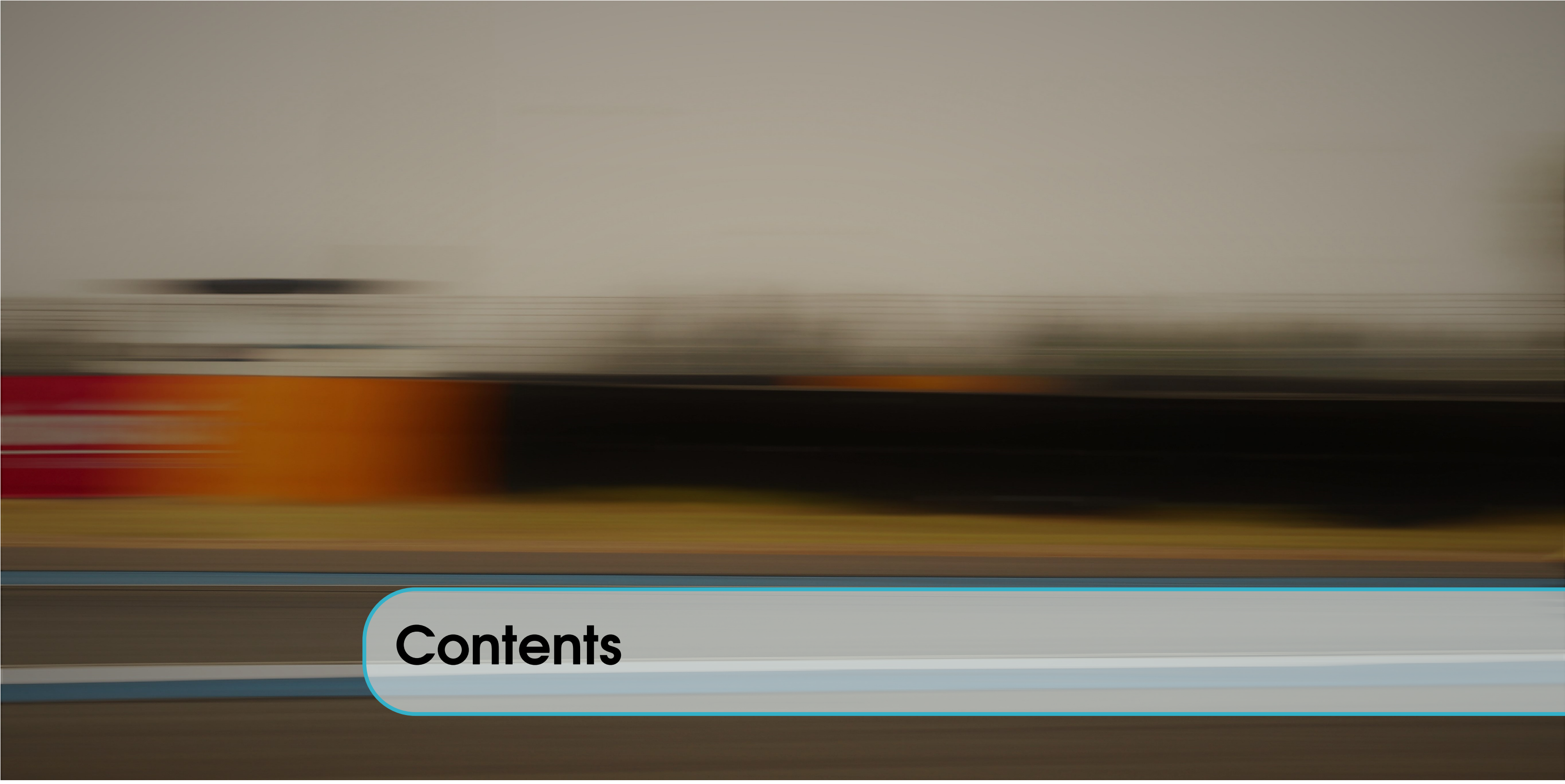
This is an exhaustive report on the use of simulators in driver training in Denmark and a description of an effective hazard perception skill training procedure by the use of a simulator preformed at the Technical University of Denmark (DTU) with financial support by TrygFonden. Improving road safety among young drivers is an efficient way to improve road safety due to the large over-representation of young drivers in road traffic accidents. Therefore, the development of new methods to improve driving skills among young drivers is highly relevant.

Research shows that a lack of hazard perception skills (HPS) is a central element in the high risk among young drivers, and driving experience is a key factor for the acquisition of HPS. A driving simulator offers the possibility to train driving experience in a safe environment.

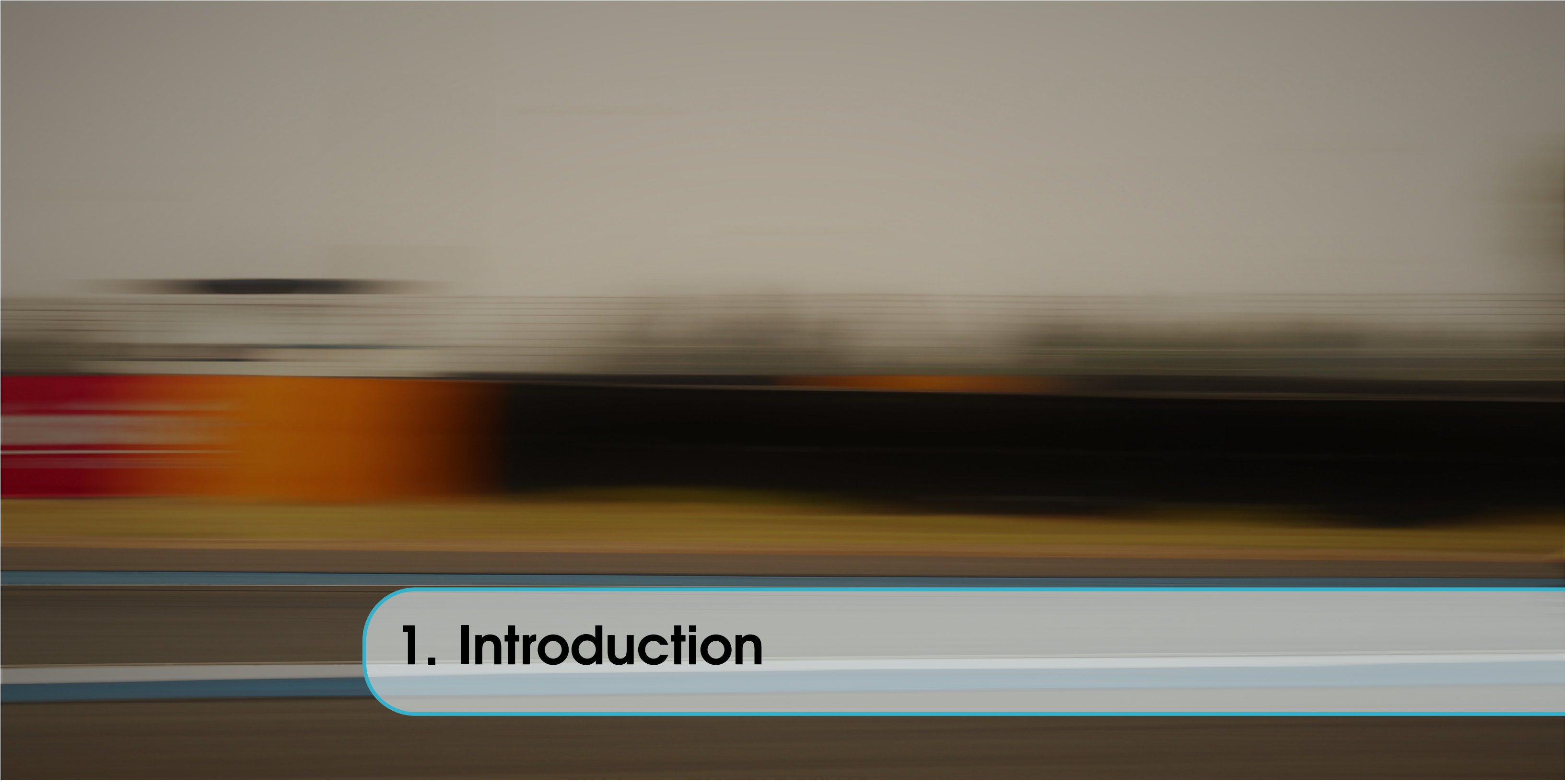
This report presents studies aimed to map driving simulator use for driver training in Denmark and to develop a training to improve young drivers' HPS in the driving simulator. Mapping the use of a driving simulator for driver training purposes shows that driving simulators are not widely used in Demark. However, instructors and driving coaches from institutions that have experience in driver training stated many advantages for simulator use. In Denmark, driving simulators are mainly used for regular driver training and teaching basic driving skills, such as starting and manoeuvring a vehicle in different traffic situations. The use of simulator training of higher-order skills, such as HPS, is neglected.

Prior to development of the training for young drivers, a preparatory experiment was carried out. The results indicated the need for training focusing not only on the detection, but also on an adequate response to hidden pedestrian-related potential hazards that demand more advanced HPS. Based on the results, the training procedure was developed, consisting of a training drive, a video with an expert commentary and a replay of the training drive. The training aimed to improve young drivers' hazard detection and response in pedestrian-related potential hazard situations. The results demonstrated that the training had a beneficial effect on improved tactical

HPS, particularly in relation to more challenging, hidden pedestrian-related potential hazards. Improvement in advanced HPS suggests that it is relevant to consider ways to include similar training procedures in basic driver training to support the development of more advanced HPS among newly licensed drivers. This type of training program in the driving simulator, further improved, could be considered as an additional tool to improve the driver learning curriculum in addition to the traditional means of driver training.



Contents



1. Introduction

Improving road safety among young and newly licensed drivers is an efficient way to improve overall road safety due to the large over-representation of young drivers and the greater risk of being involved in an accident in the first three years after licensing (e.g. Foss et al., 2011). While age- and exposure-related factors play a role (e.g. Arnett, 1996; González-Sánchez et al., 2017; Jonah, 1986), low hazard perception skills (HPS) are identified as one of the main risk factors associated with the occurrence of accidents among young drivers (e.g. Fisher et al., 2006; McKnight and McKnight, 2003). Driving experience is a key factor for the acquisition of HPS.

Technological development has a beneficial effect on road safety in many ways, including the development of new driver testing and training methods. Traditionally, new drivers learn to drive in a car on the road; however, optimisation of the learning process may benefit from the use of other available training methods and tools, such as driving simulators. A driving simulator offers the possibility to gain driving experience in a safe environment with no injury risk for the driver and other road users. A few Danish driver training institutions include driving in a simulator as part of the driver training. However, no systematic evaluation or mapping of this effort is available. Moreover, a driving simulator holds the potential to be a useful tool to increase road safety based on increased HPS among young drivers. However, evidence is needed to verify this potential.

1.1 Aim

The aim of this report is twofold. The first aim is to map the use of simulators for training purpose in driving training institutions in Denmark. The second aim is to determine if hazard perception training in a driving simulator can be used to improve hazard perception skills among young drivers particularly in pedestrian-related situations.

1.2 Driving simulator types

To date, driving simulators are typically used for entertainment, research and training. Depending on the use, driving simulators differ in their physical fidelity. Physical fidelity regards the degree to which the simulator imitates the physical properties of the driving situation, and it often contributes with a starting point of providing behavioural fidelity (the degree to which behaviour in the simulator matches behaviour on the road). Distinctions can be made among low-level, mid-level, and high-level physical fidelity driving simulators (Kaptein et al., 1996):

- Low-level fidelity simulators.
  These typically consist of one PC, one screen and a steering wheel. Low-level physical fidelity driving simulators are cheaper than other simulators and they are usually portable; therefore, they are more feasible for driver training and entertainment.
- Mid-level fidelity simulators.
  These typically include advanced imaging techniques, a large projection screen or multiple screens providing a wider angle view than one screen, all necessary vehicle controls, and possibly a simple motion base. Mid-level physical fidelity simulators are more expensive than low-level simulators and are typically used for research purposes.
- High-level fidelity simulators.
  These typically consist of screens providing close to a 360° field of view, a complete car mock-up and an extensive moving base. High-level physical fidelity driving simulators are quite expensive to purchase and operate, and are therefore relatively rarely used for research.

Different views exist on fidelity requirements for driving simulators. A contributing factor to the discussion is that the simulator might provide the information needed for one task but not another. Consequently, a driving simulator may be a high-level physical fidelity simulator for one set of tasks and only a mid-level physical fidelity simulator for other tasks. For example, a driving simulator with high resolution and a narrow field of view might render and present road signs very accurately and would be a high-level physical fidelity driving simulator for driving that involved sign reading. In contrast, this same simulator might be a low-level physical fidelity driving simulator for driving that involves 90° turns because it does not provide a preview of the side road. Choosing the appropriate level of simulator physical fidelity to address a particular issue represents a critical challenge (Lee et al., 2013).

1.3 Driving simulator as a training tool

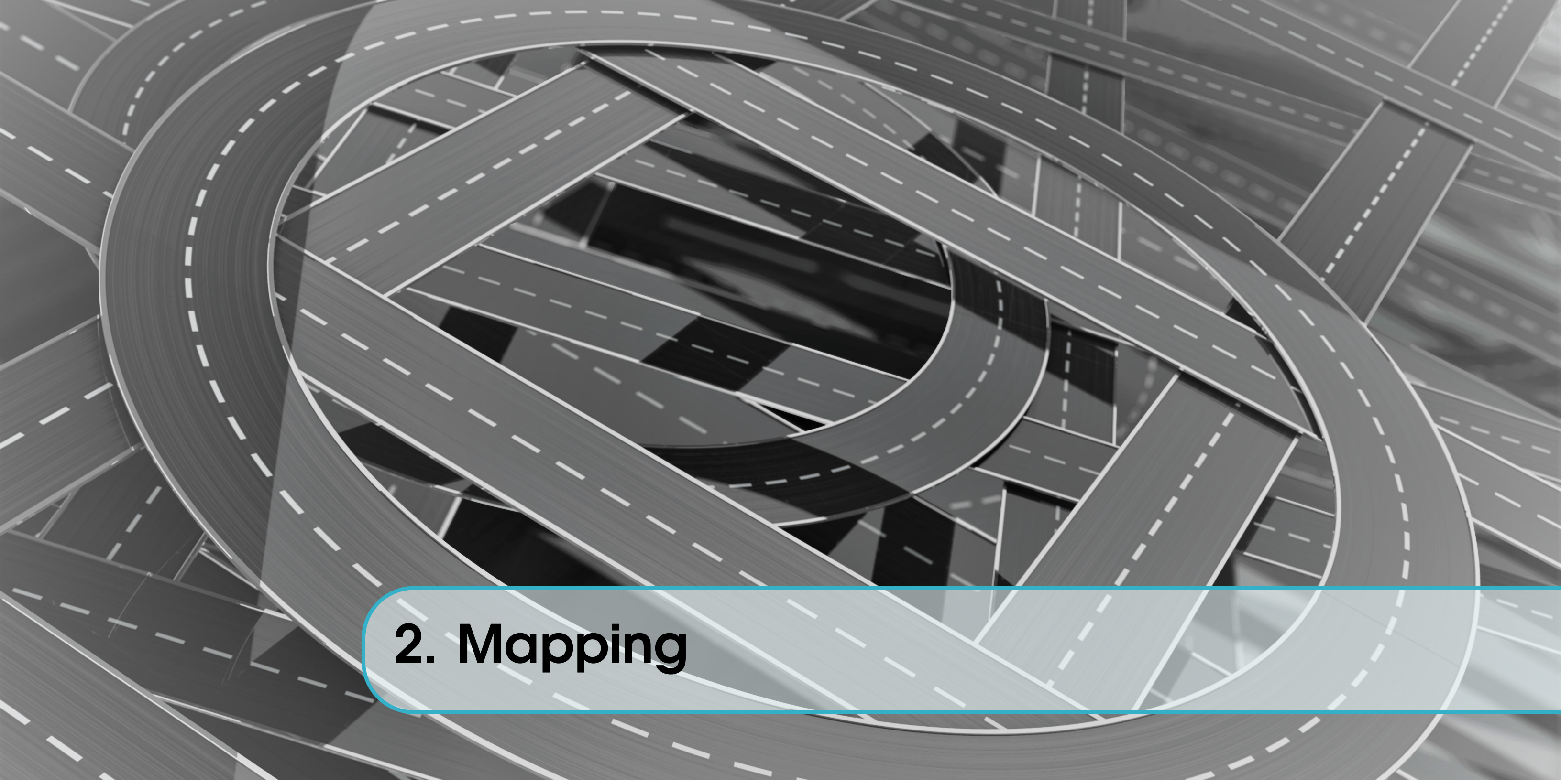
The very first transport-related training simulator was made for air force pilots training at the beginning of the twentieth century (Bouchner, 2016). As training in real planes meant higher training costs and a high danger rate for novice pilots, the simulator considerably improved pilot training. After a successful launch of pilot training simulators, other vehicle simulators were rapidly developed. Car driving simulators have become the most common. Moreover, due to the development of powerful computer systems at a reduced cost, the use of driving simulators for both training and research purposes in the field of driving behaviour has spread widely in recent decades. Simulators are increasingly used now in driver education programmes around the world: for example, in the Netherlands, more than 150 simulators are in operation in driving schools (SWOV, 2010).

A driving simulator is shown to be an efficient tool to learn basic skills, like vehicle operation, steering, manoeuvring and interaction with other traffic (OECD, 2006). To master the basic skills, learner drivers do not need all the complexity of the real driving environment, but can learn well in a simulated setting. With virtual traffic in a detailed road environment, the currently used low-, mid- and high-level physical fidelity driving simulators can offer such an environment, providing virtual instruction and feedback.

Furthermore, an increasing amount of research shows that driving simulators are valuable for learning higher order skills that require more experience, such as hazard perception skills and attention maintenance (e.g. Falkmer and Gregersen, 2003; Wang et al., 2010b). The virtual world in a simulator provides a safe environment for drivers to interact and receive feedback if an error in detecting or responding to a hazard occurs. This is essential for training the higher-order hazard perception skills and is difficult and dangerous to establish in real traffic (e.g. Keith and Frese, 2008). Additionally, by committing errors, learner drivers gain knowledge of their limitations; therefore, the experience of errors facilitates proper self-assessment of skills. Driving in a driving simulator can provide exposure to hazard situations that can show the benefits of safety practices, motivating learners to drive more safely (Mayhew and Simpson, 2002).

1.4 Outline of the report

The report consists of two parts. The first part focuses on the use of a driving simulator as a part of driver training in Denmark. The second part of the report includes an experimental study with a focus on the possibility of using a driving simulator as a tool to increase HPS among young drivers. Conclusions of the report are described in the closing chapter.



2. Mapping

This chapter describes the results of mapping the use of driving simulator for driving training in Denmark. First, the method for collecting data is described; then the results are presented. Finally, results are discussed.

2.1 Method

Mapping of the use of driving simulators for training in Denmark is based on telephone based interviews, last updated in November 2017. For the purposes of this study, those institutions that have experience in using a driving simulator for driver training are divided into three categories.

- Driving schools
  Institutions where students receive education and training to obtain a driver's licence for personal cars (B). For the purpose of this report, driving instructors from driving schools were interviewed.
- Professional driver training centres
  Institutions where professional drivers (trucks, emergency vehicles, taxis, buses) receive additional training to improve their driving skills. We interviewed driving instructors who train these drivers.
- Motorsport driver training centres
  Institutions where motorsport drivers receive training to improve their skills. We interviewed motorsport coaches who use driving simulators for training.

Representatives (driving instructors or coaches) of all three types of institution were interviewed by telephone to collect information about their experience of using a driving simulator for training. Institutions in which the simulator is used were identified by an extensive internet-based search and chain referral sampling.

The interview contained questions about simulator use for driver training, motivation behind trying such a training method, and the pros and cons of using a driving simulator for novice, professional and motorsport driver training. The complete list of questions is included in Appendix A.

Driving instructors from six driving schools, coaches from two motorsport driving centres, and driving instructors from three professional driver training centres were interviewed. In these institutions, the conventional driver training is (or was previously) supplemented by training in a driving simulator.

2.2 Results

A total of eleven institutions with experience in the use of a driving simulator for driver training were identified. Based on the interviews, information was collected about the driving simulator, simulator users, training procedure, and personal feedback on simulator use for driver training. It is summarised in the next section.

2.2.1 Motives for driving simulator use

The interviews revealed small differences between the institutions regarding the motives underlying the use of a driving simulator.

The driving instructors in the driving schools stated various motives for choosing to use a driving simulator for driver training. The use of simulators for air pilot training inspired one of the instructors; others wanted to be different and attract new students to the school, while one saw the driving simulator as a beneficial tool for protecting the learning vehicle from wear and tear. However, the basic motive for all of them was to make the learning process easier, faster and more relaxed for students who had problems with starting to drive in real traffic. Driving simulator training is mostly used to teach basic vehicle handling skills: starting the vehicle, use of pedals, gear shifting, parking and overtaking. Based on the interviews, it is specifically useful for people who have problems performing several movements at the same time. Additionally, the students can be exposed to different weather conditions, road environments and night driving to gain more experience with these situations.

In relation to motorsport driver training, use of the driving simulator was motivated by the possibility of creating optimal training possibilities. For motorsport drivers, due to the increased noise and limitations of how many hours one is allowed to work in these conditions, it is not possible to acquire enough training in real racing cars. Driving in real racing cars is also expensive because of the wear of the vehicle. Furthermore, mental coaching is easier when the coach can stand right next to the driver and observe what happens. In the simulator, the coach can also just stop the training and talk to the student about a specific problem or mistake. Additionally, training in the simulator can be used independently of weather conditions, such as in winter.

The main reason for introducing simulator training for professional drivers is that it is very efficient. For professional driver training, or labour market education[1] (AMU), use of the driving simulator was motivated by the possibility of developing a training programme that focused on specific skills and competences. Thus, courses were developed to improve professional driver skills in manoeuvring and knowledge of defensive and energy-efficient driving in a safe and

[1] In Danish, Arbejdsmarkedsuddannelser

controlled setting. Defensive driving contains a set of driving skills that allow a driver to prevent possible accidents caused by other drivers or poor weather (e.g. being able to control speed, being alert and avoiding distractions, being aware of driving in special road and weather conditions).

2.2.2 The driving simulators

In the driving schools, the driving simulators were bought between 2011 and 2015. The simulators are low-level or mid-level physical fidelity simulators that are equipped with a driving seat and basic vehicle controls, such as a steering wheel, a gear stick and pedals. Driving scenarios are presented on one or three screens. Low-level physical fidelity simulators have a screen in front of a real car seat, and the simulator has a steering wheel, pedals and clutch. The more advanced, mid-level physical fidelity simulator is custom-made, consisting of three computer screens, a racer seat, pedals and a steering wheel. The instructor, who constructed the simulator himself, pointed out that building his own simulator decreased its cost significantly.

For motorsport driver training, more advanced mid-level physical fidelity simulators are used. In one of the centres, the coach built the simulator himself. The simulator has three screens, a steering wheel, pedals and various clutch systems. It is possible to exchange most parts, so he can fit the simulator to the car of the individual student to provide the best training experience. The simulator is continually updated and improved. In the other centre, the simulator consists of a full car mock-up and has all necessary controls. Additionally, there are four low-level physical fidelity simulators in the centre.

The institutions using a driving simulator for professional driver training purchased their simulators between 2011 and 2013. For the training of professional drivers, high- and low-level physical fidelity simulators are used. High-level fidelity simulators are equipped with a full size cabin and have all the same controls as a real truck. In these simulators, around the vehicle cabin, three large screens provide a 180° field of view. Additionally, there are screens behind the mirrors for a more realistic driving setting. The simulator has a great advantage in that it can simulate driving with many different types of vehicle, including a lorry, semitrailer, trailer, emergency vehicle and bus. The high-level fidelity simulators are mobile; therefore the training can take place in any convenient location (e.g. in the building of the company that has ordered the training course). The low-level fidelity simulators are used for taxi driver training. The software in the simulators is updated according to the different course—e.g. a course for truck drivers who mainly drive in mountains.

2.2.3 Simulator users

From the interviews, it became clear that students of all ages and genders use the simulator in driving schools. In general, most of the students in the driving schools are young (up to 19 years old), so they are the main users of the driving simulator. According to the driving instructors, male students use the simulator more as they are generally more interested in the technology and find the simulator more attractive than female students. In the driving schools, where simulator use is encouraged among students with difficulties learning basic driving skills (e.g. turning on the engine, changing gear, fear of driving on the road), it is mainly women and people who take their driving test at an older age who use the simulator. Based on the answers provided by driving instructors, many older students think that it is difficult to learn how to drive a car and feel much safer in the simulator, and therefore take driving in the simulator more seriously than younger students.

Motorsport drivers with various levels of experience and ages practice in the simulator. Members of various motorsport centres use the simulator during the winter. Additionally, the club sponsors and members occasionally drive in the simulator for fun. In one of the centres, about 100 students have trained in the simulator over the last five years. Approximately 10–25 per cent of students enrol on a longer course with the coach, but the majority of students have only one lesson.

Professional drivers have already acquired the basic driving ability and take the training to master specific skills. The simulators are used by companies that want their truck, emergency vehicle, taxi and bus drivers to master energy saving and defensive driving. Driving instructors stated that older professional drivers have a resistance towards modern technologies and are sceptical about the possible benefits of simulator training.

2.2.4 Training procedure in the Danish institutions

Various training programmes and methods are used in the simulator among driving schools. The driving schools use training scenarios designed specifically for a purpose or scenario in the form of a racing computer game. In addition, training instruction and feedback on performance are provided by various means.

- Only by the driving instructor
  No feedback is provided by the simulator software, but the instructor interrupts the driving session if a mistake is made and discusses it with the student.
- Only by the driving simulator
  An instructor is not present during the training sessions and students receive feedback only from the simulator in a form of audio instructions.
- By combining simulator and instructor feedback
  Training scenarios that are played in the simulator have an English instruction audio and Danish subtitles providing feedback after each driving session. However, there is always an instructor sitting next to the student. The student receives feedback about mistakes from the simulator and the instructor can add to the feedback with additional instructions if needed. If students do not master the task in the session at the first attempt, they have to repeat the session.

Training lessons in the simulator are mandatory or voluntary, depending on the driving school. In the school where it is mandatory to use the simulator during training, it is seen as an addition to theory training before driving on the road. Students have to participate in at least two driving simulator lessons before entering an initial manoeuvre track. In addition, selected students (every twentieth) have extra lessons in the driving simulator once a week throughout the education period. The driving instructor has decided this training procedure. Additionally, students are encouraged to complete the training scenarios available on the simulator before each theoretical lesson. In other driving schools where training in the simulator is not mandatory, if the students had trouble during the first driving lesson and on the manoeuvre track, they are advised to use the simulator and have a training session in the simulator before starting on-road driver training. Use of a driving simulator is free of charge for students of the driving school. Students from other driving schools also can book and use the simulator, but then there is a fee, because the presence of a person who can instruct them on how to use the simulator is required.

Motorsport driver simulators have software that contains racetracks from all over the world. Training on a specific racetrack is used when the motorsport driver is going to drive in a race on an unknown track, so they can get used to it. The motorsport driver can also drive on a standard track if they wish to work on bad habits or optimise their driving. Additionally, it is possible to learn from accidents by reconstructing the situation where a student had an accident in real life. In this way, the driver can try driving again in the same situation and get feedback on their errors. During the drives, the simulator gathers data. Thereafter, a mechanical engineer can also analyse and discuss the data with the driver. The simulators used for motorsport driver training do not provide any direct instruction. A coach is always next to the student to give them instructions and talk to them about their performance. Sometimes the coach provides instructions and feedback when the driving session is finished, and sometimes the coach stops the simulator as soon the student makes a mistake and provides feedback immediately. Motorsport drivers can sign up for single sessions or have longer courses in the simulator.

For professional driver training, AMU courses using a driving simulator used to be offered. The courses are no longer available and can be organised only for companies with an interest in improving their drivers' skills and performance. The courses were designed with a focus on learning energy-efficient driving, defensive driving and improving manoeuvring. Usually it was a mix of simulator training, interactive programs and classroom teaching to cover the curriculum. Typically, during the simulator drive, the students experienced a wide variety of everyday driving situations. Drivers had to drive in heavy city traffic, on roundabouts and on the highway. They experienced driving in diverse weather conditions (e.g. rain, snow, fog) that changes the friction of the tyres and unexpected situations (e.g. bicycle-related events and distracted driving). The situations can be adjusted to meet the needs of a company ordering the course. For example, emergency vehicle drivers in Copenhagen can practise emergency driving in heavy traffic. Alternatively, for driving in the Alps, the course and the simulator situations are designed to represent situations typical of a hilly environment with steep slopes and limited angles of visibility. Additionally, the drivers are exposed to unexpected situations to surprise the drivers when they are inattentive. This way, drivers are trained in defensive driving, to keep a safe distance, observe the environment more carefully and be more attentive to cyclists.

2.2.5 Driving instructors' and coaches' feedback on the use of a driving simulator

The driving instructors and motorsport coaches were asked to share their personal reflections on simulator use in driver training, because no official statistics or evaluation of the benefits of driving simulator training are available. The instructors from the driving schools and professional driver training centres believe that the students need less on-road driver training when also using a driving simulator as part of their training. Moreover, they think that students who care about becoming good drivers and become interested in training in the simulator will be better drivers because they have experienced a wider range of difficult situations that are rarely met during regular on-road training.

Conversely, some instructors reported that there are students who finish all the driving simulator training scenarios but do not pass the practical driving test. In one of the driving schools, the instructor experiences resistance towards simulator training among different ethnic groups, even though the instructor contends that these students struggle the most to learn the combination of movements to start to drive. According to the instructors, training in a simulator is considered the cheapest and easiest way for these students to learn. Some instructors are very satisfied with the experience of using a driving simulator, whereas the experience disappoints others.

As the main benefit of simulator use, the motorsport coaches singled out the ability to practise on racetracks all over the world, thus cutting the travel and training expenses for preparation for participation in races. Additionally, racing car mechanics and engineers use the data gathered by the simulator to adjust the driver's actual car to the driver's specific driving style.

According to the professional driver training instructors, one day simulator course is equivalent to a three-day course in the classroom and on the road, and even then, drivers are not exposed to the same number of different situations and have limited opportunity to practise the theoretical knowledge gained compared to driving in the simulator. Instructors think that it is much easier and more efficient to train in the simulator than on the real road, and that drivers save around 5–8 per cent on gas after they have learned energy friendly driving during a course in the simulator. After simulator training, professional drivers become better at their job, given that they take the simulator practice seriously. Instructors believe that simulator training for professional drivers is a good way to remind them that it is necessary to drive defensively and be attentive, and to provide them with new knowledge on how to do their job better. In the high-level physical fidelity simulator, drivers are exposed to reasonably realistic driving. However, an advantage of the low-level fidelity simulator is that students usually do not experience motion sickness, which is sometimes the case when driving in the high-level fidelity simulator. Therefore, the students can use the low-level fidelity simulator for longer driving sessions.

Based on their experiences with the use of a driving simulator, the driving instructors and coaches stated several advantages and disadvantages for training purposes. These are listed below.

Advantages

Training elements

- It is easier to teach the motor movements of starting the car.
- The simulator provides a safe and comfortable practice setting where mistakes do not have any physical and monetary consequences. This is important for students who are afraid and anxious about driving.
- Students can easily experience driving in different road environments—for example, in a city and on a highway. This is mostly beneficial for students who live in a small town where it can be easy to acquire the licence without experiencing driving in heavy traffic.
- Training in the simulator allows the student to be exposed to different difficult and hazardous situations that cannot be guaranteed to be met on the road and gives the student confidence that he/she is able to handle them. The simulator provides the possibility to experience driving on a slippery road, in fog, rain and similar challenging weather conditions. Additionally, students can experience the consequences of distracted driving and being inattentive in a safe setting.

- It is easy to control driving situations, and instructors know exactly what the students are going to be exposed to.
- There is unlimited repetition of educational moments.
- There is the possibility to continue training during the winter when racing tracks are closed.
- There is the possibility to train on different tracks from all over the world without travelling.

Interaction with the student

- It is possible to stop/turn off/pause the simulator if there are important things to talk about.
- It is possible for the instructor to explain things slowly and thoroughly in the simulated traffic. When driving in real traffic, sometimes the student can be under pressure and if the student makes a mistake, the driving instructor has to react quickly—for example, brake hard—and sometimes the tone of the voice is therefore less friendly.
- It is a good way to get to know the student as there is not as much time pressure as in real traffic.
- It is beneficial for other drivers that are often not happy about driving amongst learner drivers as they slow down the traffic flow.

Sustainability

- The training vehicle is not exposed to dangerous situations and wear of the clutch because the training vehicle is not used as often. Therefore, later in the process of learning how to drive, the training vehicles maintain their standard for a longer period.
- It is environmentally friendly. There is less CO_2 emission when the simulator is used compared to on-road driving.

Disadvantages

Physical fidelity of a simulator

- A driving simulator does not provide a realistic sense of speed and motion.
- A driving simulator is not visually authentic.
- Some drivers experience motion sickness and dizziness in a high-level fidelity simulator.

Training elements

- In some cases, it is not possible for a student to use it independently.
- The simulator training program is not linked to the theoretical driving education. It would be better if training lessons in the simulator followed the theme of the theoretical lesson.
- Older students have resistance towards modern technologies and are sceptical about the possible benefits of simulator training.

Economic aspects

- A driving simulator is expensive.
- Promoting driving simulator use is not financially profitable for driving instructors, because drivers who are getting training on the simulator need fewer on-road driving lessons.
- It is not financially profitable for the student, as the minimum on-road driving lessons may not be replaced by simulator lessons.

2.3 Discussion of the use of driving simulators in driving training

Mapping the use of a driving simulator for driver training purposes in Denmark shows that driving simulators are not widely used. According to instructors, this is mainly because of the high costs involved in operating the simulator. However, instructors, in line with studies (e.g. Kappé and van Emmerik, 2005), acknowledge that when considering the benefits of the ability to easily manipulate and control scenarios in a simulator, providing exposure to the same set of situations in a limited time span, training in a simulator can be cheaper than training on the road.

The results of the mapping show that driving simulators in Denmark for regular driving training, like in the Netherlands (SWOV, 2010), are mainly used to teach basic driving skills, such as starting and manoeuvring the vehicle in different traffic situations.

In line with studies (e.g. de Winter et al., 2009), driving instructors and coaches stated more advantages than disadvantages of using the driving simulator for driver training. Results show that the instructors' and coaches' satisfaction with their simulator use experience depends on the simulator's physical fidelity and the reliability of the software that provides visuals and scenarios.

As a disadvantage, some driving instructors reported that despite completing all training scenarios, some drivers did not pass the practical driving test. The reason might be that the practical driving test depends highly on the student's level of anxiety, and anxious students use the simulator the most but perform worse when driving on the road (e.g. Fairclough et al., 2006).

In relation to professional driver training, there are no official statistics available in Denmark, but according to a professional driver training instructor, it is estimated that drivers save around 5–8 per cent on gas after they have learned energy-friendly driving on a simulator course. Indeed, on-road studies have shown a significant reduction in fuel consumption after such training among trained drivers (e.g. Strayer and Drews, 2003). Additionally, research shows that training in a high-level fidelity truck driving simulator is favourable for training manoeuvres, suggesting that it can be used for more than two thirds of the training, and that it is twice as time-efficient as a real vehicle (Flipo, 2000; Seecharan et al., 2016; Uhr et al., 2003).

In addition to training, high-level fidelity simulators in professional training centres could be used to ease the pre-hire screening process and target training for professional drivers. Simulation minimises the risks and costs associated with screening and retraining drivers, as these processes occur in a safe and controlled environment.

To gain the benefits of simulator use for driver training, a comprehensive method should be developed that can be easily used in all driving schools and training centres that have a simulator. Moreover, due to rapid advancements in technology, simulators will become much cheaper and thus available for more schools if the advantages of their use are promoted. To best address overall training requirements, simulators need to be integrated into the total learning framework, which involves several training methods, tools and strategies (Salas et al., 2006).

3. Hazard perception skill training

In this chapter, the development of a short Hazard perception skill (HPS) training in a fixed-based driver simulator is described and evaluated. This chapter describes the background, method, tools and measures, and presents the results of the HPS training experiment.

3.1 Background

HPS training is crucial because HPS are essential to safe driving. HPS in relation to detecting pedestrians is especially important because more than 400 pedestrians are injured and killed in road traffic accidents in Denmark, every year (Statistics Denmark, 2017) and pedestrian accident injuries continue to be a serious road safety problem. All pedestrians face specific road safety problems. Firstly, pedestrians lack physical protection; therefore, they are unshielded from the speed and mass of the vehicle involved in the accident (e.g. Wegman et al., 2006). Secondly, pedestrians are small compared to vehicles, and so it is easier to overlook them in the road environment (e.g. Langham and Moberly, 2003). Thirdly, the varying levels of pedestrian knowledge and compliance with traffic rules make their behaviour less predictable to car drivers (e.g. Granié, 2007; West et al., 1993). Fourthly, unlike vehicle drivers, pedestrians can cross a road not only at intersections and marked locations, but also at any other convenient location (e.g. Hill, 1984). Lastly, pedestrians are usually located on the side of the road and not in front of the driver; therefore, a wide horizontal angle of view is needed (Shahar et al., 2010). Based on these differences, it is important to examine pedestrian-related accident situations separately from those involving other road users.

The results of mapping the use of a driving simulator as part of driver training show that, in Denmark, driving simulators are mainly used to teach basic driving skills such as starting and manoeuvring a vehicle in different traffic situations. However, a number of studies show that simulators can also be used to improve HPS (Allen et al., 2011; Carpentier et al., 2013; Wang et al., 2010a,b). To our knowledge, no simulator-based training programme to enhance HPS specifically in pedestrian-related situations has been developed. However, as the skills needed to identify a pedestrian as a potential hazard differ in a number of ways from the skills needed to identify an approaching motor vehicle as a potential hazard, developing such a training programme is relevant.

Lack of HPS is suggested the key skills gap between novice and experienced drivers (Horswill et al., 2004). Although young drivers acquire basic vehicle handling skills rather fast (Deery, 1999), to master higher order skills, such as HPS, requires experience and exposure to certain types of situation (Borowsky et al., 2009; McKenna and Crick, 1994; Wallis and Horswill, 2007; Wetton et al., 2010). In line with an established definition (Crundall et al., 2003), we operationalise HPS as:

> *A driver's ability to detect and respond in time and appropriately to potentially dangerous events on the road.*

Studies show that a lack of HPS results from inexperience (i.e. lack of exposure to hazardous situations) (Braitman et al., 2008); error in self-assessment of skills (i.e. young drivers overestimate their skills) (Horrey et al., 2015); and limitations in training (i.e. insufficient emphasis on training higher-order skills in the learner driver curriculum) (e.g. Mayhew and Simpson, 2002).

In this study, we aimed to improve the driver's tactical HPS. Tactical HPS is related to the ability to detect potential hazards that are not directly on the collision course (that will result in collision if the direction of the movement remains unchanged) (Engström et al., 2003). Potential hazards are possible hazards that have not developed into actual threats. Potential hazards are either visible, indicated by behavioural precursors, or hidden, indicated by environmental precursors (Crundall et al., 2012). The difference between visible and hidden potential hazards is exemplified in relation to pedestrians below.

- Visible potential hazards
  These are visible pedestrians who might start to act dangerously and create an actual hazard. Visible hazards have behavioural precursors (cues) directly related to the hazard (e.g. Crundall, 2016; Crundall et al., 2012). An example of a visible potential hazard is a pedestrian running on the pavement and turning towards the road to cross it but stopping before entering the road. In this situation, the driver has to perceive the behavioural cues of the pedestrian to detect and respond to the potential hazard in time if it develops into an actual hazard.
- Hidden potential hazards
  These are pedestrians who are hidden from the view of the driver by other vehicles or the road environment. Hidden hazards have environmental precursors that are not directly related to the hazard. A bus at a bus stop is an example of an environmental precursor to a hidden potential hazard. In this situation, the driver has to imagine a pedestrian possibly wanting to cross the road based on the hazard precursors in the environment in order to detect and respond to the potential hazard in time if it develops into an actual hazard.

3.1.1 Preparatory experimental study

To specify the need for the training, we carried out a preparatory experimental study in a driving simulator. The aim was to provide a better understanding of how HPS differs among drivers of similar experience, age and gender (male). This study identified and examined young drivers with higher and lower HPS. For training purposes, it is important to know what aspects of HPS should be trained, particularly in pedestrian-related hazard situations among young drivers. In this study, identification of the sub-groups of drivers with higher and lower HPS was based on the hazard response to pedestrian-related potential hazard and further examined based on hazard detection.

Hazard response is the reaction to a hazard that involves deliberate actions—for example, intentional braking. While more likely to be positive, an ill-chosen deliberate response can still be negative. For example, a negative response would be if driver tries to overtake a braking car when oncoming traffic is too close. In this study, we examined whether and when drivers decreased their driving speed or changed lateral position in a response to the potential hazard. However, for drivers to be able to respond to the hazard, it first has to be detected by looking at it (fixated), and then identified as dangerous. The efficiency of visual search strategies and visual attention is one of the underlying skills that distinguish less and more safe drivers (Underwood, 2007). When and where drivers look is of crucial importance to driver safety and hazard perception (e.g. Lee et al., 2008; Underwood, 2007). In this study, eye movements were analysed and fixations were used as a measure of detection and visual attention to the potential hazard to confirm the division between lower and higher HPS among young drivers.

Among young drivers, the sub-group of drivers with lower HPS are the drivers who did not respond to potential hazards by decreasing their driving speed or adjusting their lateral position further away from the pedestrian. When the hazard was visible and the driver had to predict the behaviour of the pedestrian, this study differentiated between drivers who would slow down (the sub-group of drivers with higher HPS) and the drivers who would not adjust their speed (the sub-group with lower HPS). When the hazard was visible, 49 participants (79 per cent) reduced their speed in time in response, while 13 (21 per cent) did not respond at all. However, the difference was not significant in situations with hidden hazards that had to be predicted based on environmental precursors. When the hazard was hidden, 36 participants (59 per cent) did not respond to the hazard at all, while 25 (41 per cent) responded in time. All drivers who did not respond to the visible potential hazard did not respond to the hidden potential hazard either, supporting the conclusion that higher levels of HPS are needed to detect hidden hazards, and the non-responding participants had the lowest HPS among all participants. This result is in line with studies analysing the HPS of drivers with varying experience of a variety of hazard types, demonstrating that hidden hazards are more difficult for novice drivers to identify (Borowsky et al., 2010; Crundall, 2016; Crundall et al., 2010, 2012).

The sub-group differentiation was reinforced by eye movement data. Eye movement analysis showed that drivers with lower HPS fixated on the pedestrians for the first time when closer to them, therefore having less time to respond to the hazard in an adequate manner if the pedestrian suddenly decided to cross the street. Drivers with lower HPS also had longer fixations, indicating a longer processing time to detect a pedestrian as a potential hazard. Additionally, the drivers with lower HPS fixated fewer times on the pedestrian, indicating that these drivers were not considering that the potential hazard could develop into an actual threat. The sequence of the fixations showed that a larger share of drivers within the higher HPS sub-group followed the pedestrian's movements from the onset of the hazard until the driver passed the pedestrian, in comparison to drivers in the lower HPS sub-group. This result suggests that the drivers with higher HPS paid closer attention to potential hazards. In addition, the fixation analysis showed that the drivers with higher HPS considered their driving speed more, having more fixations on the speedometer. For a summary, see Table 3.1.

Table 3.1: Comparison of hazard fixations between 'higher HPS' and 'lower HPS' sub-groups in visible and hidden conditions in adult potential street-crossing situations.

higher HPS	lower HPS
• fixated more than once on the pedestrian • fixated continuously on the pedestrian • fixated on the speedometer one or more times	• longer distance driven until the first fixation • did not fixate, but swiped over the pedestrian

As HPS develops with driving experience, these results should be taken into consideration when designing training programmes for new drivers using the driving simulator to ensure that a variety of hazards are included in hazard perception training. Previously, training has shown benefits in improving tactical HPS by enhancing visual search, hazard fixation (Fisher et al., 2002; Pollatsek et al., 2006; Pradhan et al., 2009; Vlakveld et al., 2011) and hazard response (e.g. Crundall et al., 2012; Muttart, 2013), but not particularly in hidden pedestrian-related potential hazards. The study indicates a need for training focusing not only on detection but also on adequate response to hidden pedestrian-related potential hazards that demand more advanced HPS. This could be useful to ensure that new drivers have high HPS when acquiring their licence. This study resulted in two research papers (Ābele et al., 2018a,b).

3.2 Method

3.2.1 Procedure

Upon arrival, participants read the instructions for the experiment. The stated aim was to examine drivers' everyday driving style. All drivers undertook a short introductory drive to get used to the simulator and the virtual environment. Thereafter, they filled in a short questionnaire (pre-questionnaire; see section 3.2.7). The participants continued with a base drive followed by a short break. The drivers in the control group (CG) then continued with a test drive and finished the experiment by filling in the post-questionnaire (see section 3.2.7). The participants in the training group (TG) had a training before the test drive. The whole experiment lasted about 1.5 hours. The procedure for the experiment is shown in Figure 3.1.

The study employed a randomised control group design, although the specific hazard situations encountered in the base drive and the test drive were modified to avoid bias caused by a learning effect. Two of the situations (situation 5 and situation 7; see Table 3.5) did not involve

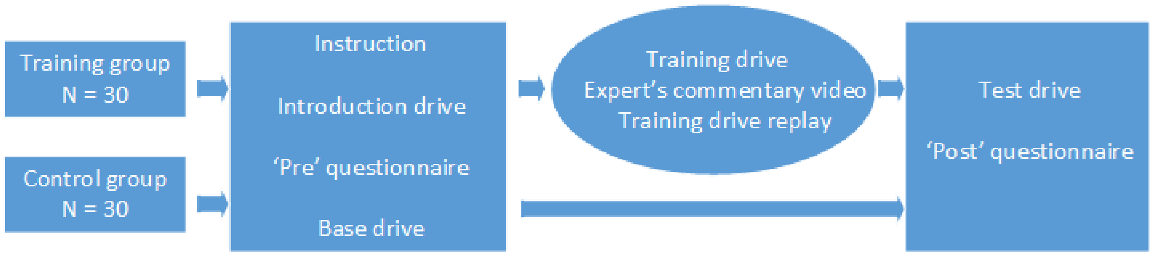


Figure 3.1: Procedure of the experiment.

any pedestrians. In addition, the driving environment was different in the base and in the test drive, as described in the following subsections.

3.2.2 HPS training

In this experiment a training consisting of three parts—a training drive, the expert's video commentary and a training drive replay—was developed and tested.

Background to HPS training: committing errors and receiving feedback

Humans learn the best ways to perform new tasks by committing errors rather than by receiving instructions in error-avoidance settings (e.g. Keith and Frese, 2008). Errors are crucial when acquiring a new skill, as they show the learner that their behaviour should be changed and that the task should be handled differently not to commit the errors again. One of the reasons that drivers' HPS increases so slowly is the lack of correct performance feedback regarding their skills, which is hard to obtain while driving on the road unless involved in accidents (Horswill et al., 2017). The advantage of using a driving simulator for HPS training is the opportunity for drivers to experience the consequences of their driving behaviour in a safe setting and learn from their errors (error learning). When exposed to hazards without any explicit feedback, drivers can easily conclude that the accident or near accident occurred because of the environmental conditions and the other road users involved. Therefore, feedback is necessary to guide drivers on where to look and how to respond to avoid hazards. Horswill et al. (2017) demonstrated that providing drivers with feedback on their performance using videos and graphs improved HPS. However, young drivers not only have to learn to predict and detect potential hazards, but also not to overestimate their abilities and underestimate the risks (e.g. Weiss et al., 2013). Providing drivers with detailed information on the cause of the failure and what they should do to improve their performance is needed for the feedback to be effective in reducing self-enhancement bias (Dogan et al., 2012). In error learning, drivers gain information about a task through exploration and trial and error, creating an opportunity for active processing (e.g. Frese, 1995). Studies show that training based on error learning reduces accident occurrence in a simulator (Ivancic and Hesketh, 2000). Moreover, combined with verbal and visual instruction, the training improves visual search of hazards (Vlakveld et al., 2011). However, the training employed by Ivancic and Hesketh (2000) was mostly concerned with actual hazards that materialised suddenly, and the training method tested by Vlakveld et al. (2011) focused on hazard detection and did not include measures of hazard response. So far, improvements have been reported on average across all situations without distinguishing between the various types of hazard instigator (e.g. car, pedestrian or cyclist).

Training drive

The HPS training started with a training drive. The drive ran through a virtual city that represented a typical urban street; it consisted of six potential hazards and two situations with hazards that materialised (see Table 3.2). In the first situation that materialised (situation 3), the child continues to run and crosses the street. There is an adult on the other side of the street serving as a cue, indicating that the child might cross the street to meet the adult (see Figure 3.2). In the second situation that materialised (situation 5), there is a bus at the bus stop. As the driver approaches, 100 metres further up the street a woman crosses the street in front of the bus. When the driver is 50 metres ahead of the bus, a child runs out from behind the bus and crosses the street. The first pedestrian crossing the street is used as a cue to indicate that other pedestrians might follow.

When the cues were visible to the driver, there was enough time in both situations for the driver to stop and avoid the hazard if it materialised. If an accident happened, the simulation stopped and the drive started again from the beginning. Drivers had to complete the drive without accidents to continue with the training. The training drive was recorded to allow a replay as part of the training, as described in the following section.

Figure 3.2: Screenshot of the training drive.

Expert's video commentary

The training continued with participants watching an expert's video commentary. The video was created with the assistance of a driving instructor. The video included a soundtrack with verbal advice on driving speed, what to pay attention to, and how to respond to potential and actual hazards during the drive. More specifically, the advice concerned:

- Adjusting driving speed when anticipating a hazard (slowing down in time by removing the foot from the accelerator and placing it on the brake pedal).
- Paying attention to situations that might develop into a hazard (pedestrian running along the pavement).
- Areas in which hazards might appear (e.g. five metres before and after a zebra crossing, around a bus at a bus stop, and around a business truck, as this space is the driver's workplace).

The commentary was recorded by a male voice and was synchronised with the video, pausing the visuals when a longer description of the scene was required. The participants watched the

Table 3.2: Description of the hazard situations in the training drive.

Sit.	Cue	Description of the situations	Type
1	A ball lying on the right side of the street indicating that the pedestrian might run out to pick it up.	A ball is lying on the right side of the street and a child is standing on the pavement on the left side of the street. The child starts to run out into the street between parked cars towards the ball, but stops after two metres.	Visible
2	A pedestrian turning towards the street indicating the intention to cross it.	An adult is walking on the pavement on the right side of the street. As the driver approaches, the adult starts to run and turns towards the street.	Visible
3	An adult on the other side of the street serving as a cue indicating that the child might cross the street to meet the adult.	A child is walking on the left pavement. As the driver approaches, the child starts to run and turns towards the street. The child continues to run and crosses the street.	Visible
4	A parked business truck obstructing the view of the right pavement.	A business truck is parked on the right side of the street.	Hidden
5	A bus stop indicating that there might be another pedestrian crossing the street from behind it and The first pedestrian crossing the street is used as a cue to indicate that other pedestrians might follow.	A bus stop on the right side of the street. As the driver approaches, 100 m further up the street the woman crosses the street in front of the bus. When the driver is 50 m ahead of the bus, a child runs out from behind the bus and crosses the street.	Hidden
6	A skateboard lying on the right side of the street indicating that the pedestrian might cross the street to pick it up.	A skateboard is lying on the right side of the street. An adult, standing on the left pavement, runs out 2 metres into the street and stops.	Visible
7	Parked cars obstructing the view of the pedestrian.	An adult is standing between parked cars on the right side of the street.	Visible
8	A parked car obstructing the view of the potential pedestrian on the pavement.	A car is parked 10 metres before the zebra crossing on the right side of the street.	Hidden

expert’s video commentary alone on the 24" monitor. The expert’s driving speed was displayed as a graph below the video (see Figure 3.3).

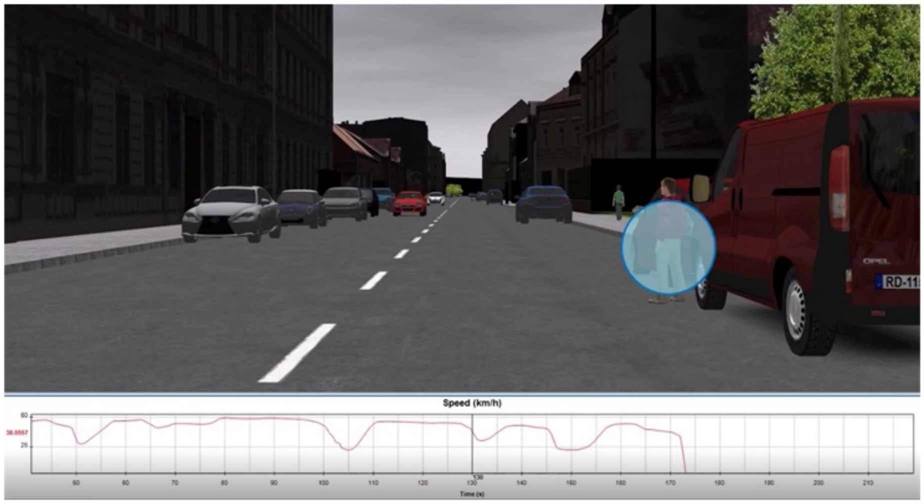


Figure 3.3: Screenshot of the expert’s commentary video.

Training drive replay

At the end of the training, participants watched a replay of their own training drive. The video was shown on the 24" monitor. The driving speed of the participant was displayed as a graph below the video (see Figure 3.4). During the replay, the participants did not receive any feedback as it was intended for them to reflect on their driving behaviour and compare it to the expert’s suggested performance.

Figure 3.4: Screenshot of the training drive replay.

3.2.3 Driving simulator

A fixed-based mid-level physical fidelity driving simulator equipped with the necessary vehicle control systems and 3D sound system (5.1 channel) was used to conduct the experiment (see Figure 3.5). Scenarios were presented at a rate of 60 frames per second on three plasma displays (size: 42”; front screen resolution: 1920 x 1080 dpi; side screens’ resolution: 1360 x 768 dpi; 150° horizontal and 40° vertical perspective). Speedometer, rear- and side-view mirror information was visible on the centre and side screens. The scenarios were developed and real-time simulation was controlled with SCANeR Studio (OKTAL) software.

Figure 3.5: The driving simulator set-up.

3.2.4 Participants

Sixty young male drivers participated in the study. The participants were recruited from among university students and all held valid driver’s licence. As HPS is a higher-order skill that cannot be trained before drivers know how to handle the vehicle and know all the traffic rules, learned drivers without driving licence were not chosen for this study. All participants had self-reported normal or corrected-to-normal vision. The drivers were randomly assigned to one of two groups (see Table 3.3). Each participant was offered a 30-euro gift card upon completion of a 1.5 h session.

Table 3.3: Experimental groups.

Group	N	Age, mean (SD[1])	Years of having a licence, mean (SD)
Control (CG)	30	22.4 (1.3)	4.5 (1.3)
Training (TG)	30	22.5 (1.2)	4.6 (1.3)

[1] standard deviation

3.2.5 Base drive

The base drive ran through a virtual city that represented a typical urban street. During the drive, the drivers encountered five visible and three hidden pedestrian-related hazard situations (see

Table 3.4). In all the situations, the participants had to apply their tactical hazard perception skills to be aware that the pedestrian might cross the street, thereby creating an accident situation. The base drive was similar to the training drive, but in this drive none of the situations materialised.

Table 3.4: Description of the hazard situations in the base drive.

Sit.	Cue	Description of the situations	Type
1	A ball lying on the right side of the street indicating that the pedestrian might run out to pick it up.	A ball is lying on the right side of the street and a child is standing on the pavement on the left side of the street. The child starts to run out into the street between parked cars towards the ball, but stops after two metres.	Visible
2	A pedestrian turning towards the street indicating the intention to cross it.	An adult is walking on the pavement on the right side of the street. As the driver approaches, the adult starts to run and turns towards the street.	Visible
3	A pedestrian turning towards the street indicating the intention to cross it.	A child is walking on the left pavement. As the driver approaches, the child starts to run and turns towards the street.	Visible
4	A parked business truck obstructing the view of the right pavement.	A business truck is parked on the right side of the street.	Hidden
5	A bus stop indicating that there might be another pedestrian crossing the street from behind it and The first pedestrian crossing the street is used as a cue to indicate that other pedestrians might follow.	A bus stop on the right side of the street. When the driver approaches, a pedestrian crosses the street.	Hidden
6	A skateboard lying on the right side of the street indicating that the pedestrian might cross the street to pick it up.	A skateboard is lying on the right side of the street. An adult, standing on the left pavement, runs out 2 metres into the street and stops.	Visible
7	Parked cars obstructing the view of the pedestrian.	An adult is standing between parked cars on the right side of the street.	Visible
8	A parked car obstructing the view of the potential pedestrian on the pavement.	A car is parked 10 metres before the zebra crossing on the right side of the street.	Hidden

3.2.6 Test drive

During the test drive, participants drove through a sparsely populated area in a rural setting. The road environment was very different from that presented in the training and base drive. There were seven predefined hidden and visible potential hazards that did not materialise (see Table

3.5). Similar to the base drive, the participants had to be aware of pedestrians possibly crossing the street and thus they had to apply tactical HPS.

Table 3.5: Description of the hazard situations in the test drive.

Sit.	Cue	Description of the situations	Type
1	Pedestrians on the opposite side of the street indicating that the pedestrian might cross to meet them.	An adult is walking on the left pavement and as a driver approaches starts crossing the street, but stops after entering the street.	Visible
2	Parked cars obstructing the view of the right pavement.	A child, hidden behind parked cars on the right side of the street, runs out but stops after entering the street.	Visible
3	A pedestrian running on the opposite pavement indicating that the pedestrian might cross to meet another pedestrian.	An adult is running along the right pavement and starts crossing the street between parked cars in front of the driver aiming to reach a child running on the left pavement. The adult stops after entering the street.	Visible
4	A bus at the bus stop obstructing the view of the potential crossing pedestrians.	A bus is parked at the bus stop. There are passengers getting in and out of the bus. A child steps out behind the bus and stops instantly.	Hidden
5	A car obstructing the view of the left pavement.	A car is parked by the zebra crossing.	Hidden
6	The pedestrian looking away and not noticing the approaching participant.	An adult is standing on the right pavement near the zebra crossing and looking away. As the driver approaches, the pedestrian starts crossing the street 5 m before the zebra crossing and stops after entering the road.	Visible
7	The business truck obstructing the view of the left pavement.	A business truck is parked on the left side of the street.	Visible

3.2.7 Measures

Improvements of HPS were measured in three ways:

- Hazard response, measured in a driving simulator.
- Hazard fixation, measured with an eye-tracker.
- Self assessment of skills, measured with questionnaires.

Hazard response

Studies in a simulator show that drivers with higher HPS in pedestrian-related situations manage to avoid more accidents (e.g. Paxion et al., 2015; Wang et al., 2011), decrease their driving speed earlier (e.g. Martinussen et al., 2017), and adjust the lateral position of the car further away from the hazard (e.g. Steinberger et al., 2017) than drivers with lower HPS.

We examined the driving simulator data to analyse the participants' response to a pedestrian in a potential street-crossing situation. The participants' responses to the hazard were examined based on the lateral position and decrease in driving speed when approaching a potential hazard. The driving simulator continuously recorded the driving speed and lateral position of the participant, but only data for the hazard window (see Figure 3.6)—from 50 meters before the pedestrian (when the pedestrian became visible for the first time) until passing the pedestrian—were included in the analysis.

Lateral position

The lateral position of the vehicle is defined as the deviation in metres from the centre of the lane. The centre of the lane is the reference position (0). In this study, a value larger than 0 shows that the participant was positioned further away from the pedestrian and thus closer to the right side of the street. Mann-Whitney tests were used to compare changes in lateral position between the TG and CG for each situation in the base drive and in the test drive.

Slowing down

We interpreted a reduction in driving speed as an indication that the participant had recognised the pedestrian as a hazard. Therefore, the mean speed was calculated for five 10 metre intervals and then subtracted from the preceding interval to examine changes in speed (see Figure 3.6).

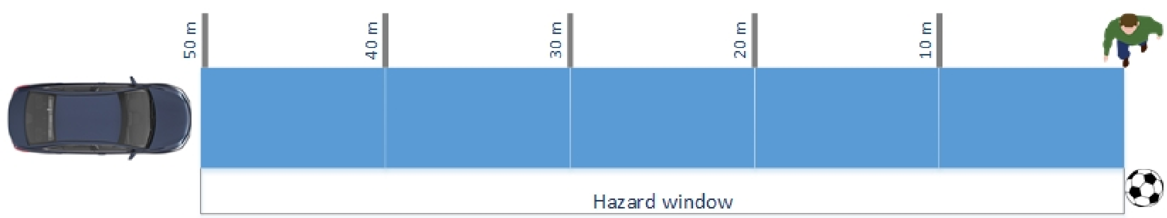


Figure 3.6: Schematically visualisation of the hazard window.

Hazard fixation

When and where drivers look is of crucial importance to driver safety and hazard perception. Borowsky et al. (2010) and Pradhan et al. (2005) have demonstrated that a failure to predict the locations from which hazards may appear and not prioritising the search for these locations may be a major contributor to errors in hazard perception. Studies show that young drivers have more difficulties in perceiving hidden potential hazards and environmental precursors than visible potential hazards with behavioural precursors (Borowsky et al., 2009; Pradhan et al., 2005; Sagberg and Bjørnskau, 2006; Vlakveld et al., 2011). In pedestrian-related situations, the most common type of hazard used in previous studies is actual hazard (e.g. Bélanger et al., 2010; Bromberg et al., 2012; Edquist et al., 2012). This is a visible or hidden active (as opposed to potential) hazard, such as a pedestrian suddenly crossing the street in front of the car.

In the case of pedestrian-related situations, a common measure used is first fixation latency—i.e. how much time passed from the hazard's onset until the driver first fixated on it. More experienced drivers are quicker to first fixate hazards than less experienced drivers (Crundall et al., 2012). Certain other components of the hazard response, such as processing, appraisal and confirmation, are likely to come after the initial fixation on the hazard. Common measures of visual attention are the horizontal search pattern (e.g. Borowsky and Oron-Gilad, 2013; Yeung and Wong, 2015), the number of fixations (e.g. Werneke and Vollrath, 2011) and the fixation duration (e.g. Divekar et al., 2012; Zimasa et al., 2017). Safer drivers are found to detect more hazards (e.g. Fisher et al., 2006), have a wider horizontal spread of search (e.g. Underwood et al., 2003), and more but shorter fixations (Chapman and Underwood, 1998; Pradhan et al., 2007).

In this study, driver's hazard fixation was assessed by analysing eye movements. Dynamic areas of interest (AOI) were created, which covered the pedestrian within the entire hazard window. For each AOI, the measurements included length of the first fixation, dwell time (percentage from the whole time available of the total length of all fixations on the hazard). Also the number of fixations and the duration of the fixations were measured, to analyse the driver's attention to the hazard from its onset until the time the driver passed it (see Table 3.6). In situations where there were no pedestrians (see situations 5 and 7, Table 3.5) the number of fixations on the parked business truck and the car near the zebra crossing were analysed.

Table 3.6: Eye movement measures.

Question of interest	Measure
Did driver look at the hazard?	Fixation within AOI
How fast did driver spot it?	Distance driven to the first fixation
How many times did driver look at it?	Number of fixations
How much attention did driver devoted to the hazard?	Duration of the first fixation and dwell time

This study focused on measuring the distance to the first fixation instead of the first fixation's latency. In other studies where eye movements are analysed for participants watching videos (e.g. Yeung and Wong, 2015); the time to first fixation was used, as the videos were shown at constant speed for all participants. In a simulator study, it is more relevant to combine the driving speed and time of first fixation, showing how close to the hazard the participant was when looking at it for the first time. Dwell time was defined as the sum of all fixations in the AOI, represented as the percentage of the total length of the hazard window (i.e. the dwell time is 100 if the driver looks at the hazard all the time during the hazard window).

Eye movements were recorded using Tobii Pro Glasses 2 eye tracker (see Figure 3.7) and the recorded videos were analysed with Tobii Pro Lab software. The visual gaze was sampled at 50 Hz. A Tobii I-VT Fixation Filter (minimum fixation duration = 60 ms, velocity threshold = 30°/s, maximum angle between fixations = 0.5°) was used as a fixation classification algorithm (Tobii Technology, 2012).

Due to re-calibration problems during the driving session, the eye fixation recordings of eight

Figure 3.7: Tobii eye-tracker.

participants were excluded from the analysis. The eye movement analysis included 26 participants from the TG and 26 from the CG. Mann-Whitney tests were used to analyse differences between the TG and the CG.

Self-assessment of skills

As important as having appropriate skills is, it is necessary to have an accurate self-estimation of them: that is, drivers' assessment of their skills has to match their real skills. Drivers with errors in the estimation of their skills, which can arise from inaccurate and incomplete processing of information (Dunning et al., 2004), might fail to take proactive measures, thereby placing themselves at risk (e.g. Deery, 1999). Studies show that even though drivers understand the value of high HPS in improved road safety, those are skills drivers believe they are already good enough at compared with their peer drivers (Horswill et al., 2004). Drivers receive less feedback from the environment on their level of HPS than on their driving skills, such as vehicle control (e.g. rolling back on a hill start). Drivers can go on without noticing that they have missed a potential hazard, leading them to misjudge the level of their actual HPS (e.g. Dogan et al., 2012; Horswill et al., 2004, 2013).

To examine the accuracy of young drivers' subjective skills, self-rated measures of drivers' assessment of their own skills relative to other drivers of the same age and gender were obtained before ('pre' questionnaire) and after ('post' questionnaire) the training. Two standardised questionnaires were used.

- **Hazard Perception Questionnaire (HPQ)**
  Developed by White et al. (2011) to measure subjective HPS, the questionnaire focuses on hazard detection and response. It contains six items, such as 'How skilful you are at spotting hazards quickly?' and 'How skilful you are at reacting to more than one potential hazard at a time?' compared to peer drivers. These items are rated on a scale from 1 ("much less") to 7 ("much more") with a midpoint of 4 ("the same").
- **Driving Skills Questionnaire (DSQ)**
  This questionnaire was designed by McKenna and Myers (1997) to assess drivers' general driving skills ('Relative to the average driver of your age and gender, how skilful do you think you are?') and driving skills in specific situations (e.g. 'Relative to the average driver of your age and gender, how skilful do you think you are at judging stopping distance?'). For consistency, the scale was adjusted to the scale of White et al. (2011) HPQ.

The overall total scores for the 'pre' HPQ and 'post' HPQ and two total scores ('overall driving skills' and 'driving skills in specific situations') from the 'pre' and 'post' DSQ were calculated. The 'post' sum scores were compared between the TG and CG and the 'pre' and 'post' sum scores were compared within both groups employing the non-parametric Wilcoxon signed-rank test. The Cronbach's alpha levels indicated an acceptable scale reliability (Peterson, 1994) for the 'pre' DSQ ($\alpha = 0.90$), 'post' DSQ ($\alpha = 0.92$), 'pre' HPQ ($\alpha = 0.89$) and 'post' HPQ ($\alpha = 0.94$).

Additionally, participants were asked to answer open-ended questions about how they reacted to potentially hazardous situations with pedestrians after the test drive to gain insight into their hazard avoidance strategies.

3.3 Results of the HPS training

3.3.1 Hazard response

To examine drivers' improvements in hazard response, we compared the changes in the average driving speed when approaching a hazard between the TG and CG in the test drive. Analysis of the driving speed in the test drive showed significant results in change of mean driving speed in two out of seven situations. The TG responded with a change of approach speed earlier in one hidden situation (situation 5; see Table 3.5) than the CG. When comparing the mean speed in the intervals 30–40 metres and 20–30 metres before the hazard ($U = 260$, $p = 0.005$, $r = 0.4$) when approaching the bus, the difference was greater for the TG (Mdn = 1.45) than for the CG (Mdn = 0.85). Thus, in one hidden situation out of three, the TG adjusted their driving speed in anticipation of the potential hazard.

In one visible situation out of four, the TG responded earlier than the CG (situation 7; see Table 3.5). When approaching the pedestrian near the zebra crossing, the TG's mean speed increased less (Mdn = -2.66) in the last 10 metres before the pedestrian compared to the mean speed in the interval 20–10 metres to the pedestrian than was the case for the CG (Mdn = -7.83, $U = 314$, $p = 0.044$, $r = 0.3$). As there was no significant difference in driving speed for hidden situations between the CG and the TG in the base drive, we interpret the difference in the one hidden situation in the test drive as an effect of the training.

3.3.2 Hazard fixation

Fixation analysis of the test drive showed that the dwell time, average duration of fixations and duration of the first fixation were not significantly different between the TG and CG. However, the TG fixated significantly more times on the hazard in four out of seven situations (situations 3, 4, 5 and 7; see Table 3.5). The TG fixated more often (Mdn = 5) on the pedestrian than did the CG (Mdn = 3, $U = 167.5$, $p = 0.019$, $r = 0.3$) in situation 3. In situation 4, the TG fixated significantly more times (Mdn = 3) on the bus than did the CG (Mdn =2, $U = 221$, $p = 0.043$, $r = 0.3$).

The situations 5 and 7 were the same in the base drive and in the test drive. The results show that there were no significant differences between the CT and the TG in the number of fixations on these hazards in the base drive (see figures 3.8 and 3.9). The drivers in the two groups had the same number of fixations on the parked car near the zebra crossing as well as on the business truck parked on the side of the street. In addition, the dwell time, average duration of fixations and duration of the first fixation were not significantly different between the TG and the CG.

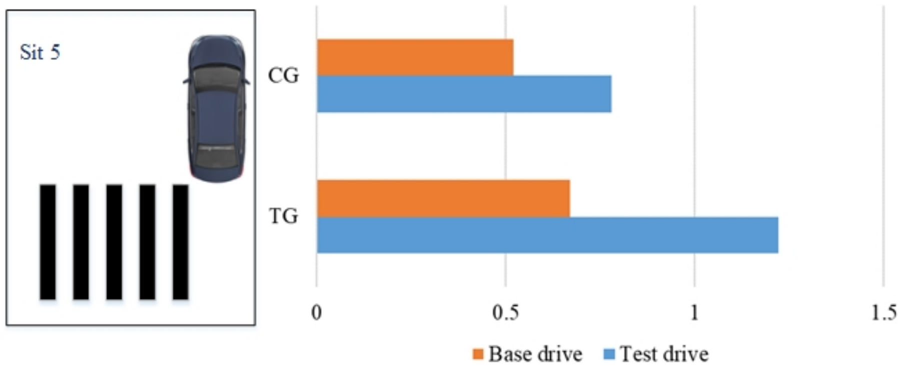


Figure 3.8: Mean number of fixations in the situation with the parked car near the zebra crossing.

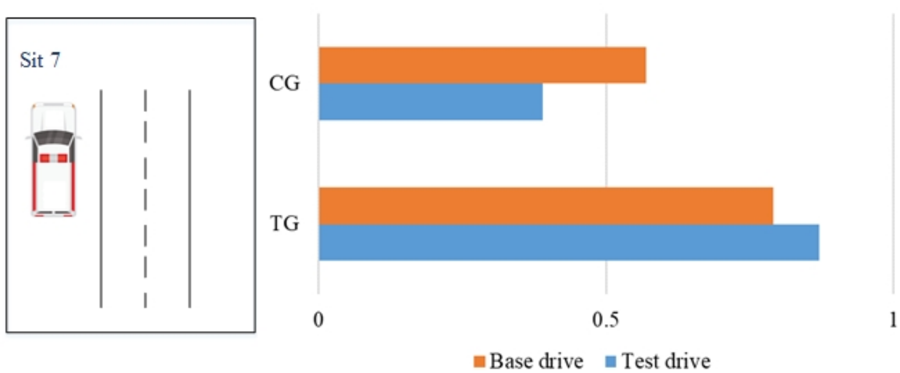


Figure 3.9: Mean number of fixations in the situation with the parked business truck.

In the test drive, the TG fixated more often (M = 1.22) on the pedestrian than did the CG (M = 0.78; U = 167.5, p = 0.017) in situation 5. Figures 3.10 and 3.11 depict how many times (number of fixations) each group of drivers look to the particular location in situation 5. Locations marked with the red frame are AOI in this situation. The red colour indicates a greater number of fixations, whereas green indicates a smaller number of fixations.

Figure 3.10: Fixations of CG in the situation with the parked car near the zebra crossing.

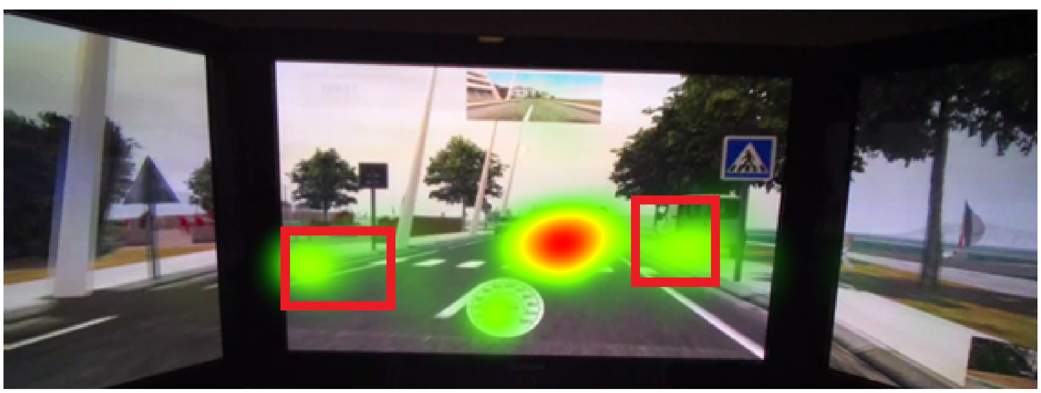


Figure 3.11: Fixations of TG in the situation with the parked car near the zebra crossing.

In situation 7, in the test drive, the TG fixated more often (M = 0.87) on the pedestrian than did the CG (M = 0.39; U = 162, p = 0.012).

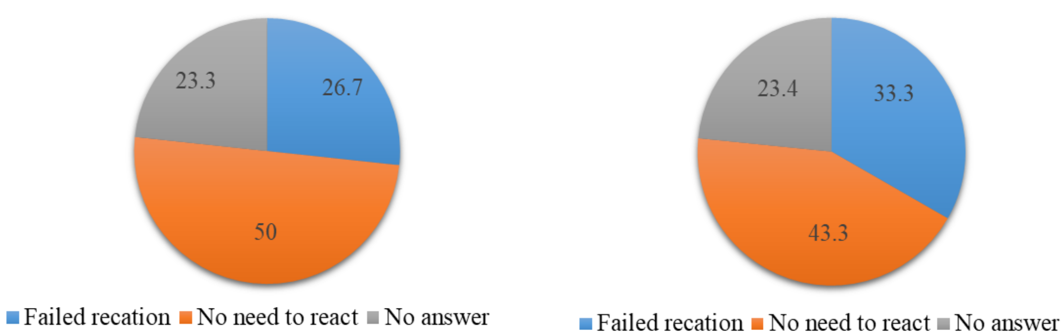
In addition, in those situations which were the same in base and test drive, comparison of fixations in base drive and test drive was possible. When comparing number of fixations in test and base drives, in the situation 5, with the parked car near the zebra crossing, the TG was fixating more on the car and on the other side of the street looking for potential pedestrians in test drive than in the base drive (Z = -3.28, p = 0.001). Also, CG were fixating more in the test drive, but the difference was not significant (see figure 3.8).

3.3.3 Self-assessed skills

There was a significant difference in the before and after total scores for self-assessed driving skills (DS) within the TG. The drivers in the TG rated their DS in specific situations higher before (M = 70.57) than after (M = 68.67) the training (Z = -2.03, p = 0.043, r = 0.3). However, analysis of the self-reported HPS and DS in specific situations and overall driving skills did not show significant differences between the TG and the CG.

3.3.4 Answers to the open-ended questions

The participants were asked in an open-ended question to state the reason that they did not react to certain pedestrian-related situations (if that was the case). The answers were first coded and then merged into two major categories: the category 'No reaction required' summarises answers in which each participant explains why a reaction was not necessary (e.g. because the pedestrian was standing still; he was sure that the pedestrian would not cross; the situation was not dangerous). The category 'Failed reaction' summarises answers where the participant reports why he did not react (in time), although he should have (e.g. because he noticed the pedestrian too late; he was distracted). As Figure 3.12 shows, drivers in the TG group responded less that there was need to react and more that they have failed the reaction. However, differences between the TG and the CG are not significant.



(a) CG respondents (%) (b) TG respondents (%)

Figure 3.12: The frequencies of the respondents reasons for not reacting to the potential hazard.

The participants were also asked to indicate their behavioural response in hazardous situations with pedestrians in the simulator drive. The answers were coded and assigned to five categories.The TG and CG varied in their answers, as it is shown in Figure 3.13. Most drivers in both groups reported having reacted by reducing the speed. However, more drivers in the training group (N = 10; 33.3 per cent) than in the control group (N = 3; 10 per cent) reported that they kept an eye on the pedestrian (p = 0.028).

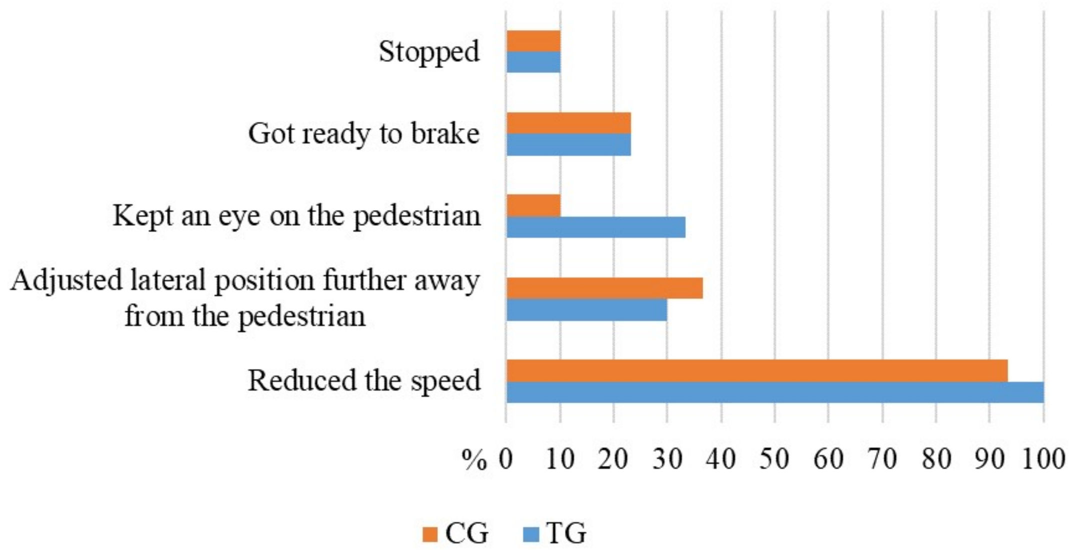


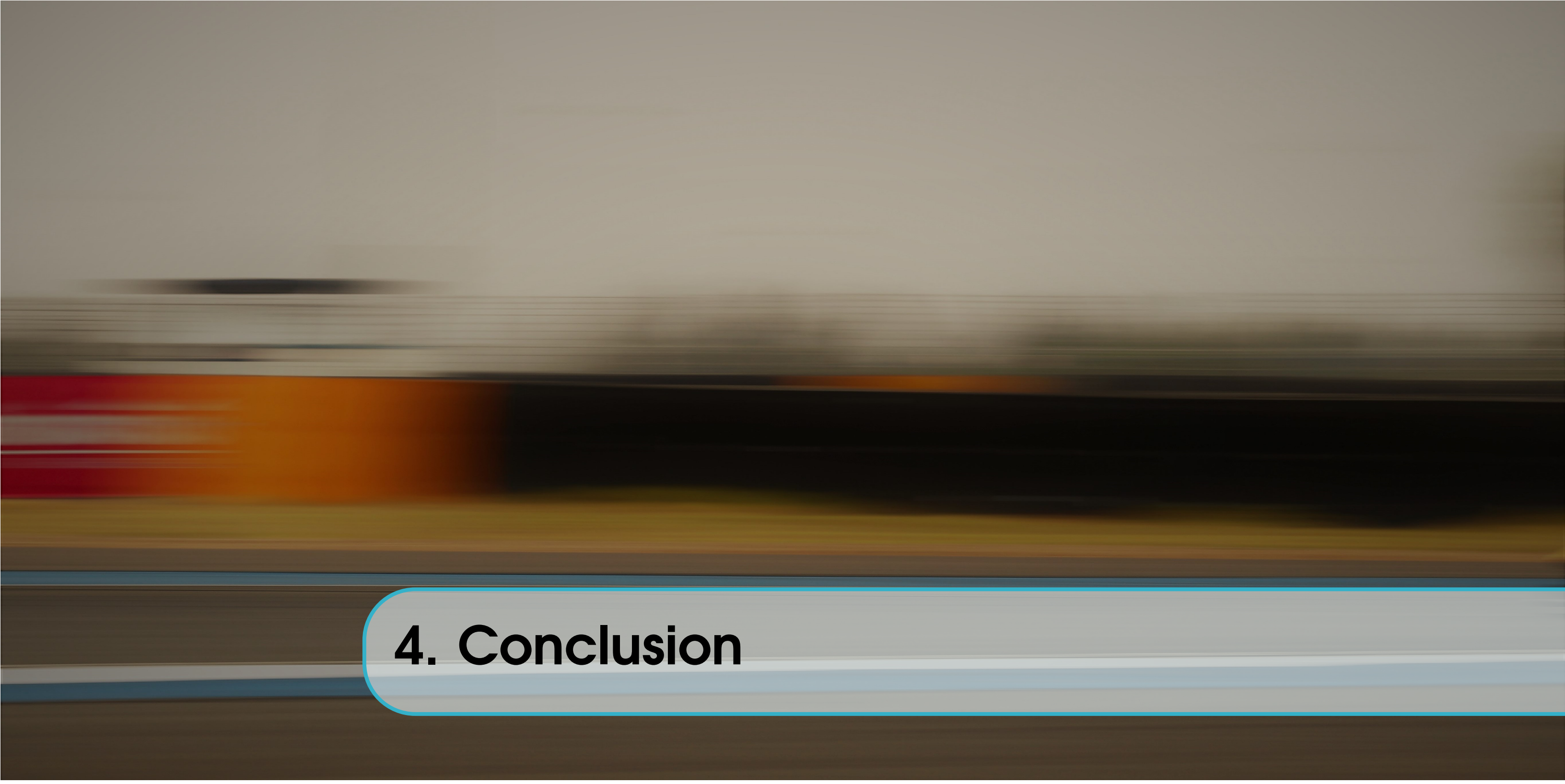
Figure 3.13: The frequencies of the reaction to the potential hazard.

3.4 Discussion of the HPS training results

The experimental study demonstrated that the training drive, supplemented by an expert's commentary and the replay of the training drive, has a beneficial effect on improved tactical HPS, particularly in more challenging, hidden pedestrian-related potential hazards. These results are supported by the previous findings in studies examining the effect of error training in the simulator (Ivancic and Hesketh, 2000; Vlakveld, 2011). In this study, drivers presented limited improvements in HPS in response to visible pedestrian-related potential hazard situations. This behaviour may be explained by the level of HPS the participants began the training with. It is possible that the young drivers in the sample had sufficient skills to detect the visible, easier hazards and respond to them and hence could not benefit from the training. Future research is required to examine whether the training has a higher effect on drivers with lower HPS compared to drivers with higher HPS.

Interestingly, the TG rated their driving skills lower after the training, suggesting that the training made drivers more aware of their driving skills and possible limitations. In line with (Vlakveld et al., 2011), this finding indicates that the training provided the drivers with a more profound understanding through confronting their own limitations in the error drive. Understanding their relevant competences in combination with the expert's instructions for the driving task was linked to the predictability of the driving situations in the test drive. It is possible that the expert's video commentary provided the TG with crucial information regarding recognition of and response to the hidden hazards.

While it is not possible to separate the effects of the training drive in the simulator from the instructions provided via the expert's commentary and the performance replay video, it can be concluded that, as a whole, the training has a positive effect on young male drivers' hazard fixation and response, at least concerning driving in the simulator. Further, preferably on-road, studies are needed to assess the relative contribution of the expert's video commentary and the error drive.



4. Conclusion

This report presents the results of a project consisting of two parts: first, institutions in which a driving simulator is used for training purposes were mapped; then a training was developed and tested with the purpose of improving hazard perception skill based on driving simulator training.

By means of the individual interviews, the use of simulators for training purposes in driving training institutions in Denmark was mapped. In Denmark, driving simulators are used in driving schools and in professional and motorsport driver training.

In driving schools, low- and mid-level physical fidelity simulators are mainly used for teaching basic driving skills, such as starting and manoeuvring a vehicle in different traffic situations.

In motorsport, the use of a driving simulator helps save on travel and training expenses to practise on race tracks abroad. Also, due to the limitations of exposure to noise, motorsport drivers can spend more time training in the simulators than would be possible on the real track.

According to professional driver training instructors, a simulator is an effective tool for training professional drivers by exposing them to a wide variety of traffic situations in a limited time span and in a safe setting. Additionally, simulators are successfully used to promote professional driver education programmes.

There is no common way in which a driving simulator is used: driving instructors decide themselves on the didactic principles of the simulator use by employing different types of hardware, software and feedback methods. The interviews reveal that the technical quality of the driving simulator, the quality of the simulator lessons, and the way in which these lessons are embedded in the driving course influences the possible benefits of using a driving simulator. Driving simulators are not widely used in Denmark but, based on the experiences of the instructors who uses a driving simulator, it seems that it holds some potential as a tool for improved driver training.

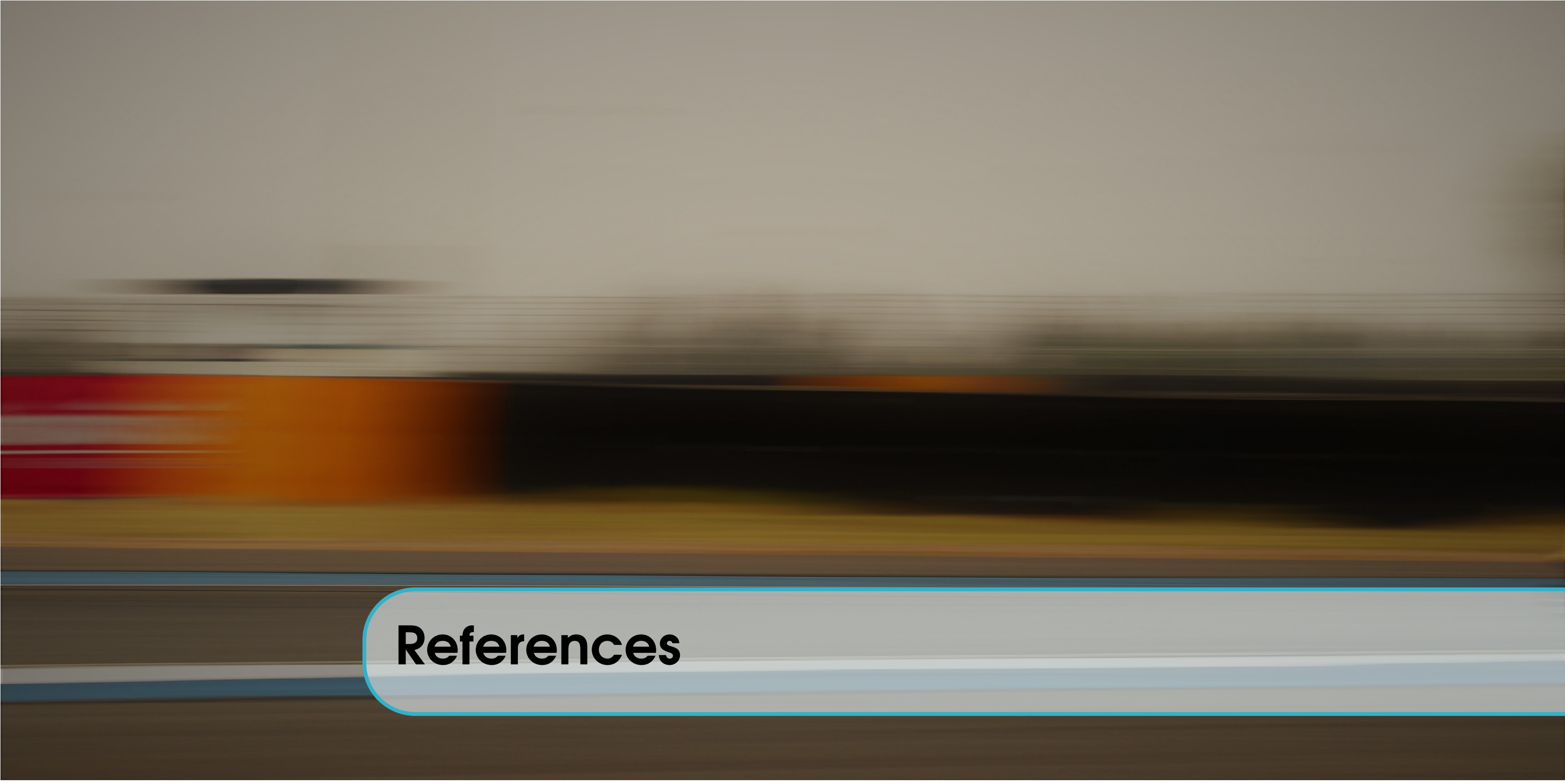
The results of the mapping show that driving simulators in Denmark for regular driving training are mainly used for teaching basic driving skills, such as starting and manoeuvring a vehicle in different traffic situations. However, by using a control group design, our study examined whether a short training in a driving simulator can also improve young drivers' higher level driving skills, such as tactical HPS.

As HPS develops with driving experience, the results should be taken into consideration when designing the curriculum for new drivers to ensure that a variety of hazards are included in hazard perception training. The preliminary study indicates a need for training focusing not only on the detection of, but also an adequate response to, hidden pedestrian-related potential hazards that demand more advanced HPS. This could be useful to ensure that new drivers have high HPS when acquiring their licence.

The training consisted of a training drive, a video with an expert's commentary and a replay of the training drive. By allowing drivers to perform errors in the simulator, they received feedback on the HPS that they lack on the road. An expert's commentary provided drivers with explicit advice about pedestrian-related potential hazard fixation and response, and training drive replays allowed them to reflect on their driving performance compared to the expert's. To assess the effect of the training, we compared the eye fixations and changes in driving speed of the TG and the CG. In addition, we compared the self-rated DS and HPS in both groups before and after the training.

The results show that the training improved tactical hazard detection and response skills among young drivers in relation to hidden pedestrian-related hazards. Improvement in the advanced HPS suggests that it is relevant to consider ways to include similar training procedures in basic driver training to support the development of more advanced HPS among newly licensed drivers. This type of training in the driving simulator, further improved with separated child and adult situations in various road environments, could be considered an additional tool to improve the driver learning curriculum in addition to the traditional means of driver training. As the implementation of a video commentary is relatively easy, and since simple driving simulators are becoming more available and affordable to the wider public, HPS training in pedestrian-related situations in a driving simulator should be considered. It would be naive to reason that HPS training in a simulator alone could influence young drivers' behaviour, because if not motivated to employ the learned skills in daily driving, the accident rates will remain high among young drivers. Therefore, to achieve sufficient effect, HPS training in a simulator needs to be included in the overall learning curriculum, traditionally taught in classrooms and mastered on-road with an instructor. Training in the simulator could be performed not in every driving school, but in centralised locations, as is the case with advanced training on slippery tracks.

It is suggested that further studies examine whether drivers of all ages, genders and experience levels perform similarly in pedestrian-related situations, helping to tailor this problem to the relevant target groups and adjust preventive methods not only for young drivers, but for the rest of the driver population.



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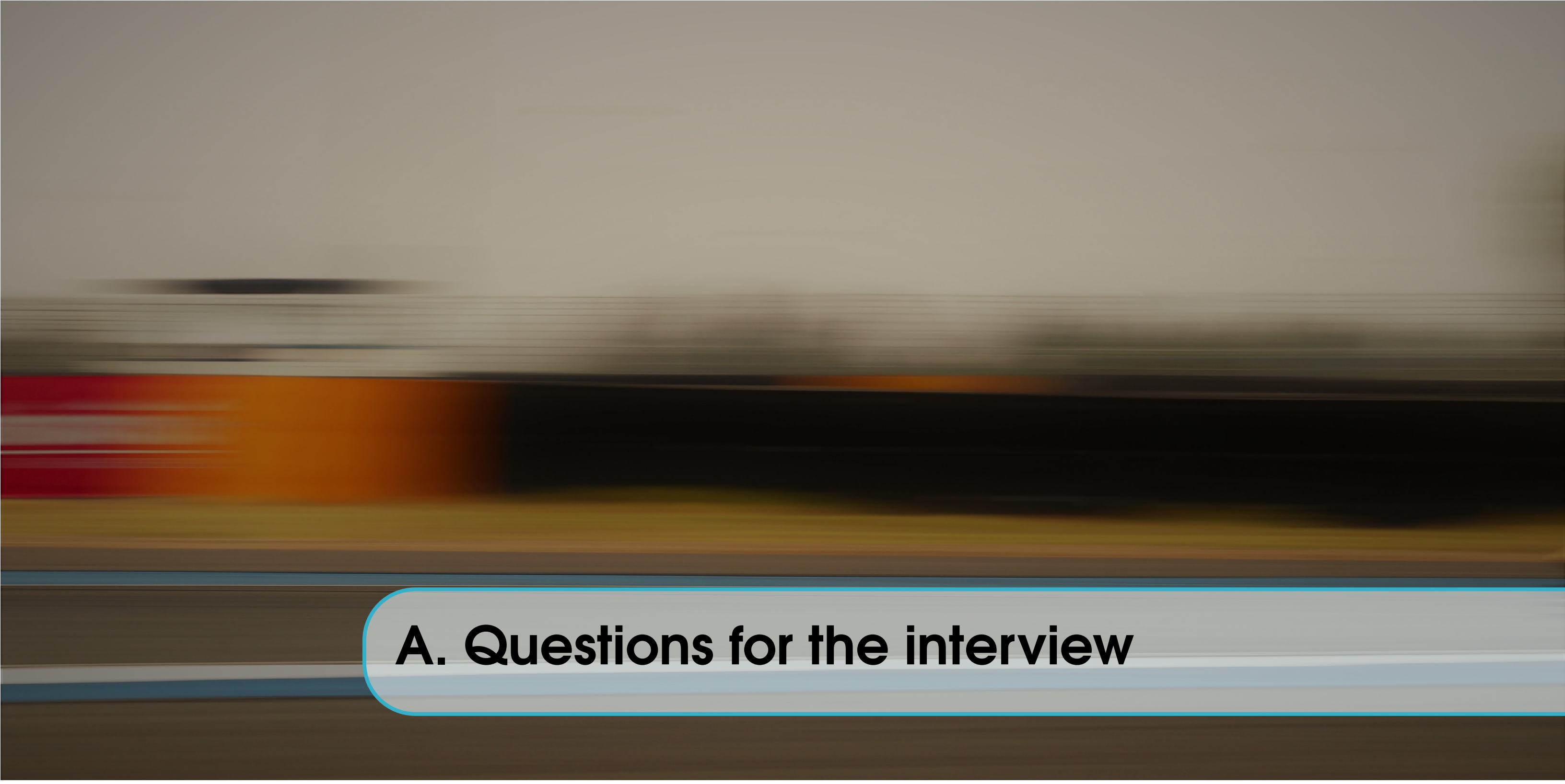

A. Questions for the interview

Questions to the driving instructors form the driving schools and coaches from the motor-sport driver training centres.

1. Simulator itself
   (a) What kind of simulator do you have in your driving school?
   (b) How many driving simulators do you have in the school?
   (c) When did you acquire it?
2. Who uses the simulator the most?
   (a) Older/younger students?
   (b) Women/men?
3. How is the simulator used?
   (a) How/why did you decide to use a driving simulator in your driving school?
   (b) Can students use the driving simulator voluntarily or is simulator practice obligatory?
   (c) Do students have to pay an extra fee to use the simulator?
   (d) How accessible is the simulator?
   (e) How is the training designed? (e.g. Do learners get feedback on their performance? Do they repeat situations until they learn them?)
   (f) What kinds of situation can students experience during the simulator training?
   (g) Do students use the simulator as a part of their theoretical/practical training?
   (h) When are students encouraged to start using simulator training: during their theoretical lessons/ before they start practical training?
4. Do you have any statistics/evaluation showing how students who use simulator performed in the driving test compared to those who did not use it?
5. Do you have any subjective estimation of the effect of the driving simulator use?
6. What are the advantages of the driving simulator?
7. What are the problems/challenges when using the driving simulator?
8. Do you know any other driving school in Denmark where a driving simulator is used in driver training?

Questions to the driving instructors form the processional driver training centres.

1. Simulator itself
    (a) What kind of simulator do you have in your training centre?
    (b) How many driving simulators do you have in the training centre?
    (c) When did you acquire it?
    (d) Have you changed hardware/software during this time?
    (e) Have you changed the simulator training procedure during this time?
2. Who uses the simulator the most?
    (a) Older/younger students?
3. How is the simulator used?
    (a) How/why did you decide to use a driving simulator in your training centre?
    (b) Do students have additional training apart from simulator training or do they only practice in the simulator?
    (c) How accessible is the simulator? (Do they sign up for separate sessions or the whole course run on the simulator?)
    (d) How is the training designed? (e.g. Do learners get feedback on their performance? Do they repeat situations until they learn them?)
    (e) What kind of situations can students experience during the simulator training?
4. Do you have any subjective estimation of the effect of the driving simulator use?
5. What are the advantages of the driving simulator?
6. What are the problems/challenges when using the driving simulator?
7. Do you know any other institutions in Denmark where a driving simulator is used in driver training?