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Sleepiness, Safety and Transport

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Abstract

The economic development of modern society requires continuous improvement of transport and their efficiency throughout the span of 24 hours. Drowsiness may be a serious risk to the safety of employees, passengers and third parties. Sleepiness at the wheel is responsible for 5% to 30% of road accidents. Several pathophysiological factors governing the driving skills were studied: lifestyles, work schedules, prolonged wakefulness, stress, and sleep disorders. Screening of sleep disorders and education of workers at proper sleep hygiene are fundamental keys to the safe transport. The individual initiatives to reduce the risk of drowsiness should be framed in a more general safety effort of the institutions.

Keywords: Sleepiness; Transport; Accident; Prevention; Sleep disorders; Safety

Introduction

Both in developed and developing countries, transport plays a prominent economic role because it conveys goods and services to customers, passengers to work or school, shops or leisure centres. Around 8.8 million Americans and 10.5 million Europeans [1] are employed in the transport sector.

Economies rely on transportation and communication systems that operate well beyond the 'normal' 8-hour workday to transport people and goods to meet personal and business requirements. However, the need for transport and communication systems to operate around-the-clock may exceed the capacity of human beings to work efficiently and safely. This incapacity to perform optimally around the clock is typically attributed to sleepiness that results from sleep homeostasis, circadian rhythms, and workload [2].

Road Safety is a major societal issue. In 2011, more than 30,000 people died on the roads of the European Union, i.e. the equivalent of a medium-sized town. For every death on Europe's roads, it is estimated that there are 4 permanently disabling injuries such as brain or spinal damage, 8 serious injuries and 50 minor injuries. In 2003, the European Commission introduced an ambitious Road Safety Programme [3] which aims to cut road deaths in Europe between 2011 and 2020. The programme sets out a combination of initiatives, at European and national level that focus on improving vehicle safety the safety of infrastructures and road users' behaviour.

Safety problems also regard railways and sea transport, air transport, pipelines, postal and courier services. Road Accidents (RA) remain the largest single cause of death among people aged 15 to 29. According to Eurostat statistics on the causes of death, the number of people in the European Union who died as a result of transport accidents (covering all transport modes) fell by 37 % between 1999 and 2009 [4].

Although alcohol and recreational drugs are recognized as significant risk factors for transport accidents, the role played by sleepiness is less well known, but may be more important. This may be due to a sleep pathology, voluntary (non-pathological) sleep reduction, or activity during the circadian low. Night or morning work is a prominent factor with regard to the two latter causes. Sleep disorders with impaired or shortened sleep (as i.e. sleep apnea) are major cause of RA, more than drugs [5].

The literature abounds with studies on road safety, while less research has been carried out on industrial safety. In fact, the link between sleep restriction (or shift work) and safety is much better established in the transport industry than in other industrial areas. The reason is that driving a vehicle is a task that requires continual attention and lapses are immediately punished, whereas in most cases industrial work does not make the same demands. Nevertheless, there are important effects and consequences may be far-reaching. Many industrial disasters have occurred in off-peak hours, or when the workers lacked sleep or rest. Proper sleep management and fatigue control are priorities for workplace safety [6,7].

The pathophysiology of driving

Driving is a complex task that requires a number of skills (multitasking task). A driver continuously receives information from the road, analyses it, and reacts according to his/her knowledge of traffic systems, driving regulations, conditions of the vehicle, application of the Highway Code and previous driving experience.

Driving also involves the processing of complex visual, tactile, and auditory information in order to produce a well-coordinated motor output [8]. The capacity to drive safely declines with chronological age, and this decline is associated with an age-related decrease in several higher order cognitive abilities involving manipulation and storage of visuospatial information under speedy conditions [9]. On the other hand, younger drivers show greater vulnerability to sleep loss. After sleep restriction, younger drivers show significantly more sleepiness-related deviations and greater electro-encephalographic changes (4-11 Hz power - indicative of sleepiness) than older drivers [10].

Night driving performance may be seriously affected by sleepiness. Simulated driving tasks have been designed to tap into the key processes

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that are involved in driving. These simulations are able to investigate driving-related performance in a controlled, measurable, and safe environment. They clearly show that subjective and objective sleepiness is much higher during night conditions [11]. Sleep deprivation, sleep restriction, circadian variations and extended periods of time-on-task have been shown to cause a qualitative decline in driving performance in both on-road and simulated driving tasks [12-14].

Anecdotal claims also point out the adverse effects of larger lunches on afternoon driving ability. The 'post-lunch' dip is a bi-circadian phenomenon, largely unrelated to lunch, and worsened by a disturbed prior night's sleep. Studies conducted with an interactive simulator showed that a heavy lunch causes significant increases in both sleepiness-related lane drifting ('incidents') and electroencephalographic (EEG) changes and a tendency to greater subjective sleepiness [15].

Individual differences in cognitive functioning during extended work hours and shift work are of considerable importance, and may be observed both in the laboratory and in the workplace. These individual differences have a biological basis in trait-like, differential vulnerability to fatigue from sleep loss and circadian misalignment. Trait-like vulnerability can be predicted partly by functional gene polymorphisms that may be located in the promoter region of the Monoamine oxidase a gene [16], and by other biological or psychological characteristics, but remains largely unexplained. A complicating factor is that individual vulnerability or resilience to sleep deprivation depends on the fatigue measurement taken into consideration--subjective versus objective assessment, or one cognitive task versus another. Such dissociation has been observed in laboratory and operational data resulting from a simulated setting. Disparity between subjective and objective measurements of fatigue may be one of the reasons why vulnerable individuals do not systematically opt out of professions involving high cognitive demands and exposure to fatigue [17].

As driving involves a number of combined cognitive processes, it is difficult to determine from a simulated driving task alone which components are causing the impairment in overall driving performance. A number of cognitive domains have been associated with crash risk in on-road driving studies, including attention and vigilance, visual processes, processing speed and reaction time, working memory and executive function [8]. Many of these functions also overlap with neurocognitive impairments observed in sleep-deprived individuals [18]. Experiments have been conducted to decompose sleep-deprived performance into underlying cognitive processes using cognitive-behavioural, neuroimaging and cognitive modelling techniques. Furthermore, computational modelling in cognitive architectures has been employed to simulate sleep-deprived cognitive performance on the basis of the constituent cognitive processes. These efforts are beginning to enable quantitative prediction of the effects of sleep deprivation to be made across different task contexts [19].

Driver inattention has been identified as one of the leading causes of motor vehicle accidents. Distractions are a common component of everyday driving. In terms of overall event durations, the most common distractions are eating and drinking (including preparations for eating or drinking), distractions inside the vehicle (reaching or looking for an object, manipulating vehicle controls, etc.), and distractions outside the vehicle. Visual attention performance significantly predicts real-world accident frequency [20]. Studies with unobtrusive video camera units showed that distractions are frequently associated with decreased driving performance, as measured by higher levels of no hands on the steering wheel, eyes directed inside rather than outside the vehicle, and lane wanderings or encroachments [21]. Low scores on attention and vigilance tasks are associated with higher crash risk rates and on-road driving performance [22]. Clearly, sleep deprivation exacerbates exponentially the distractions and attention deficit.

Aspects of motor speed, such as simple visual reaction time, are also important skills in adverse situations (e.g. being able to brake quickly if a pedestrian steps out on the road). Moderate correlations have been observed between simple reaction time tasks and on-road driving performance, with stronger correlations observed for complex reaction time [23]. Slowing of reaction times and lapses in attention are also commonly observed after periods of extended wakefulness [24,25] and are associated with lane drifting on a simulated driving task [26].

Driving is primarily automatized, although it does involve some shifts to controlled processing when routine reactions are insufficient to deal with novel or complex traffic situations. The driver needs to process multiple stimuli simultaneously, select and filter stimuli according to the road situation, and process the information in a short time frame in order to judge the traffic scene and act appropriately [27]. Therefore, information processing speed is an important component of driving. The Digit Symbol Substitution Test (DSST) is one measurement that assesses information processing and motor speed, and has been shown to be related to simulated driving performance in rested subjects [28]. Impairment in DSST performance has been observed in some [25,29] but not all [30] studies of sleep-restricted subjects. Executive, higher order function is required for integrating introspective, sensorial, and situational information, whilst suppressing distracting information by focusing attention relevant stimuli and planning a response. A number of tasks that tap into executive functions have been found to correlate with driving skills [27,28,31].

The frontal cortex is largely thought to control attention and executive function and is vulnerable to events. Many conditions that impair frontal lobe functioning, such as aging, can potentially lead to a driver taking inappropriate risks, having poor insight into performance deficits, concentrating on inappropriate thoughts and actions, and having problems making behavioural modifications based on new information from the road scene.

A significant problem of our society, in which there are more and more elderly drivers due to the aging population, is the interaction between the senile degeneration of the higher functions and driving ability. There are few ways of discerning driving risks in patients with early dementia and mild cognitive impairment. Some recent findings suggest that there may be a link between hippocampal atrophy and difficulties with lane control in persons with mild cognitive impairment [32]. These observations, if confirmed, could provide useful information for the evaluation of driving skills.

Neuroimaging studies demonstrate that even a single night of sleep deprivation may negatively impact on driving performance [33]. Driving performance and neurocognitive vigilance rates and reaction times are significantly impaired after sleep deprivation [34]. Combined sleep deprivation and circadian effects (frequently present during night time driving) might have more significant effects on executive function. Short-sleep duration/sleep deprivation is common in shift and night workers. Consequently they are more likely to be at higher risk of experiencing increased fatigue than daytime workers and the unemployed [35].

To date, little is known about the link between insomnia and the risk of motor vehicle accidents. An international cross-sectional survey conducted across 10 countries showed that 20.9% of subjects suffering from insomnia reported having had at least one home accident within the past 12 months, 10.1% at least one work accident, 9% reported having fallen asleep while driving at least once and 4.1% reported having had at least one car accident related to their sleepiness. Reduced total sleep time may be one of the factors accounting for the high risk of accidents in individuals who complain of insomnia [36].

Sleep and fitness to drive

Sleepiness plays an important role in major commercial vehicle crashes [37-42]. The prevalence of excessive sleepiness in the general population around the world ranges from 6.2 to 32.4%, with an inheritability of 38-40% [16].

In the U.S.A., a series of studies by the National Transportation Safety Board (NTBS) have highlighted the significance of sleepiness as a factor behind accidents involving heavy vehicles [43]. In the very thorough 1995 study, the NTSB came to the conclusion that 52% of 107 one-vehicle accidents involving heavy trucks were fatigue related; in 17.6% of the cases, the driver admitted to falling asleep. As early as 1990 the NTSB indicated fatigue as the most important cause (31%) of fatal accidents involving heavy trucks in which the driver had been killed. The extent of fatal, fatigue-related accidents is considered to be around 30% (1990s). This compares with approximately the same level of incidence in the air-traffic sector, while equivalent accidents at sea are estimated at slightly below 20% [44].

The National Sleep Foundation has been conducting the Sleep in America® survey since 1991. The survey is representative of the U.S. population aged between 23 and 60. The 2013 NSF Sleep in America Poll confirmed that those who classify themselves as exercisers report better sleep. It then follows that non-exercisers report worse sleep and health. The study also indicated that, during the 12-month span prior to the survey, 32% of the respondents stated they had driven drowsy ≥ once/month, and 36% admitted to briefly nodding-off while driving, with 2% having experienced a drowsy-driving accident or near accident [45].

Since excessive daytime fatigue and sleepiness increase the risk of driving crashes, and sleepiness originates both from voluntary and pathological conditions, addressing impairment in commercial drivers requires addressing both insufficient sleep and a less common sleep apnea [46].

Epidemiological studies indicate that sleep-related crashes represent up to 20% of all traffic accidents in industrial societies [40,47-49], and driving while drowsy has been identified as the major cause of fatal road crashes [37-39]. Very recent studies confirm that there is an almost six-fold increase in the odds of crashes involving injury for vehicles driven by people who are not fully alert or sleepy, or by people reporting less than 6h of sleep during the previous 24 hour [50].

A cross-sectional telephone study using a representative sample of 62.8 million inhabitants from 3 American states, showed that 19.5% of the sample had moderate excessive sleepiness and 11.0% had severe excessive sleepiness. Factors associated with moderate excessive sleepiness were sleeping 6h or less per main sleep episode; obstructive sleep apnoea syndrome (OSAS); insomnia disorder; restless legs syndrome; major depressive disorder; anxiety disorder; use of tricyclic antidepressant; presence of heart disease; cancer, and chronic pain [51].

Drowsy driving is a major public health problem. A study in the USA showed that working > 40 hr per week and shift work are associated with increased risk of drowsy driving. Odds ratios for falling asleep behind the wheel are higher in shift workers with symptoms of insomnia or excessive sleepiness compared to day workers and shift workers without sleep complaints [52].

Commercial truck drivers are especially prone to drowsy driving. A congressionally mandated study of 80 long-haul truck drivers in the United States and Canada found that drivers averaged less than 5 hours of sleep per day [53]. It is no surprise then that the US National Transportation Safety Board (NTSB) reported that drowsy driving was probably the cause of more than half of crashes leading to a truck driver's death [54]. According to the US National Highway Traffic Safety Administration (NHTSA) for each truck driver fatality, another three to four people are killed [55].

More recent studies confirm that a significant proportion (2.9%) of commercial drivers report near-miss sleepy accidents during their journeys [56]. A study in Tanzania showed that truck drivers usually drive an average of 10.6 h without a break, with several drivers reporting that they had to drive 24 h without rest. Almost 40 percent of the drivers reported being involved in at least one crash. Sleepiness was one of the most common causes of accidents [57]. A comparison between three Norwegian surveys on road safety, conducted in 1997, 2003, and 2008 showed that tiredness or sleepiness behind the wheel still contributes to between 1.9 and 3.9 per cent of all types of accident. Accident-involved drivers who were not responsible for the accident, reported a reduction in the incidence of sleep behind the wheel for the preceding year, decreasing from 8.3 per cent in 1997 to 2.9 per cent in 2008 [58].

Individual sleepiness symptoms are related to impairment during acute sleep deprivation and might be able to assist drivers in recognizing their own sleepiness and ability to drive safely. Research has revealed a few indicators of drowsiness and drowsy driving [59-61]. These include: frequent blinking, longer duration blinks and head nodding, having trouble keeping one's eyes open and focused, memory lapses or daydreaming, drifting from one's driving lane or off the road. As drivers are not always aware that they are becoming impaired as a result of sleepiness, using specific symptoms of sleepiness might assist with recognition of drowsiness-related impairment and help drivers judge whether they are safe to drive a vehicle. A recent study showed that symptoms related to visual disturbance and impaired driving performance are most accurate at detecting severely impaired driving performance [62].

Although people who fall asleep for more than a few minutes are often aware of those lapses in wakefulness, drivers may not be aware of shorter lapses and micro-sleeps, which can also have serious consequences when a quick reaction is needed to avoid high-speed crashes [63]. Most people also are not aware of how drowsiness affects their driving performance, even without falling asleep. Studies suggest that people cannot reliably detect how sleepy they are, and when they are likely to fall asleep, presumably because they are either unaware of, or do not pay attention to signs that sleep onset is likely [64]. People frequently deny how sleepy they are, and whether sleepiness interferes with their driving. Factors that strongly suggest a sleep-related accident include a vehicle leaving the road and a lack of braking, skid marks, or other evidence that the driver made no attempt to avoid crashing. Police investigators often take that evidence into consideration when classifying an accident as sleep-related.

Sleepiness caused by sleep disorders

Sleep disorders are the most common sources of excessive daytime sleepiness (EDS) and fatigue. Several studies performed in the last 20 years show a clear relationship between sleep disorders and RA. Those with OSAS frequently complain of EDS because of non-restorative and continuously disrupted sleep [65,66]. This is also the situation with other sleep disorders, such as restless leg syndrome, periodic limb movement disorder, narcolepsy, and insomnia [67].

Studies on the relationship between sleep disorders and RA are impressive. In an Australian study it has been observed that approximately 50% of injured motor drivers surviving vehicle collision had at least one sleep-related risk factor [68]. In a large cohort of regular highway drivers, 16.9% complained of at least one sleep disorder, 5.2% reported obstructive sleep apnea syndrome, 9.3% insomnia, and 0.1% narcolepsy and hypersomnia; 8.9% of drivers reported experiencing at least once a month an episode of sleepiness at the wheel so severe they had to stop driving. One-third of the drivers (31.1%) reported near-miss accidents (50% being sleep-related), 7.2% reported a driving accident in the past year, and 5.8% of these driving accidents were sleep-related [69].

OSAS, one of the main medical causes of excessive daytime sleepiness, has been shown to be a risk factor for motor vehicle crashes [70].

There are several reasons for this high prevalence. Firstly, the prevalence of OSAS is rather high in the general population, as it ranges between 2% and 4% [71]. In selected populations the prevalence of OSAS has been reported to range from 12% [72] to 26% [73] or even 50% [74].

Knowledge about risk is established for over 30 years. Findley et al. [75] found a higher risk of RA among patients suffering from sleep-related breathing disorders compared to controls. Haraldsson et al. [76] observed that the single-car accident rate was almost 12 times higher among patients with sleep spells whilst driving, compared to controls. A study on heavy vehicle drivers in the UK [77] showed that drivers who reported snoring regularly whilst sleeping at night or who were obese or who had a noticeably large collar size had higher accident liabilities than those not exhibiting these characteristics. Accident liability increased with increasing scores on the Epworth daytime sleepiness scale. Truck drivers with sleep-disordered breathing had a two-fold higher accident rate per mile than drivers without sleep-disordered breathing [66]. Connor et al. [49] showed that being sleepy while driving increased the risk of a serious injury crash by eight-fold.

Treating OSAS normalizes the rate of RA [70,78]. However, performance may remain impaired in patients with severe OSAS even after treatment [79]. A growing body of evidence indicates that some neurobehavioral deficits in patients with severe OSAS are not fully reversed by treatment. One of these may be resistance to monotonous driving conditions. With a normal night's sleep, effectively treated older men with OSAS drive as safely as healthy men of the same age. However, after restricted sleep, driving impairment is worse than that of controls. This suggests that, although successful CPAP treatment can alleviate the potentially detrimental effects of OSAS on monotonous driving following normal sleep, these patients remain more vulnerable to sleep restriction [80].

Despite the available scientific evidence, most countries in Europe do not include OSAS or EDS among the specific medical conditions to be considered when judging whether or not a person is fit to drive. There is no consistency in the way OSAS is considered by the national 'Physical Fitness to Drive' legislation within the 27 member countries of the European Union (EU), and most ignore OSAS. This is further reflected by the absence of any reference to OSAS in Annex III of the Directive 91/439/EEC, harmonizing Driving Licence regulations in the EU [81]. A common European Directive seems desirable.

Individual prevention of drowsy driving crashes

Experts agree that there is no substitute for sleep, so to prevent crashes; drivers should ensure they are well rested. Being aware of signs of drowsiness might be helpful, but only if drivers act on those signs by pulling off the road and getting sufficient sleep. If that is not possible, studies suggest two useful interventions: taking a short 20-minute nap, and/or drinking two cups of coffee or other equivalently caffeinated beverages. Caffeine will improve alertness only for a short period of time, and should not be relied upon to make up for a sleep deficit.

The use of drugs to ward off sleepiness has many drawbacks. There is no evidence that modafinil, the alertness enhancing drug, can reduce drowsy driving. In one small study in which sleep-deprived individuals were given the drug and then tested on a driving simulator, modafinil reduced lane deviation but had less effect on speed deviation, off-road incidents and reaction time, while self-assessments indicated that the drug gave the sleep-deprived participants false confidence in their driving abilities [82].

Patients receiving armodafinil had significantly greater improvements in late-in-shift clinical condition and in wakefulness and overall global functioning than did placebo-treated patients, regardless of shift duration [83].

There is also no evidence for anecdotal reports that opening car windows, stopping to stretch, or turning up the volume of a car radio can prevent drowsy driving crashes. In conclusion, drowsy driving is a prevalent and serious public health issue that deserves more attention and specific initiatives designed to educate drivers, save a significant number of lives and avert disability due to RA.

Recent data suggest that continuous blue light exposure during nocturnal driving resulted in significantly reduced ILC and weaving compared with caffeine placebo, and that it was similar to caffeine (a countermeasure reference) in improving driving ability [84].

Nowadays, the old saying that "only sleep can make up for a loss of sleep" is still true: napping before driving or stopped during driving for a nap is an effective countermeasure to alertness and performance deterioration associated with night work and sleepiness at the wheel [85].

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