Barriers to acceptance

Barriers to driver acceptance of the systems were identified. Drivers will lose trust in systems that are unreliable. Based on the amount that drivers were willing to pay for the systems, cost may also be a barrier to acceptance, particularly maintenance and service costs. It is encouraging that several potential barriers to acceptance turned out not to be of concern. Drivers found the level of control of the systems acceptable, they did not feel that they would rely too strongly on the systems at the expense of their own judgement, and did not think the systems would distract them from their driving.

General issues/limitations

The quality of self-reported behaviour data is always subject to the accuracy of self-report. Drivers may want to be regarded in a positive manner and thus report more acceptable behaviours. Drivers may also not be aware of how often they perform a specified behaviour. Self report data for any of the behaviours in this study could be subject to these problems.

The questionnaires that were used in this study were comprehensive. However, this meant they were also long and sometimes repetitive. Data quality can be affected if participants become bored and/or annoyed. The difficulty in designing questionnaires for this study was that previous research in this area had taken what the authors regarded as a piecemeal approach to subjective data collection. It was unclear what type of subjective data should be collected. Thus it was difficult to know how to reduce the questionnaire length while still retaining important concepts. Fortunately, the extensive subjective data collected during the TAC SafeCar study can now inform the design of subjective data collection instruments for future research of this sort.

Conclusions

Overall, the TAC SafeCar systems were rated as being acceptable in terms of their usefulness, effectiveness, social acceptability and usability. That is, the systems were considered to serve a purpose and to do what they are supposed to. Drivers were consistent in their belief that the TAC SafeCar systems would be effective for drivers who inadvertently practice unsafe driving behaviours and that the systems would be less effective for drivers who intentionally drive in an unsafe manner. None of the systems increased driver workload, and some positive changes to driver attitudes resulted from exposure to the ITS. Importantly, the two systems which were found to have the greatest effect in enhancing safe driving performances – the ISA and SBR systems – were also acceptable to drivers. On this basis, the authors recommend that these two systems be widely deployed on passenger vehicles in Victoria.

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Reducing road accidents through fatigue detection and monitoring: A review.

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Abstract

Driver fatigue is recognised as a major risk for road safety. Fatigue reduces drivers' ability to react to road and traffic conditions, resulting in potential serious injuries and fatalities. A method of reducing the risk of fatigue related accidents is through monitoring/detecting fatigue changes in drivers. Fatigue is shown to be associated with factors like psychological, physiological and performance based changes in drivers, and these could be used to indicate the occurrence of fatigue. This paper reviews the literature concerned with these measures, and discusses the implications of these measures for road safety as well as their limitations. Research suggests that these measures have the potential to be used in fatigue detection/warning systems. However, further research is needed before such devices could be implemented in vehicles as fatigue countermeasure devices.

Notations

ATSB Australian Transportation Safety Bureau
RTA Road Traffic Authority
TAC Transport Accident Commission, Victoria
EEG Electroencephalography
HRV Heart Rate Variability

Introduction

Driver fatigue accounts for approximately 20-40% of motor vehicle accidents (1, 2). It has been shown to affect physiological arousal, sensorimotor and cognitive functions, and thus impair a drivers' ability to react appropriately to road conditions (3). Brown (4) described " the main effect of fatigue to be a progressive withdrawal of attention from road and traffic demands, which may impair the drivers' ability to control the vehicle and/or to avoid collisions" (p.311). Furthermore, signs such as an increase in driver errors and slowing of reaction time also suggest that fatigue impairs cognitive processes (5). Research has found that the majority of drivers agree that their driving deteriorates as they fatigue, resulting in problems like slower reaction time and poorer gear changing (6). Due to these reasons, accidents resulting from fatigue are found to cause more severe damage and have a higher risk of resulting in fatalities (7). The Bureau of Transport Economics, Australia has estimated the annual cost of fatigue related road accidents to be as high as $3 billion (8). Driver fatigue is associated with loss of concentration, drowsiness, yawning, slow reaction time, sore or tired eyes and microsleeps (2), and is believed to be influenced by factors such as time of the day (9-11), age and gender (10,12,13,14) and work conditions (9,15,16,). For instance, Horne and Reyner (13,17) found that young adults were more likely to be involved in fatigue related accidents during the morning, and a roadside survey also found that tiredness is prevalent among young night-time drivers (18). RTA has reported that 46% of fatigue- elated accidents happened in highways (2), which could be accounted to monotonous and long distance driving in these roads.

Fatigue is more common among occupational drivers, and the problem of the risk of fatigue among Australian and New Zealand truck drivers is well recognised (3,9,19,20). Furthermore, 40-70% of truck drivers agreed that sleepiness is a problem while driving (9,16,21). However, the prevalence of fatigue related accidents has been found to vary between 5-50% (22). For example, The Transport Accident Commission (TAC), Victoria identified driver fatigue as the cause of 21% of fatal accidents in Victoria in 2003. Furthermore, fatigue accidents were believed to be responsible for around 70 deaths and approximately 500 serious injuries each year on Victorian roads (23). The Road Traffic Authority (RTA) of NSW reported 122 and 112 fatalities in 2000 and 2002 respectively, accounting for approximately 20% of fatalities (2). In contrast, the Australian Transportation Safety Bureau (ATSB) identified fatigue as the contributor of only 7% of accidents in Australia in 1998, based on coroner and police reports (22). This variation in statistics suggests that fatigue accident reporting is difficult, and this may be due in part to drivers' unwillingness to acknowledge they were fatigued for fear of prosecution and/or loss of insurance claims (13). A large number of fatigue related accidents could also go unnoticed and therefore the actual numbers could be higher than the figures recorded. For instance, a survey among New York State drivers revealed that 54.6% had driven while drowsy within a year, and 2.5% had driven in a very drowsy state (12). These variations could also be due to a lack of an agreed method to measure fatigue levels and this is a major problem associated with driver fatigue (22).

Attempts to define fatigue related accidents have been made. Horne and Reyner (17) identified characteristics such as a vehicle running off the road, brakes not being applied, speed over 50km/h, no obvious mechanical defect, driver blood alcohol level below legal limits, as evidence of inattention resulting from fatigue (17,24). The RTA (22,25) identify a fatigue related accident as (a) police identify the driver as being fatigued and/or (b) signs of loss of concentration due to fatigue (such as a vehicle moving to the wrong side of the road). The ATSB operational definition of fatigue accidents includes those that occur during " critical times" for fatigue related accidents, namely midnight to 6am and 2 to 4pm (22). There are limitations involved in measuring fatigue related accidents. For instance, fatigue can often be masked by prevalent factors such as speed and alcohol, and the presence of these factors increase the difficulty of assessing the impact of fatigue in an accident (26,27). Furthermore, these limitations have resulted in a lack of methods that can be used to identify a fatigued driver or to measure objectively the level of fatigue following an accident. Consequently, fatigue countermeasures have mainly focused on reducing fatigue related accidents through education and research. Clearly, additional countermeasure work needs to be conducted to improve this situation if we are to reduce fatigue related accidents in Australia.

Driver Fatigue Management

A number of initiatives have been introduced to reduce the risk of fatigue-related motor accidents. These countermeasures have focused on three key areas, which are, introducing driver-friendly road conditions, liaising with stakeholders and initiating education campaigns. Some of the improvements in road conditions include the introduction of driver rest areas (fatigue revive sites), profile line marking designed to warn drivers when they cross the lines and divided roads to minimise head-on collisions (head-on collisions are responsible for 38% of fatigue related accidents) (2). Education has been an important part of driver fatigue awareness campaigns. A television commercial entitled " Nightshift" aired in 1996 by TAC, carried the message " driver fatigue kills" , and is believed to have increased the public's awareness of the consequences of driving while fatigued (2). In 2001, the RTA launched its “ Microsleep” “stop, revive, survive” campaign, educating drivers of the effects of microsleeps, and the importance of reviving when signs of fatigue begin to appear (2). However, despite increased awareness, drivers tend to rely upon less effective practices such as drinking tea/coffee, rolling down the window, listening to the radio, and talking to passengers as methods of reducing fatigue (4,6). Research in the Australian transport industry found the majority of bus drivers reported using strategies such as drinking coffee, listening to the radio, or rolling down the window whereas truck drivers more likely report sleep or taking breaks to avoid fatigue (6). Some studies have found that caffeine and short naps, especially when taken together, increase the driver's alertness (28). Research among college students in the USA found strategies such as talking to a passenger, snacking and rolling down the window help to avoid driver fatigue (29). Nevertheless, these strategies have been found to provide only short-term benefits (28), and more importantly, should not be relied upon to ensure the safety of drivers.

Another important area in the development of fatigue countermeasures is the use of fatigue detection and monitoring technology. Whilst still experimental, this technology has the potential to reduce fatigue related accidents and improve road safety. Therefore, the aim of this paper was to review the literature on existing fatigue detection/ monitoring methods and to explore their implications for driver fatigue countermeasure devices. A comprehensive literature search was conducted using Science Direct and Medline journal databases. Google was used to obtain particular articles and information on some countermeasure devices.

Fatigue Monitoring and Detection

Fatigue monitoring/detection should be considered an important component in the effective management of driver fatigue (30). A range of measures have been used to detect fatigue, and these vary due to a lack of an agreed definition of fatigue. In the literature, terms such as fatigue, sleepiness and drowsiness have been interchangeably used to describe the state of driver fatigue; however, these terms are distinct physiological states (7,21,31). For instance, Grandjean (32) referred to fatigue as a feeling of tiredness and reduced alertness, which impairs both capability and willingness to perform a task. Johns (7) defined sleepiness as sleep propensity or the probability of falling asleep at a particular time. Drowsiness has been defined as “ the moment when persistent eyelid closure occurs (slow/prolonged eye closures as opposed to normal eye blinks)” (31,33). However, Williamson et al. (3) pointed out that physiological arousal and subjective experience should be considered when studying fatigue. More recently, Craig and colleagues also encouraged the notion that driver fatigue is both a physiological and a psychological phenomenon (31). In line with this, Hancock and Verwey (34) defined fatigue as “ a multidimensional physiological-cognitive state associated with stimulus repetition, which results in prolonged residence beyond a zone of performance comfort” (p. 497). For the purpose of this paper, the term “fatigue”, rather than “sleepiness” or “ drowsiness” , will be used to describe tiredness phenomenon.

Driver fatigue is a complex, multidimensional phenomenon that gives rise to behavioural, physiological, and psychological changes in a person (3,7,34), and due to its complex nature measures of driver fatigue vary. Current fatigue monitoring/detection methods can be divided into three categories based on the method being used to measure fatigue. These are: (i) subjective/psychological measures of fatigue such as self-report, (ii) Performance measures such as steering errors and deviation in lane position, and (iii) physiological measures such as eye movement and brain wave activity. The search for reliable in-vehicle systems aimed to monitor, detect and alert drowsy drivers, has become a major goal of driver fatigue research. Therefore, the second two measures particularly are of interest in terms of their use in fatigue monitoring devices.

Fatigue countermeasures based on self-reported fatigue

Most of the early literature on driver fatigue has defined fatigue as a subjective experience that results in psychological and behavioural changes in a person (4,21). Brown (4) defined fatigue as “ the subjective experience of tiredness and a disinclination to continue performing the current task” . Self-reported fatigue is commonly used in research (21). For instance, research found a moderate to high reliability between perceived alertness level and performance (35). Self-reported fatigue level of pilots increased with the time on the task and these subjective measurements were significantly correlated with performance decrements (36). Subjective measures of fatigue are preferred by those who are reluctant to use objective measures such as heart rate and brain wave activity, due to the intrusive nature of these measurements (5). Nevertheless, some researchers are less optimistic about the validity of self-reported fatigue, simply because a persons' ability to understand his/her own fatigue level is believed to be impaired when they are fatigued (30,31). Subjective reports of fatigue could also be susceptible to individual bias and differences (5) and some have suggested that individual differences influence self-reported fatigue (37). Therefore, subjective measures such as self-reports alone should not be used as a fatigue detection method. The self-assessment of fatigue may help to increase drivers' awareness of their fatigue level, and may assist them to determine their ability to continue driving. This method should be reinforced by driver education of fatigue and its consequences, if it is to be effective. Future research should give attention to improving current self-report measures.

Countermeasures based on monitoring driver performance

Driving performance measures are used to monitor the decremental effects of fatigue on the driver. Researchers have utilized performance measures such as steering wheel movements, lane/track position, maintenance of speed, and driving off the road and lane crossing (30,38). Most common changes in driving performance associated with fatigue include changes of speed and lateral lane position, and some have concluded that steering movement could be a valuable fatigue decrement measure (21). Research found that timing and design of warnings could prevent 85% of lane departures associated with fatigue (39). Some have argued that these performance measures could be used as fatigue countermeasures as they are designed to detect fatigue related deterioration in driving performance (30). In spite of this, some researchers have suggested that changes in driving behaviour caused by reasons other than sleepiness need to be investigated before using performance measures such as steering movement as a monitoring tool (21). For example, steering patterns and driving behaviour can also be affected by individual differences such as driver personality and experience. Furthermore, research in this area is still at the experimental stage, and the reliability and efficacy of these devices on real-road situations has yet to be comprehensively tested.

Countermeasures based on measuring physiological changes in drivers

The association between eye activity and fatigue has been well demonstrated (40). Researchers found that eye blink rate increases after sleep deprivation (41). Caffier and colleagues (42) found that alert eye closure during a blink occurs for around 200 ms (range from 100 to 300 ms) increasing to around 300 ms during fatigue (range from 200 to 450 ms). The blink rate of a person also increases as a person fatigues. However, researchers (40) advise that care should be taken when using blink rate as a measure, as it is influenced by factors other than fatigue. Nevertheless, eye activity can be considered a good indicator of fatigue (31, 36, 40,43-45). For instance, PERCLOS (percentage of eyelid closure over the pupil over time) identifies slow/prolonged eye closure compared to regular eye blinks and is considered to have potential as a fatigue monitoring device (30,46,47). Another system detects driver fatigue based on the movement of the eyes, and is focused on identifying episodes of microsleep (48). A camera continuously feeds-in images of the face to a processor and the system identifies a microsleep based on the time the eyes are open or closed, and the duration that the eyes are closed. The system warns the driver when fatigue is detected. Advantages as a fatigue detection method: they are non-invasive and most importantly, the method has been validated (30,33, 49). Although eye activity is a potential reliable measure for monitoring driver fatigue, using eye activity, especially eye closure, as a driver alerting device is problematic as eye movement changes appear in late stage fatigue (30). Furthermore, costs associated with installing devices such as a camera could be very high, and drivers may not want to bear additional costs. Issues of privacy may also be a concern, as few will like the idea of being under surveillance.

Electroencephalography (EEG) has been used as a measure of fatigue (41, 45,50-53). For example, altered alpha wave activity is associated with fatigue and impaired cognitive attention (53-55) and changes in alpha and theta waves were found to be related to fatigue and reduced performance (51). The results of much of this research suggest that EEG could be a useful measure of driver fatigue and importantly, enables fatigue levels to be measured directly. Attempts to utilize EEG in fatigue monitoring (56) employing an EEG based algorithm device have been trialled offline. Its usefulness for in-vehicle detection has yet to be demonstrated. However, a major barrier of using EEG is its intrusive nature. For instance, currently in order to record brain wave activity, a driver would need to wear a set of electrodes in some form of an attachment to the head, and one may suspect that most drivers would resent such an apparatus, regardless of safety benefits. In addition, artefact from eye/face/head movements can contaminate brain signals and therefore, real time mechanisms to detect and remove signal noise must be incorporated into EEG detecting systems.

Heart Rate Variability (HRV) and heart rate are additional measurements that could be used as indicators of driver fatigue. Research findings show a consistent relationship between fatigue and changes in heart rate and HRV, suggesting these measures could be promising indicators of driver fatigue. Increases in the sympathetic component of HRV have been found to be associated with fatigue (57-59) and research has found decreased heart rate and altered HRV during lengthy tracking tasks (60). These changes were associated with increased reaction times and fatigue (60). Heart rate/HRV measures have an advantage over EEG signals in that they are large signals and therefore less likely to be contaminated by artefact (e.g. eye blinks). Heart rate measures can also be considered to be less invasive and more adaptable to real-time driving conditions, compared to measures such as EEG. Physiological measures such as electrodermal activity may also be used as an indicator of fatigue. For example, a gradual change in galvanic skin resistance between awake and sleep states has been found, and skin resistance has been shown to be higher when participants were drowsy compared to an alert phase (61). However this measure has yet to be investigated for its usefulness in detecting and monitoring driver related fatigue.

Countermeasures based on measuring psychological predictors of fatigue

Another area of interest is the study of potential psychological traits and states that could be used to predict susceptibility to driver fatigue. Extraversion has been found to be a possible predictor of fatigue proneness. For instance, those who score higher on the extraversion-boredom dimension fatigue faster than those who score low on this trait (62) and extraverts display larger decreases in vigilance compared to introverts (63). In contrast, high fatigue scores were found for individuals who scored low on Emotional Stability, Extraversion, Conscientiousness and Strength of Excitation dimensions (64, 65). Despite the contradicting results, the extraversion construct is a potential personality measure of interest for measuring fatigue proneness, and needs to be investigated further. Anxiety is another factor that has been shown to predispose an individual to fatigue (31, 45, 66, 67). Individuals who were more anxious, depressive, less self-assured, more conscientious (rule-bound), less socially bold and less adaptable had shown a higher predisposition to fatigue (31). The Sensation-seeking construct is another trait shown to be associated with driver behaviour. High sensation seekers, who are more tempted to seek novel, varied and intense sensations and experiences, have been shown to be more at a risk of traffic accidents compared to low sensation seekers (67). Moreover, the sensation-seeking dimension has been shown to be significantly related to deviations of the steering wheel (68).

While a personality trait or a psychological status alone could not predict when someone would fatigue, these could provide a viable approach to understanding and managing driver fatigue. For instance, it could be used to predict the effects of individual differences on the appearance and extent of driver related fatigue. An understanding of the relationship between psychological factors and fatigue, and identifying possible psychological indicators of fatigue proneness would aid in enhancing current fatigue countermeasures. This knowledge could also be used for the benefit of professional drivers by designing shift/work patterns to suit individual needs, and in determining the task load for each person.

Conclusions

It is clear that fatigue has an adverse effect on drivers and that it presents a serious threat to road safety. One way of potentially addressing this problem is by utilising suitable measures and technology to monitor/detect fatigue. For this reason, a clear understanding of available fatigue detection/monitoring strategies and devices is essential. Despite the enthusiasm shown by many, some researchers remain sceptical about the use of fatigue detection/monitoring devices as a countermeasure strategy. For instance, MacLean (21) has expressed his concern that such devices may give drivers ' a false sense of security' . Horne and Reyner (13) also argue that alerting devices may tempt drivers to take further risks, which commonsense would otherwise have prevented. They have proposed that self-awareness of driver fatigue should be encouraged as opposed to using in-car alerting devices. Desmond and Matthews (69) recommend that task-specific effects on fatigue should be considered when implementing in-car fatigue detecting systems. Factors such as the difficulty of tasks, performing secondary tasks and time-on task can have an effect on a person' s vigilance level and the extent of fatigue (69, 70). Additionally, one assumes that fatigue detection/ monitoring technology would need to be highly reliable before it would be accepted (i.e. the technology should detect almost every fatigue occurrence, with few false positives). The technology would also need to be economically viable. These limitations provide real challenges to the development of fatigue detection/monitoring technology.

On the other hand, fatigue detecting devices that provide early warning (ie. before driving skills are impaired) could be valuable and may be more practical than devices that alert the driver once signs of fatigue have appeared. Williamson and Chamberlain (30) have pointed out that such early warning systems would give the driver the option to take necessary early avoidance measures such as drinking coffee, unlike late warning systems when the driver is already fatigued, in which case the only suitable step is to take a substantial break from driving. It is important to bear in mind that most detection/monitoring devices are still in the experimental stage, and the results of laboratory testing may not necessarily mirror the real-road experience (4, 5).

In the absence of a usable detection/monitoring device, practical strategies such as taking adequate breaks, planning trips/shifts, reducing sleep debt, and avoiding driving when fatigued remain the most viable countermeasures against driver fatigue. Danger hours should be avoided when planning long trips, and adequate rest/sleep periods between trips should be implemented to reduce fatigue (3). For example, irregular shifts force professional drivers to drive during circadian rhythm troughs which would result in a lower performance level (4) and risky driving behaviour.

Given the multi-factorial nature of fatigue, combining measures of performance, physiology and self-report has been recommended so that a clearer picture of an individual's level of fatigue can be obtained (31). This would enhance the understanding of the effects of fatigue and improve fatigue countermeasure technology. Furthermore, incorporating psychological indicators of fatigue should be considered when implementing fatigue detection strategies. For instance, this knowledge could be used in implementing a driver screening process to identify suitable drivers for varying shifts or used as a self-assessment guide before non-professional drivers take to the road. Most importantly, there is no substitute for sleepiness but sleep, and therefore it is important that drivers take adequate rest prior to driving. Individuals or authorities should never underestimate the consequences of fatigue, and investigating measures to detect/monitor driver fatigue with the ultimate goal of establishing a ' gold standard' should remain a road safety priority.

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