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The effect of three low-cost engineering treatments on driver fatigue: A driving simulator study

Natasha Merat*, A. Hamish Jamson

Institute for Transport Studies, University of Leeds, LS2 9JT, UK

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ABSTRACT

Three engineering treatments were implemented in a driving simulator study to assess the effect of road-based measures on alleviating the symptoms of fatigue. Using results from previous research on the effect of circadian rhythms on fatigue-related crashes, two groups of male drivers were recruited for this study: young shift workers under the age of 35, who attended immediately after their night shift, and older drivers over the age of 45, who completed the study during the 'post lunch dip' period, after consuming lunch. Eye tracking (PERCLOS) and lateral driver performance measures were used to assess whether baseline measures of fatigue changed after drivers experienced each of the three treatments, which included variable message signs, chevrons and rumble strips. Results showed a marked difference in these measures between drivers' baseline (not fatigued) and experimental (fatigued) visits. There were also some reductions in lateral deviation and eye closure (as measured by PERCLOS) when the treatments were encountered, but no marked difference between the three treatments. These results suggest that in addition to driver- and vehicle-based methods currently employed to mitigate the effects of fatigue, the inclusion of such engineering measures may help alleviate fatigue-related impairments in driving, particularly if such treatments are implemented during long stretches of straight monotonous roads which are known to be associated with fatigue-related crashes. However, positive effects of the treatments were short lived, prompting the need for further investigations on their optimal frequency of presentation and combination to achieve maximum impact from these low-cost, road-based treatments.

1. Introduction

Fatigue[1] is a common and well known cause of road traffic accidents worldwide, with around 20% of UK road accidents thought to be caused by fatigue (Maycock, 1997), whilst this figure is closer to 40% in Australia (Fletcher et al., 2005) and North America (McCartt et al., 1995). The 100-car naturalistic driving study also links 'drowsy driving' to a five-fold increase in the risk of a crash or near crash (Klauer et al., 2006). Some well accepted characteristics of sleep or fatigue-related accidents include those that involve single vehicle occupants in a monotonous driving environment (typically high-speed highways), at night or during the early hours of the morning. These types of accidents often result in serious injury and death, and there is usually no sign of an attempt from the driver to try and stop the crash, as reports show that such incidents are not usually associated with skid marks or other signs of severe braking on the road (Horne and Reyner, 1995; NCSDR/NHTSA report, 1998). It is also widely acknowledged that the method by which such crashes are recorded in the UK is both inaccurate and unreliable (Horne and Reyner, 1995; Liu et al., 2009).

Whilst factors such as the consumption of alcohol, drugs and medication are known to increase the risk of fatigue-related accidents, severe sleep loss, long hours of driving (which is usually work-related) and sleep disorders are all known to contribute to such fatigue-related road accidents (Dinges, 1995). In addition, although any member of the driving population is likely to suffer from fatigue and sleep related driving problems, research has shown that young drivers aged between the ages of 16 and 29 (especially males), shift workers, and those with chronic sleep problems such as sleep apnoea are particularly at a high risk (Pack et al., 1995). The 24-h biological clock and circadian rhythms have also been shown to contribute to fatigue-related road accidents,

* Corresponding author. Tel.: +44 113 343 6614; fax: +44 113 343 5334.
E-mail address: n.merat@its.leeds.ac.uk (N. Merat).

[1] As outlined in a recent review commission by the Department for Transport (Jackson et al., 2011) terms such as fatigue, sleepiness and drowsiness are used interchangeably and inconsistently in the literature. As fatigue and sleepiness are inextricably linked and can both cause impairments to driving performance, we use the generic term fatigue here to refer to a condition where capacity and motivation to perform the driving task is impaired.

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with a higher proportion of sleep-related accidents occurring during the early hours of the morning (between 2 am and 6 am) and, to a lesser extent, during the 'post lunch dip' period in the early afternoon (between 2 pm and 4 pm) (Pack et al., 1995; Thiffault and Bergeron, 2003a). Research also suggests that fatigue-related crashes are linked to the time at which different age groups are on the road, with young drivers more involved in early morning crashes, and older drivers' crash risk increasing in the early afternoon (Summala and Mikkola, 1994).

The choice of counter measures that are currently in place to combat such fatigue- or sleep-related road accidents fall into three main categories: driver-related, vehicle-related and road-related. Driver-related counter measures are perhaps the most logical method by which fatigue-related road accidents can be reduced, and involve ensuring that drivers are reasonably educated and informed about the signs of the onset of fatigue, as well as the detrimental consequences of driving whilst fatigued. Laboratory-based driving simulator tests have shown that preceding a short (20 min) nap with a caffeinated drink is one of the most effective methods by which sleepiness and fatigue-related driving errors can be temporarily alleviated (Reyner and Horne, 1997). A 'slow-release' caffeine dose has also been shown to lessen the signs of fatigue for up to 5 h, and is therefore useful to minimise the risk of fatigue on longer journeys (de Valck and Cluydts, 2001). The results of such research have, in recent years, been used in the UK to inform public information campaigns, such as the 'Think!' messages commissioned by UK Department for Transport (DfT), suggesting that drivers "Take a Break" and "Don't Drive Tired" (Department for Transport, 2008). However, a recent DfT review suggests that the success of such campaigns is not yet clear, and whilst some of the more responsible companies carefully educate their drivers about the dangers of fatigue, fatigue-related crashes continue to pose a major public health problem in the UK (Jackson et al., 2011).

Another popular technique used to tackle driver fatigue is via in-car technologies, which have become more feasible with advancements in sensors and systems. Typically, these systems can detect driver sleepiness using sensors and provide warnings should driver performance fall below certain thresholds. Examples include technologies based on monitoring drivers' eye and head movements, which then warn drivers of their fatigue if their eyes are closed for certain durations (e.g. the seeing machines driver state sensor or the eye alert® fatigue warning system). However, the challenge that still remains with such systems is that they are not always able to account for individual driver differences (Liu et al., 2009). In addition, over-reliance on such systems poses an obvious danger, if drivers choose to use them as a method for monitoring their safety on the road, whilst knowingly driving in a fatigued state (Balkin et al., 2011).

In terms of road-related countermeasures to fatigue, perhaps the best known and most widely used interventions are edge or centre line rumble devices (Anund et al., 2008; Mahoney et al., 2003) which can alert drivers by causing audio-tactile vibrations, as the vehicle tires drive over them. The motivation for implementing such road-related changes is based partly on research which suggests that fatigue-related crashes are particularly prevalent for long straight sections of roads which do not provide adequate visual stimulation for drivers (Oron-Gilad and Ronen, 2007; Thiffault and Bergeron, 2003b).

Examples of other treatments involving changes in the road surface and surrounding environment include surfacing the road shoulders with different coloured asphalt (Rosey et al., 2008), and the musical road sponsored by Honda in California, which used grooves in the road to produce a well-known sound track (BBC, 2008). Research on rumble devices has shown a 15–20% reduction in fatigue-related accidents as a result of centre line rumble strips (Persaud et al., 2004), whilst edge line rumble strips are thought to have reduced such accidents by around 40% (Mahoney et al., 2003; Räsänen, 2005). However, the long term success of other innovative treatments is yet to be determined.

The study reported here was partly motivated by the desire of UK Highways Agency engineers to understand the effect of implementing low-cost and easy-to-deploy road-based treatments on alleviating the symptoms of driver fatigue. As edge-line rumble devices are already quite widely used for this purpose, there was a desire to employ other treatments which were envisaged to reduce the monotony of the simulated road used in this study. Previous research (Thiffault and Bergeron, 2003b) was used to design a simulated road which was likely to induce fatigue due to its geometrical characteristics (i.e. long, straight stretches with little visual stimulation). The effect of including our chosen treatments on the performance of two groups of fatigued drivers was then assessed in designated sections of this road. Whilst some studies suggest that passive fatigue develops with time on task over a long period of time (Åkerstedt et al., 2005; Oron-Gilad and Ronen, 2007), others have observed fatigue-related behaviour after only 20 min of driving on their monotonous simulated road (Thiffault and Bergeron, 2003b). The treatments used in the current study were therefore encountered by drivers after about 30 min of driving.

Previous studies have used a number of methods to impose fatigue, including sleep deprivation, time of day (based on circadian rhythm changes) and time on task. In this study, we recruited two groups of drivers and observed their performance on two separate days (alert versus fatigue visit) as well as assessing the effect of our three engineered treatments on their performance during a time when we were confident participants would be suffering from fatigue. The effect of these treatments on alleviating driver fatigue was investigated by observing lateral driver performance and by monitoring drivers' eye closure (using PERCLOS). Observations were conducted at three designated sections within a drive: before, during and after each engineering 'treatment'. Lateral deviation, as measured for example by standard deviation of lane position (SDLP) or the high frequency component of steering wheel movements (HFS). HFS is known to increase with driver fatigue (Boyle et al., 2008; Ingre et al., 2006; Summala et al., 1999; Thiffault and Bergeron, 2003b). HFS, normally associated with driving task demand, is defined as the ratio between the power of the high frequency component and of all steering activity. The magnitude of the high frequency band of steering wheel angle reflects steering corrections. However, this method aims at excluding the effect of open loop behaviour, only focussing on steering corrections. Increased corrections are commonly associated with more erratic steering performance (MacDonald and Hoffman, 1980).

Fatigue is also shown to increase variations in driving speed (Arnedt et al., 2000), although in this study, drivers' speed was controlled by a speed limiter (set at 80 mph) during the three treatment drives. The main reason for this intervention was to ensure that all drivers approached the three treatments at around the same point in time, eliminating the temptation for some drivers to drive as fast as possible through the road, because they may have been bored and wished to add some interest to their drive. Finally, PERCLOS (PERcentage eyes CLOSed) has been shown to be sensitive to sleepiness and fatigue (Dinges and Grace, 1998; Lal and Craig, 2001), whilst an increase in fatigue is also associated with longer blink durations (Dinges et al., 2005). As well as assessing driver's eye movements and driving behaviour when they drove through each treatment, we asked participants to describe their impression of the treatments and also report their level of alertness after driving through each treatment.