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THE EFFECT OF THREE LOW-COST ENGINEERING TREATMENTS ON DRIVER FATIGUE: A DRIVING SIMULATOR STUDY

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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, McCulloch, Baulk, Dawson, 2005) and North America (McCartt, Ribner, Pack & Hammer, 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, Dingus, Neale, Sudweeks & Ramsey, 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 & Rayner, 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 & Rayner, 1995; Liu, Hosking, & Lenné, 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-hour biological clock and circadian rhythms have also been shown to contribute to fatigue-related road accidents, with a higher proportion of sleep-related accidents occurring during the early hours of the morning (between 2am and 6am) and, to a lesser extent, during the 'post lunch dip' period in the early afternoon (between 2pm and 4pm) (Pack, et al., 1995; Thiffault &

[1] As outlined in a recent review commission by the Department for Transport (Jackson, Hilditch, Holmes, Reed, Merat, & Smith, 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.

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 & 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 minute) 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 & Horne, 1997). A 'slow-release' caffeine dose has also been shown to lessen the signs of fatigue for up to 5 hours, and is therefore useful to minimise the risk of fatigue on longer journeys (de Valck and Cluydts, 2001). The results of such research has, 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, Horrey, Graeber, Czeisler, Dinges, 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, Kecklund, Vadeby, Hjälmdahl, & Åkerstedt, 2008; Mahoney, Porter & Donnell, 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 & Ronen, 2007; Thiffault & 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, Auberlet, Bertrand, & Plainchault, 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, Retting & Lyon, 2004), whilst edge line rumble strips are thought to have reduced such accidents by around 40% (Mahoney, Porter & Donnell, 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 & 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, Peters, Anund, & Kecklund, 2005; Oron-Gilad & Ronen, 2007), others have observed fatigue-related behaviour after only 20 minutes of driving on their monotonous simulated road (Thiffualt & Bergeron

(2003b). The treatments used in the current study were therefore encountered by drivers after about 30 minutes 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, Tippin, Paul & Rizzo, 2008; Ingre, Åkerstedt, Peters, Anund, & Kecklund, G., 2006; Summala, Hakkanen, Mikkola & Sinkkonen, 1999; Thiffault & 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, Wilde, Munt, & Maclean, 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 & Grace, 1998; Lal & 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.

2. Method

2.1.1. Participants

According to a North American report (NCSDR/NHTSA, 1998) time of day plays an important role in distinguishing between the road traffic accidents of different age groups. Whilst those under the age of 45 are more prone to accidents in the early hours of the morning, over 45 year olds are more likely to be involved in accidents between 12 noon and 4 p.m., the so called ‘post-lunch dip’ period. Research also suggests that men are more prone to fatigue-related accidents than women (Nelson, 1997). Therefore, to assess the effectiveness of the chosen engineering treatments on alleviating driver fatigue in this study, we recruited two groups of male drivers who attended the simulator at a time when they were most likely to be suffering from fatigue: shift workers under the age of 35 (‘shift’ group) who arrived immediately after a night shift, and older drivers over the age of 45 (‘older’ group) who were asked to take part in the experiment in the afternoon, after consuming a large lunch.

Thirty-eight drivers were recruited in total, but as 5 drivers withdrew from the study for various practical reasons, results from 33 participants (17 shift, 16 older) are reported. The participants were recruited from a cross-section of the population, with shift workers consisting of nurses, policemen, security officers and engineers. All participants completed a 7 day sleep diary (not reported here) and were asked to refrain from consuming tea/coffee and alcohol during the 12 hour period prior to their visits. Further details about the drivers’ age and driving experience are provided in Table 1.

Table 1 about here

2.2. Experimental Road and Engineering Treatments

Following a consultation workshop with the sponsors and a group of highway engineering experts, three engineering treatments were implemented in this simulator study: transverse rumble strips, chevrons and variable message signs (see Figure 1). The design of each treatment was informed by the Department for Transport (DfT) Traffic Signs Manual: Chapter 5 - Road markings (DfT, 2003). Exactly the same road geometry was used for both the baseline and experimental roads, which consisted of a 54 km long, 3-lane motorway, with very little visual clutter such as road signs or roadside objects. The roadway was made up of individual “tiles”, each 250m long and containing the visual representations of the roadway, side areas, and signage also to Chapter 5 specifications (DfT, 2003). Each tile was either straight or a 1000m radius curve to the left or right with a random selection providing the impression of gentle curvature interspersed by long straights. Every 10km an intersection was implemented where the sparse ambient virtual traffic (approximately 500 vehicles per lane per hour) could join or leave the virtual motorway.

For the three experimental drives in this study (one road for each treatment) the treatments were placed over a 3 km stretch of the road, in exactly the same place: 48 km after the start of the drive. This ensured drivers' fatigue levels were further enhanced, before a treatment was encountered. The effect of each treatment on drivers was examined by comparing vehicle- and driver- based measures before, during and after each treatment section (Figure 2).

- **Chevrons**: typically used in the UK to denote a safe following distance, chevrons were placed in all three lanes of the road, appearing every 40 metres during the 3 km stretch.
- **Rumble strips**: more commonly deployed as a hazard warning (for example on the approach to a village gateway), three rumble strip "trios" were positioned evenly within the 3km treatment section. Each trio consisted of 12 yellow transverse bars covering 7.5m, separated by a 40m gap and hence covering a distance of 102.5m.
- **Variable Message Signs:** three VMS were located over the 3km treatment zone and displayed non-standard messages intended to alert a fatigued driver through an invitation to take part in some simple mental arithmetic. In the order that participants experienced them, the signs read "TIREDNESS KILLS, ENGAGE YOUR MIND", "(3x4x5) ÷ 6 = ??", "3x4x5) ÷ 6 = 10, STAY ALERT".

Figure 1 about here

Figure 2 about here

2.3. Design and Procedure

The experiments were conducted in the University of Leeds Driving Simulator (Figure 3). The simulator consists of a Jaguar S-type cab, associated control loading (steering, brake and accelerator), a nine-channel 300° field-of-view projection system, a 4m diameter simulation dome (rigid glass-fibre construction) and a large amplitude eight degree-of-freedom motion. The motion system was particularly useful for creating the high frequency vibrations of the rumble strip treatments.

Participants were asked to visit the simulator on two occasions. The first visit was used to record baseline data, and took place when drivers were less likely to be suffering from fatigue. Therefore, the shift drivers attended after a normal night's sleep, whilst the older drivers were asked to complete their baseline trial during the morning (but not on the same day of their 'experimental' drive). During their first visit, participants were briefed about the study, although the engineering treatments were not discussed. Upon providing consent, they were then familiarised with the driving simulator and took part in a practice drive of around 25 minutes, with the experimenter present to answer any queries. This familiarisation period was followed by the baseline drive, where they drove the simulator unaccompanied. This first visit was used to record drivers' baseline driving performance as well as the percentage of eyes closed (PERCLOS), using Seeing Machines' faceLAB™ version 4.5 eye tracker. After completing the baseline drive, participants recorded their level of alertness on a 10 point scale (1 = not at all alert, 10 = extremely alert).

Figure 3 about here

All drivers then returned for a second visit, which took place at 8 am for the shift workers and 1:30 p.m. for the older drivers. The shift workers arrived at the driving simulator immediately after their night shift, whilst the older group attended after consumption of a meal of their choice. During the second visit, each driver completed three experimental drives the order of which was counterbalanced across participants. As well as measuring driving performance and eye tracking measures, drivers' subjective alertness after completion of each drive was measured using the 10 point scale described above. To reduce any carryover effects of fatigue from the previous drive, the second and third drive were preceded by a 10 minute break period which involved walking around the University campus (as employed by Thiffault & Bergeron, 2003b). At the end of their second visit participants also completed a questionnaire requesting their views on the three treatments.

3. Results and Discussion

Analysis of the eye tracking and vehicle based data was performed in two stages. First, to establish drivers' fatigue on their second visit compared to their first (baseline) visit, data were evaluated for the four drives (baseline, chevron, rumble and VMS) but only for the 3 km sections 'before' the treatments were introduced (see Figure 2). This manipulation check was done for both eye tracking and driving performance measures to establish that drivers were indeed more fatigued on their second visit. For each measure, a mixed model repeated measures ANOVA incorporating a within-participant factor of Drive (4 levels: baseline, chevron, rumble, VMS) and a between-participant factor of Group (2 levels: older, shift) was conducted. As shown in Figure 4 and Table 2, there was a significant main effect of Drive for PERCLOS and the two lateral deviation driver performance measures. Post hoc tests showed a significant rise in PERCLOS from day 1 to day 2, especially for the shift workers but no difference in PERCLOS between the three 'before' sections of day 2 (see Figure 4). Lateral deviation measures of SDLP and HFS were also seen to rise significantly from day 1 to day 2. Again, post hoc tests did not reveal any difference between the three drives on day 2. Therefore, at least for the measures used in this study, these results confirmed that our 2-day experimental design ensured that drivers were indeed sufficiently fatigued, compared to baseline, when required to drive through the three treatments investigated.

Figure 4 and Table 2 about here

Following this manipulation check, to establish the effect of the three treatments on alleviating driver fatigue, data for the 'before', 'during' and 'after' sections were compared for each of the three experimental drives on day 2, using a mixed model repeated measures ANOVA with two within-participants factors of Drive (3 levels: chevron, rumble, VMS) and Section (3 levels: before, during, after) and one between-participant factor of Group (2 levels: older, shift). Although the order of the three treatments encountered by each group was counterbalanced across drivers on day 2, in order to ensure that results were not confounded by drive order, a univariate analysis of variance with drive order as a covariate was also conducted on both PERCLOS and the two lateral measures. The results of these analyses are reported for each measure in the following sections.

Finally, in addition to the above objective measures, drivers' subjective measures after driving the baseline and treatment drives are reported. For objective measures, unless otherwise stated, violations of sphericity were detected using Mauchly's Test and post hoc Bonferroni tests were used for pairwise comparisons.

3.1. Eye tracking measures

PERCLOS (percentage eyes closed) was measured as the percentage of time the eyes were closed for 75% or more, over a 180 second moving window (discounting blinks). Successful eye tracking was recorded for all but one participant in the older group, whose glasses reduced recording accuracy of the eye tracker. Data are therefore reported for 16 older and 16 shift workers. As the original PERCLOS values were severely skewed, the numbers were transformed using the square-root function to ensure normally distributed data. The ANOVA was conducted on this data, although the figures show the average value of the original data.

The univariate ANOVA on PERCLOS for the treatment sections, with between participant factor of group and covariate of drive showed no effect of drive order ($p = 0.33$). The repeated measures ANOVA with within-participant factor of treatment (3 levels) and section (3 levels) and between-participant level of group (2 levels) did not show a main effect of treatment, with similar PERCLOS values observed during the three drives. Results showed a difference in PERCLOS between the two groups, with much higher values for the shift workers ($F(1, 30) = 8.35$, $p < .01$, $\eta^2 = .22$). A Greenhouse-Geisser adjustment was used to correct for violations of sphericity for the main effect of section ($F(1.30, 38.91) = 4.09$. $p < .05$, $\eta^2 = .12$). Post hoc pairwise comparisons showed a gradual reduction in PERCLOS from 'before' to 'after' treatment sections, although only the difference between the 'during' and 'after' treatment sections was found to be significant. No other interactions were observed.

3.2. Driving performance

As outlined above, studying the effect of the treatments on longitudinal measures such as speed was not of value in this study as maximum speed was constrained using a speed limiter. The effect of each treatment on lateral deviation measures was compared using a 3 (treatment: chevron, rumble, VMS) x 3 (section: before, during, after) x 2 (group: older, shift) repeated measures ANOVA. Results showed significant effects on measures of high frequency steering and standard deviation of lateral position.

High Frequency Steering

The HFS value of one shift worker was removed from the analysis as an outlier. The univariate ANOVA on HFS for the treatment sections showed no effect of drive order ($p = 0.68$). The 3 (treatment: chevron, rumble, VMS) x 3 (section: before, during, after) x 2 (group: older, shift) repeated measures ANOVA showed no difference in HFS between the two groups of drivers. The analyses also failed to a find a difference in HFS between the three treatments ($p = 0.91$). However, there was a significant difference in HFS between the three 3 km sections ($F (2, 60) = 17.14$, $p < .001$, $\eta^2 = 0.36$). Post hoc comparisons showed that for all three treatments, the high frequency steering component was significantly lower after drivers encountered a treatment, compared to the 'before' and 'during' sections ($p < .001$).

The ANOVA also revealed a three way interaction between treatment, section and group ($F (4,120) = 3.45$, $p < .01$, $\eta^2 = 0.10$). As shown in Figure 5, the most marked difference between the two groups was observed during the chevrons and the VMS. Older drivers' high frequency steering showed an improvement when they encountered these two measurements, reducing further after driving through the treatments. However, the shift workers showed an increase in the frequency of corrections during both chevrons and VMS, although the HFS component was seen to reduce after the treatments. Therefore, whilst chevrons and VMS seem to have had a positive effect on older drivers' behaviour, it can be argued that the severe fatigue experienced by the shift workers was perhaps too high to allow a stabilization of steering performance, as indicated by HFS.

Figure 5 about here

Standard Deviation of Lane Position

The univariate ANOVA on SDLP for the treatment sections showed no effect of drive order ($p = 0.79$). A 3 (treatment: chevron, rumble, VMS) x 3 (section: before, during, after) x 2 (group: older, shift) repeated measures ANOVA on SDLP values did not show any significant differences between the two groups. There was also an absence of a main effect of section and treatment. There was, however, a significant interaction between section and treatment ($F (4, 124) = 3.88$, $p < .05$, $\eta^2 = 0.11$). As shown in Figure 6, lateral deviation increased markedly during the chevrons section, dropping slightly during the 3 km after the chevrons were encountered. On the other hand, driving over the rumble strips was shown to reduce SDLP. No change in SDLP was seen as a result of the VMS. The increase in lateral deviation imposed by chevrons may have been because drivers were using the chevrons to keep themselves occupied and alert during the drive, perhaps trying to keep their vehicle on top of the chevrons at all times, which would have resulted in more deviant trajectories between the chevrons, as they drove from one chevron to another. This account certainly supports the anecdotal evidence put forward by Turnbull & Fenner (1998) which suggests that these markings may be distracting and disorienting to drivers. On the other hand, it can be argued that the vibration and sound generated by driving over the rumble strips seems to have had some positive effect on reducing drivers' SDLP, prompting drivers to follow the lane centreline more closely.

Figure 6 about here

3.3. Subjective Report of Alertness

Drivers were asked to report how alert they felt after completing each drive by reporting a number between 1 (not at all alert) and 10 (extremely alert). A repeated measures ANOVA with 4 within-participant levels of drive order (baseline, first, second, third) and two between-participant levels of group (older, shift) showed a significant effect of drive ($F(3,93) = 51.69$, $p < .0001$; $\eta^2 = 0.62$). Post hoc comparisons revealed that drivers reported higher levels of alertness on their first visit compared to their second visit and also significantly higher alertness for their first drive of the second visit compared to the second and third drives. There was also a significant difference between the two groups ($F(1, 31) = 22.1$, $p < .0001$; $\eta^2 = 0.42$) and a significant interaction between Drive and Group, where shift drivers reported quite a low level of alertness at the end of their third drive (see Figure 7). These subjective ratings suggest that both groups of drivers were actually more fatigued/less alert on their second visit and also felt less alert with time on task, with progressively lower scores reported for alertness from drive 1 to drive 3, regardless of the treatment encountered. Since these measures were recorded after the end of each drive, they suggest that any alerting effect of the engineering treatments encountered by the drivers was perhaps short lived. As each treatment was only presented once over a 3 km stretch, in each drive, it can be argued that this distance was perhaps not long enough to be sufficiently alerting. Future studies, using longer stretches of such treatments or many repetitions of shorter treatments may well produce a longer lasting effect.

Figure 7 about here

3.4. Feedback on Treatments

At the end of their second visit, all participants were asked to complete a short questionnaire once they had completed their third drive. Drivers were asked to provide feedback on the treatments, stating on a scale of 10 to -10 whether they thought the treatments increased their (i) general levels of alertness (ii) interest in the driving task and (iii) whether they felt more relaxed or nervous when encountering the treatments. No formal analyses were conducted on these results; however, as shown in Figure , drivers thought that all three treatments enhanced their overall levels of alertness, but that only the chevrons increased their *interest* in the driving task, with the rumble strips and VMS signs prompting less interest from both groups of drivers. Both groups of drivers reported that they were more nervous driving with the three treatments and this was especially true for the rumble strips.

Figure 8 about here

Conclusions

This study was designed to assess the effect of three 'low cost' engineering measures on alleviating the symptoms of driver fatigue, as measured by drivers' eye closure and lateral deviation data. The three treatments were chosen following a consultation workshop with the sponsors of the study. An important consideration for their selection was that these measures would need to be *low cost* and *easy to implement* on real roads, whilst also easy to reproduce in the University of Leeds Driving Simulator. As research suggests that fatigue-related accidents are particularly common during monotonous driving conditions (Sagberg, 1999; Thiffualt & Bergeron, 2003b), it was hypothesised that the introduction of an interesting visual feature in the road would reduce the fatigue-inducing monotony of the driving environment.

A comparison of driver performance between baseline (day 1) and experimental (day 2) data showed that the 2-day experimental design was effective, with both groups of drivers appearing to be more fatigued on their second visit. In line with the observations of Dinges & Grace, (1998) PERCLOS was found to be sensitive to identifying drivers' levels of fatigue in this study, showing an increase for both groups of drivers from day 1 to day 2, and indicating markedly higher values in shift workers, compared to older drivers. As the shift workers had been awake for 12 hours prior to the study on day 2, this result was perhaps not too surprising. However, our PERCLOS recordings also confirmed the effect of diurnal patterns on driver fatigue in the early afternon (Pack et al, 1999), with older drivers showing significanlty higher values during their post-lunch sessions, compared to their performance during the morning drive. The current study also confirmed the conclusions of Thiffault and Bergeron (2003a, 2003b) that a 20 minute drive containing long stretches of straight road with little visual interest is sufficient to induce fatigue in a driving simulator study.

A comparison of performance across the treatments did not show a noticeable difference between the three treatments, although in some cases, performance was seen to improve, during and after drivers encountered the treatments. In paricular, a significant drop in PERCLOS was also seen for both groups in the 3 km after the treatments were encountered, suggesting that, regardless of its nature, the presence of each treatment seems to have reduced the monotony of the sparce driving environment and increased driver alertness, at least in terms of their eye closure behaviour.

The lateral deviation results did not show any significant differences in performance between the two groups. However, driving through the treatments produced slighlty different effects on the two measures used. Whilst high frequency component of steering was found to reduce in the 3 km *after* the three treatments, changes in SDLP values were particularly prominent *during* the treatments, and especially during the chevron and rumble strip sections. These differences may be partly related to the nature of the two measures. As the high frequency steering component is a direct measure of drivers' steering performance, effectively a lane tracking task, it is possibly more prone to extreme levels of fatigue, and sudden/extreme steering corrections are therefore likely to increase with fatigue (Khardi & Vallet, 1994). On the other hand, as argued by Donges (1978; see also Summala et al., 1999) maintaining lateral position in the road may be considered a two-level process, whereby drivers first consider the trajectory of the road and then attempt to maintain it. It is then argued that this high-level trajectory planning is impaired by cognitive load (Brookhuis, de Vries & de Waard, 1991) and fatigue (Summala et al., 1999) becoming much more 'stimulus driven'. The increase in SDLP during the chevrons and its reduction when driving over the rumble strips supports this argument, with fatigued drivers using the continual road-based visual stimuli of the chevrons to assist in the planning of their trajectory through these repetitive treatments.

Drivers' own feedback on the three engineering treatments suggests that they were indeed perceived to be alerting and interesting, perhaps reducing the monotony of the driving environment used for this study. However, both groups of drivers reported a systematic reduction in their levels of alertness with the progress of the experiment from drive 1 to 3. Of course, it might be that participants were simply bored of driving the same road three times on their second visit, but it would seem that any alerting effect of the treatments is weak and short lived. A consideration to be implemented in a future study may be to increase the frequency of such engineering treatments, presenting them along a longer section of road, perhaps observing the effect of a combination of such treatments within one drive.

In summary, all three low cost engineering treatments implemented in this study were found to be effective in alleviating the fatigue symptoms in the two groups of drivers, with little obvious difference between the alerting effects of the three treatments. Until now, the main purpose of implementing chevrons and centre-line rumble strips in the UK has been to encourage a reduction in speed, for example on approach to villages, in the case of centre line rumble strips (Persaud, Retting & Lyon, 2004), or along motorways in the case of chevrons (Helliar-Symons & Butler, 1995). Likewise, Variable Message Signs are used mainly for information and advice on UK roads. This study suggests that use of such features in long stretches of road known to be prone to fatigue-related accidents due to their monotonous geometry and layout, is likely to provide some additional visually interesting features, which may promote alertness in drivers and reduce the likelihood of fatigue-related crashes. Clearly, this line of research would benefit from further investigation in field/real-world studies, especially for long stretches of straight road prone to such fatigue-related accidents. Of course, it is important to stress that the onus of safe driving must remain with drivers, who should assume an adequate approach in eliminating their fatigue before operating their vehicle on the road.

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Figure 4 – The chevrons (left) rumble strips (middle) and VMS (right) used in the study

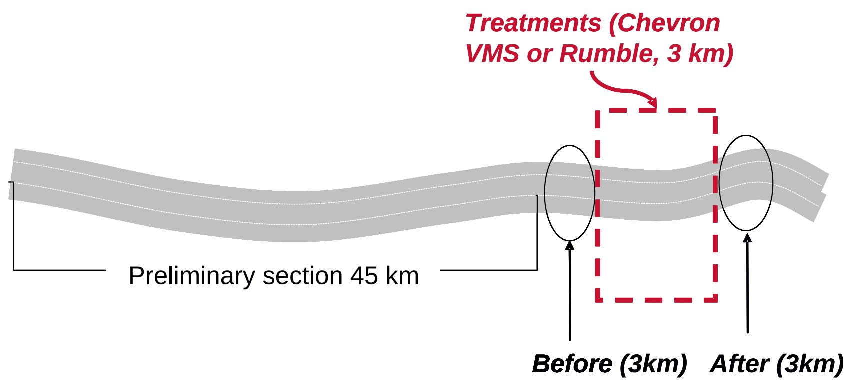

Figure 5 – The road layout used for the experimental drives

Figure 6 - The University of Leeds Driving Simulator

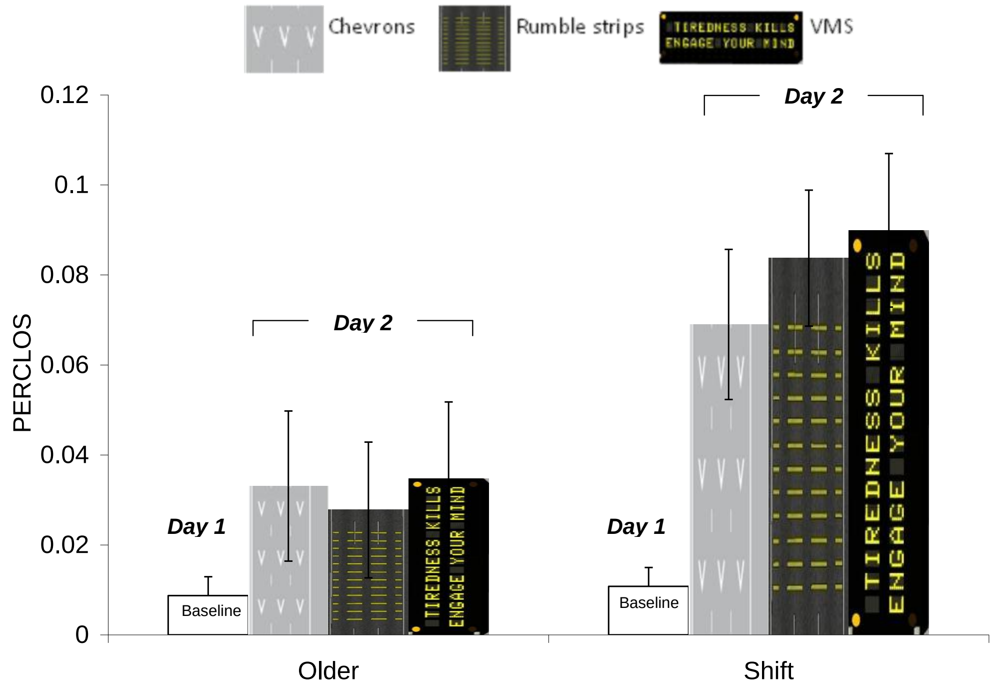

Figure 7 – Drivers' PERCLOS *before* experiencing the treatments on the baseline and three experimental roads

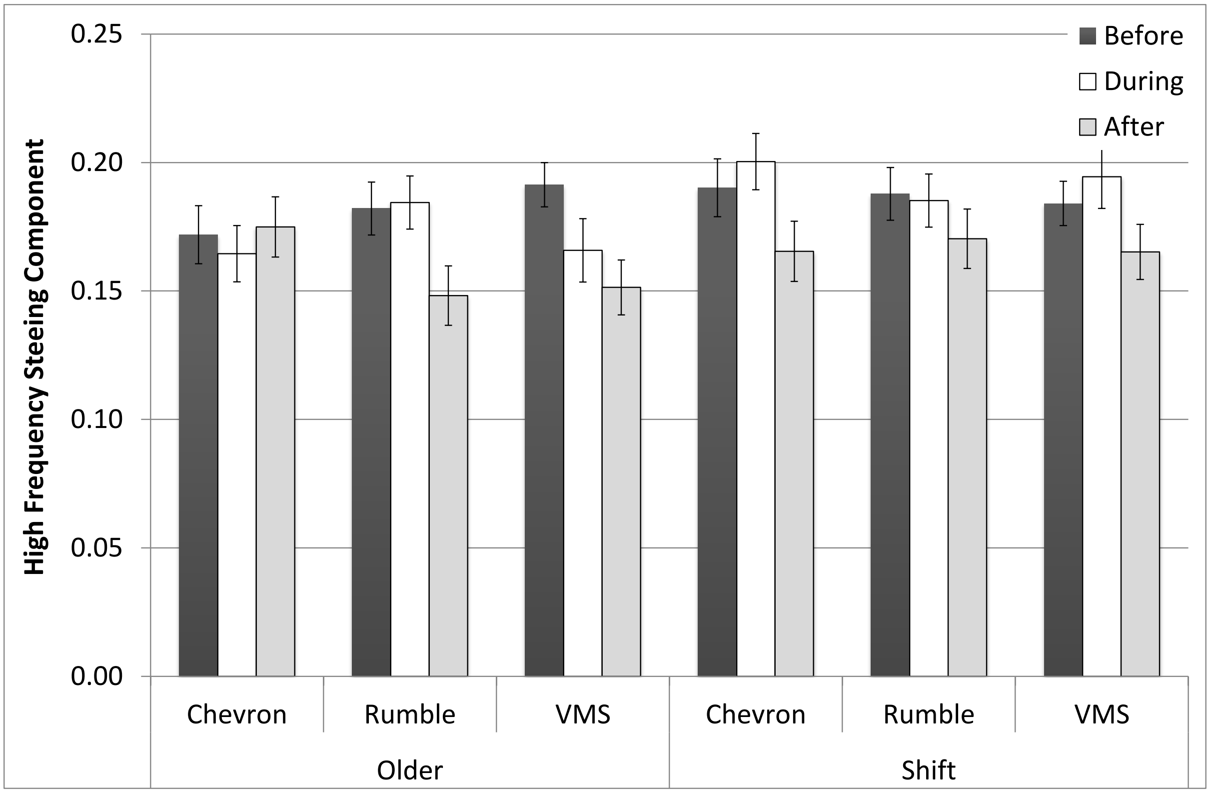

Figure 8 - The effect of each treatment on older and shift drivers' HFS

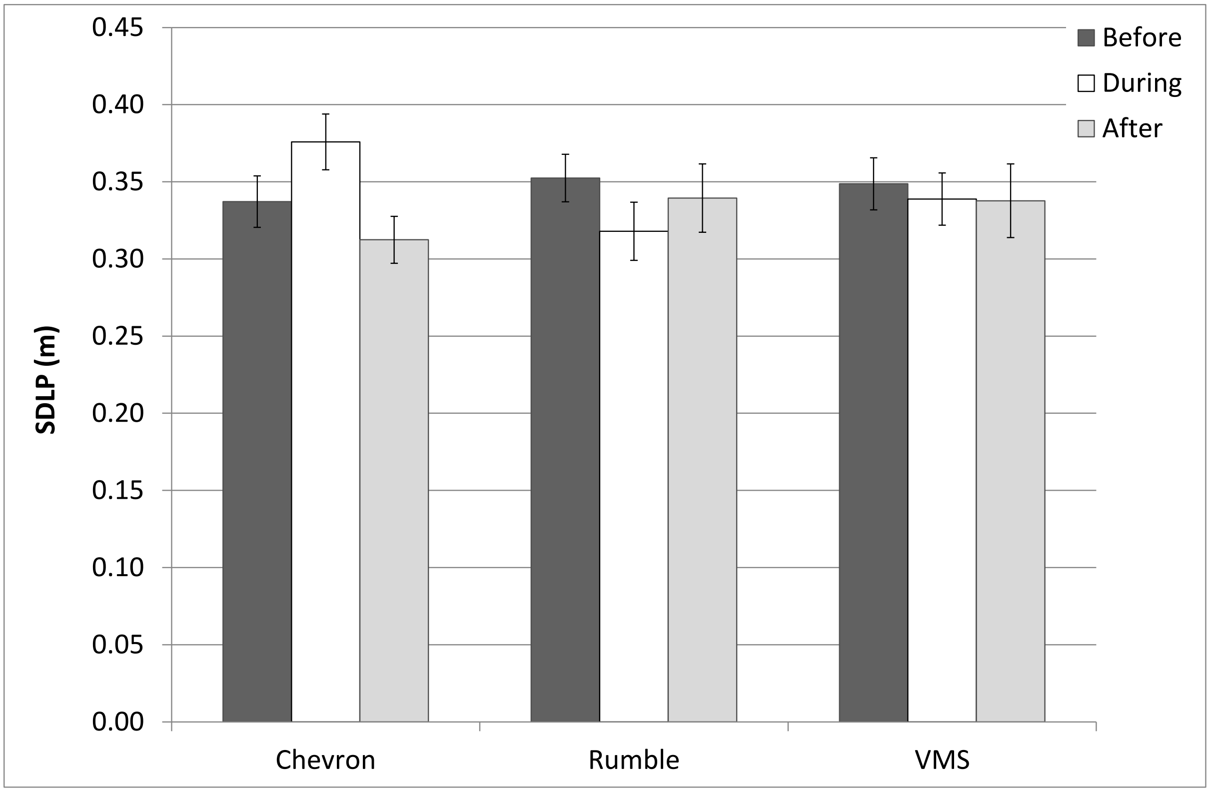

Figure 9 - Drivers' SDLP before, during and after each of the three treatments

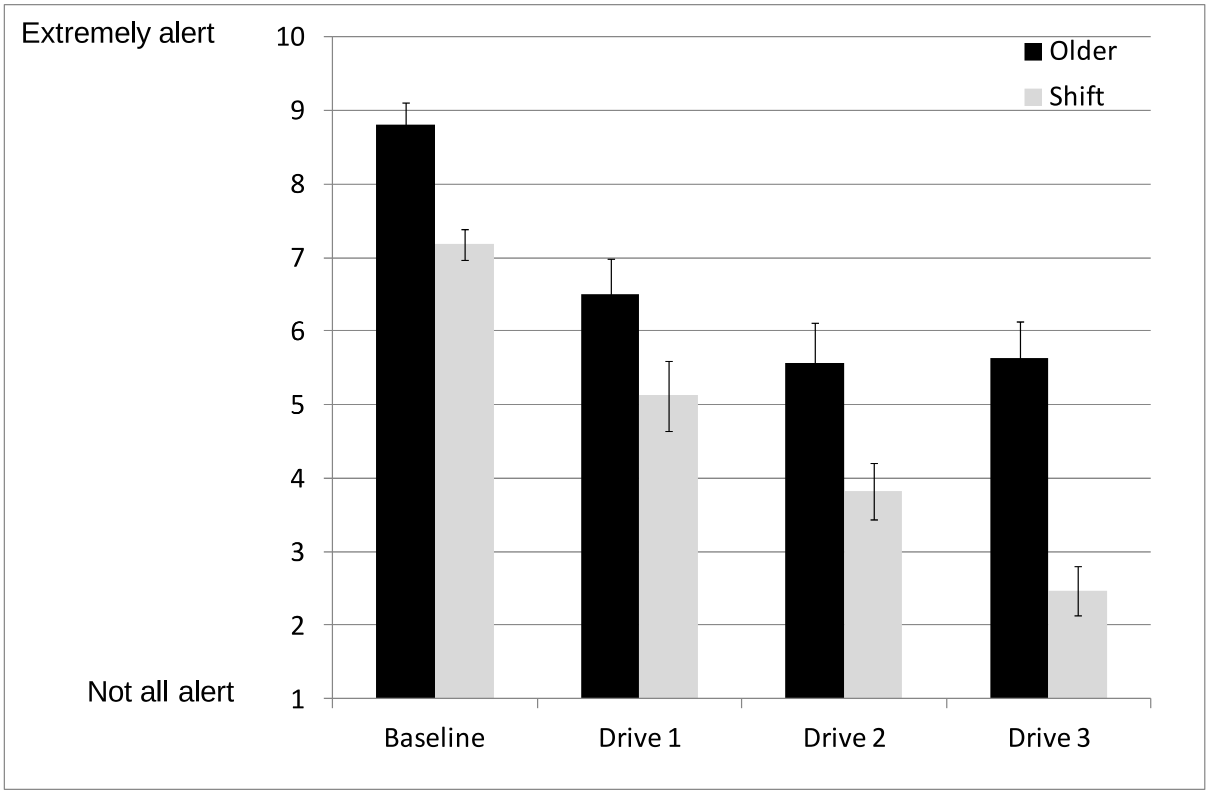

Figure 10 – Drivers' subjective score of alertness after each drive

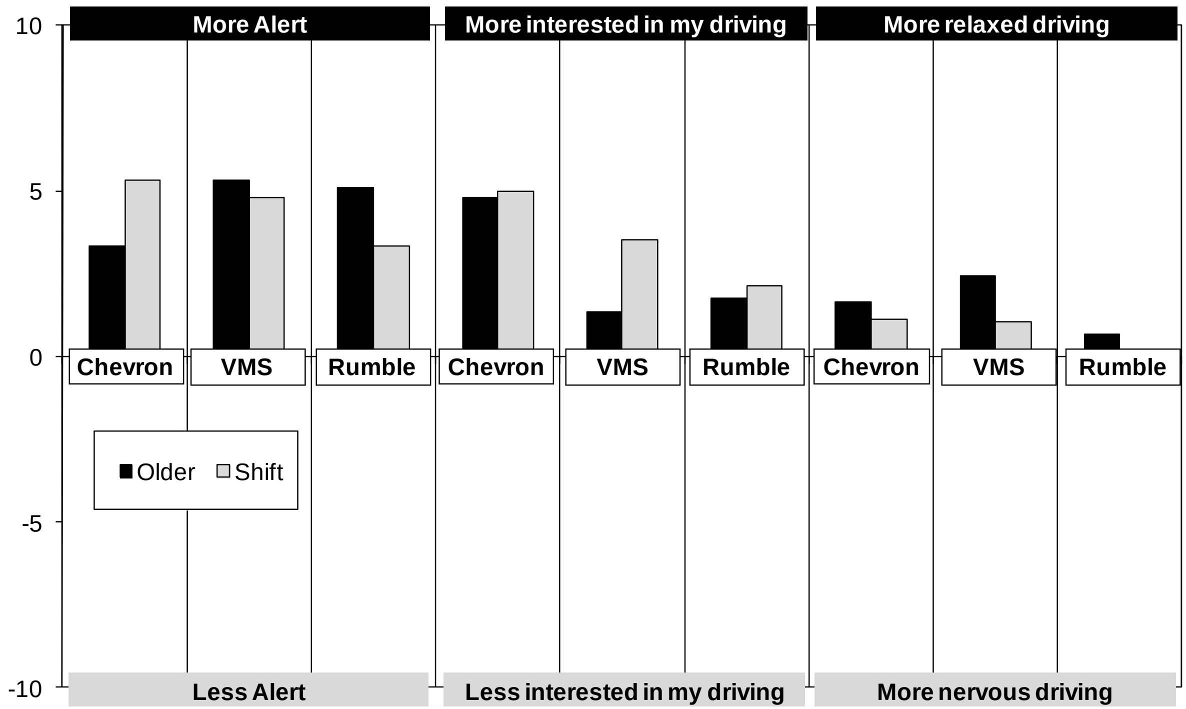

Figure 11 – Drivers' subjective feedback on the three treatments

Table 3 - Age and driving experience of the two groups of drivers

	Average age (SD)	Average driving experience in years (SD)	Average annual mileage (SD)
Older Group (N = 16)	53.2 (5.48)	31.13 (6.34)	12563 (11770)
Shift Group (N = 17)	31.41 (5.37)	12.71 (6.40)	16250 (8250)

Table 4 – PERCLOS and driving performance values for days 1 and 2

Measure	Drive	Group	Drive x Group
PERCLOS	$F(3, 90) = 19.29$ $p < .001$, $\eta^2 = .39$	$F(1, 30) = 8.74$ $p < .01$, $\eta^2 = .23$	$F(3, 90) = 3.15$ $p < .05$, $\eta^2 = .1$
SDLP	$F(3, 90) = 8.44$ $p < .0001$, $\eta^2 = .21$	n.s	n.s
HFS	$F(3, 93) = 3.64$ $p < .05$, $\eta^2 = .11$	n.s	n.s