Driving home drowsy: Driver fatigue and performance deficits on commuter trips

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Funded by NRMA ACT Road Safety Trust

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Background

This project aims to examine the nature and extent of driver drowsiness and its effects on driving performance on commuter trips between work and home and vice-versa, using drowsiness detection equipment in a driving simulator.

Driver fatigue is recognised as a major contributing factor to road crashes (Scott et al., 2007; McCartt et al., 1996; Sagberg et al., 2004; Williamson et al., 2001). It is also increasingly recognised as a workplace health and safety issue, due to the possible impact of fatigue on work-related driving including commuters and professional drivers (Williamson & Boufous, 2007; Mitchell, Driscoll & Healey, 2007). Fatigue was implicated in 15-20% of fatal crashes in NSW from 2011 to 2015 (NSW Centre for Road Safety, 2016). The conceptual framework for this study follows the model of Williamson et al., (2011) which describes how fatigue can affect safety outcomes. Fatigue is defined as a biological drive for recuperative rest, which, if unsatisfied, will result in performance impairments. Fatigue is affected by the time of day, the amount of time the person has spent awake, the amount and quality of prior sleep as well as features of the task being undertaken and those of tasks recently undertaken. Drowsiness is the aspect of fatigue most akin to sleepiness: feelings of tiredness and that one is about to fall asleep. It can be measured as one index of a fatigued state, however, a fatigued state can also be measured by decreasing alertness and increasing variability in performance.

Commuting is an activity relevant to road and workplace safety risks. Commuting crashes are the largest single cause of work-related fatalities in Australia, accounting for almost one-third of them (Safework Australia, 2012). Current data (to 2014) demonstrates that vehicle related accidents are still the most common cause of workplace fatalities, though do not provide information on commuting (Safework Australia, 2015). Fatigue is relevant to driver safety while commuting because the capacity to drive safely will depend on the driver's state when he/she gets into the vehicle. Fatigue can be produced by a range of work-related factors (e.g. lost sleep due to short turnaround time between shifts, time on work task, nature of work tasks, work schedule and time of day). Fatigue while commuting has been overlooked as a potential safety risk possibly because commuting trips are usually short and fatigue effects are usually associated with long periods of driving. Nevertheless, there is evidence that fatigue effects may manifest in driving periods of a short duration, and these commuting trips of a short duration account for a high proportion of road use (Symmons & Haworth, 2004; Wheatley, 1997). Clearly, there is a gap in our understanding of the nature and extent of drowsiness and fatigue while commuting.

Fatigue on commuter trips

Many fatigue prevention campaigns encourage drivers to avoid fatigue during holiday periods when people are known to drive long distances (e.g. "Stop. Revive. Survive" campaign; holiday road rest stops; NSW RMS, 2016 http://www.rms.nsw.gov.au/geared/your_driving_skills/staying_safe/driver_reviver.html). These strategies assume that only long trips, which involve considerable driving time, often at unusual hours, are important with respect to fatigue.

Interest has also arisen in commuter trips due to patterns of fatalities and injuries that have been found on work related trips of professional drivers and commuters. Boufous & Williamson (2009) matched 5 years of compensation data to road crash data to examine factors that contribute to work related crashes in New South Wales. 75% of work-related driver casualties occurred on commuter trips (i.e. driving between home and work rather than driving during work time), with 23% of these being serious crashes. Drivers in a commuter crash were more likely to die or be permanently injured than those involved in a crash while on duty (i.e. while driving for work). Of course it must be noted that short trips may also be the bulk of trips that drivers make. Similarly, crash data from the ACT indicates that most crashes occur at times of peak traffic volume, which are also commuting times (ACT Government, 2016). Commuter trips, especially the trip after work, may be particularly vulnerable to fatigue, as they occur after a significant period of time awake and after a full day of work. Factors such as long, or irregular work hours may also make fatigue more likely. Commuter trips therefore deserve more attention as situations where fatigue may manifest.

An early self-report study by Fell and Black (1997) highlighted the importance of fatigue on short trips compared to longer trips. In a sample of people who had experienced a fatigue related crash, Fell and Black found that 36% of the accidents occurred in metropolitan areas, and many cited the influence of working hours on prior sleep as a factor. 35% of those with city crashes had their crash on their regular trip to or from work, and 46% of these were trips of a planned duration of less than 45 minutes. This suggests that short regular trips represent a significant proportion of fatigue related road accidents.

Others have studied particular occupational groups to ascertain the effects of fatigue while commuting. A log book study of nurses driving to and from work found that 66% reported at least one drowsy driving episode during the 2-week study period (Scott et al., 2007). The mean trip length was 27 minutes. Several other studies have shown similar self-reported levels of drowsiness while commuting among medical residents (e.g. Geer et al., 1997; Marcus & Loughlin, 1996). A prospective study based on self-reported drowsiness, crashes and work shifts of medical interns found that extended shifts increased the risk of falling asleep while driving home by 16% (Barger et al., 2005). A study of Australian nurses found that extreme drowsiness was reported while driving to or from work on approximately 10% of shifts, with a mean trip length of 19 minutes (Dorrian et al., 2008). 50% of the incidents occurred at the end of nightshift, and 40% at the end of the day shift, between 2 and 6pm. In all these studies, the effects of fatigue related to work tasks and schedules manifested on driving performance relatively quickly - on a relatively short commuter trip.

While it seems obvious that sleep deprivation due to work shifts will have an effect on drowsy driving, studies that have examined the effects of work shifts on driver fatigue are limited by relying on self-report data. Self-reported fatigue and accident occurrence data is problematic because it relies on participants' recall, accurate reporting, and typically only measures major incidents, rather than indexing changes in driving performance. Degraded driving performance may not necessarily culminate in an accident, but indicates situations of increased risk. At the same time, there are significant disincentives for drivers to admit to have fallen asleep at the wheel, which can bias these data. Further, drivers can often report having felt tired, but there is doubt as to whether people can reliably detect the significance of their own levels of fatigue before an incident occurs, and take appropriate actions (Wylie et al., 1996; Horne & Reyner, 1999; Kaplan, Itoi & Dement, 2008), which casts further doubt on the reliability of self-reported fatigue investigations. While these studies are informative regarding the potential for fatigued driving after long working hours that interrupt circadian rhythms, they may also underestimate the true extent of the driver drowsiness problem on commuter trips. More systematic, objective measurement of drowsiness on short trips is required for both shift workers and non-shift workers to clarify the true nature and extent of the effects of drowsiness on driving performance.

Methods for measuring driver drowsiness

Quantifying the exact level of contribution of fatigue to road accidents is difficult because there is a lack of in-situ measures that quantify fatigue. Limitations associated with how fatigue is recorded as a contributing factor to accidents are widely recognised (e.g. Williamson & Boufous, 2007; Boufous & Williamson, 2009; Symmons & Haworth, 2004; McCartt et al., 1996). Whereas speed and alcohol consumption can be assessed before an accident by the driver, and after an accident by law enforcement agencies, fatigue is often recorded as a contributing factor either by self-report from drivers or passengers, or inferred by police observation of the driver's state or performance (e.g. veering onto the wrong side of the road), and the absence of any other relevant causal factors (NSW Centre for Road Safety, 2016a). This means that the contribution of fatigue to accidents could be underestimated. Furthermore, the use of accident occurrence data to index the extent of fatigue on the roads can also be misleading because not all episodes of fatigued driving lead to accidents. Fatigue or drowsiness can lead to "near misses" that are never recorded in accident figures (Landstrom et al., 2010; McCartt et al., 1996). These observations point to the need for better measurement of fatigue and its contribution to poor driving performance and road safety in general.

Several methods exist to measure driver fatigue and drowsiness in more reliable ways than accident data and more objective ways than self-report. These methods include electro encephalogram (EEG) data, and face and eye movement data. EEGs collect information on brain activity using electrodes attached to the scalp, and several aspects of the EEG signals have been found to correlate with drowsiness (Lin et al., 2005). However, EEGs have disadvantages in terms of real time recording, noise in the signal, and practical constraints such as cost, skills and facilities (Brookhuis & de Waard, 2010). Several studies have involved observers coding video of drivers, indexing drowsy driving by eye blinks, eye closure, head movements and yawning (Hanowski et al., 2006; Barr et al., 2005). These have been informative on the involvement of drowsiness in on-road driving, but these methods are labour intensive, lack clear indicators for coding drowsiness, and are subject to inter-rater inconsistencies. A video based measure of the percentage of time for which a participant closes their eyes while driving, called percentage of closure or PERCLOS has been found to be a valid measure of drowsiness, and while originally relying on observer coding, has also been incorporated into an automatically coded system (see De Rosario et al., 2009; Brookhuis & de Waard, 2010). A number of drowsiness detection devices have since been developed which record parameters from which PERCLOS can be calculated. These include FaceLAB (Seeing Machines) and *Smart Eye Pro* (Smart Eye AB) both of which collect human eye, face and head movement, and gaze direction unobtrusively and in real time (US Dept Transportation, 2009).

Project aims

Understanding the nature and extent of driver fatigue on commuter trips and how it affects driving performance is an important research and public safety issue. This project aims to examine the nature and extent of driver fatigue on short trips involving commuting between home and work, and its effects on driver performance. The following research questions will be addressed:

a) To what extent is fatigue a problem on commuting drives?
b) Is there a relationship between the amount of sleep before work and fatigue and performance on the commute to and from work?
c) Is there a relationship between the amount of time since sleep and fatigue and performance on the commute to and from work?

Method

Design

Three groups of 15 participants will drive for two 45 minute sessions in a driving simulator. Group 1 will be rested. Group 2 will stay awake for 2 hours longer than normal, and wake at the normal time, and Group 3 will stay awake for 4 hours longer than normal, and wake at the normal time. These periods of deprivation are consistent with what could reasonably be expected to regularly occur to people who commute regularly. Four hours of deprivation is consistent with the amount of sleep that subject matter experts consider should show driving impairment (Czeisler et al; 2016). Additional deprivation, where people have only 2 hours sleep is thought to render them unfit for driving (Czeisler et al; 2016).

A 45-minute driving duration was chosen as this is a criterion commonly used to identify shorter versus longer trips (BITRE, 2016). Average commuter trips in private vehicles are 27 minutes in Australian metropolitan areas excluding Sydney (32-34 minutes average time in Sydney). 17% of commuter trips are over 45 minutes in metropolitan areas other than Sydney, and 24-27% are over 45 minutes in Sydney (BITRE, 2016).

Driving performance will be indexed by data from the STISIM simulator, including lane deviation and percent of time spent speeding. Lane deviation is typically seen as the most reliable performance based measure associated with drowsiness (Akerstadt et al., 2010; Sandberg et al., 2011) and percentage of time spent speeding was included to have a speed measure that accounted for the changes in speed limit throughout the scenarios (which were counterbalanced in order across participants).

Drowsiness will be indexed by data derived from the Smarteye Pro system, including PERCLOS calculations, pupil diameter, and blink duration. These indices have been supported as valid measures of drowsiness or fatigue (Wang and Xu, 2015; Daza et al., 2014; Bergasa et al., 2006).

Participants

Participants were recruited and randomly assigned to groups by a recruitment company. The recruitment company sent an eligibility survey to people who had placed their details on their contact lists. To minimise transport costs and inconvenience to participants, participants who resided within a 10km radius of the university were recruited. In addition, participants were required to

- Be aged between 25 and 50 years;
- have a current drivers' license;
- regularly drive to work; and
- not have a clinical sleep disorder (such as insomnia, sleep apnoea etc, see Smolensky et al 2011).

It was intended that 15 participants would be recruited for each of the three groups (Group 1, 0 hours sleep deprivation; Group 2, 2 hours sleep deprivation; Group 3, 4 hours sleep deprivation). Samples of a similar size, and much smaller, are regularly used to achieve significant effect sizes in driving simulator research (e.g. Daza et al., 2014; Vadeby et al; 2010; Godley, Trigs & Fildes, 2002; de Rosario et al., 2009; Young et al., 2010).

Materials

Sleepiness/Drowsiness detection. Drowsiness of drivers in the simulator will be measured using the *Smart Eye Pro* tracking system. *Smart Eye Pro* consists of three cameras and monitors eye and eyelid movements using eye-tracking technology, blink analysis and eye closure in real-time and has been configured for use in simulators. *Smart Eye Pro* has been used previous studies to assess drowsiness as well as changes in gaze and eye scanning which are likely to occur with increasing fatigue and drowsiness (Horrey & Wickens, 2007; Bretzner & Krantz, 2005). It will be used to assess extent of eye closure which is associated with increasing drowsiness (as well as blink duration, and pupil diameter). The Smart Eye Pro system records data as video and logs variables of interest at 60Hz.

Actiwatch. An actiwatch is a wrist watch-like device that measures sleep patterns. Actiwatches will be worn by participants in all studies to verify sleep patterns for 24 hours prior to test sessions in all studies. Participants will be instructed in how to use the actiwatch at the practice session for each study.

STISIM driving simulator. A fixed based STISIM driving simulator (Drive 2.08.04) located in the human factors lab at the School of Aviation, UNSW was employed. The simulations are displayed on a 27-inch wide screen LCD monitor (B273HU), and drivers control the simulator via a Logitech G25 Racing Wheel set (steering wheel, shifter module as well as the accelerator and brake pedals). Audio feedback is provided via a Dell 2.1 sound system (Zylux Acoustics Corporation; Model A525). Participants were seated in 2002 Mazda 626 car seat. Simulator scenarios comprised arterial road and highway conditions with speed zones of 70 and 80 km/h spread evenly throughout, designed to neither be too monotonous nor be too stimulating. Data were collected at 20 Hz.

Questionnaire measures. Demographic information including age, gender, job, usual sleep/wake cycles, and previous road crash history was collected at the practice session. Other self-report data including regular and recent caffeine and food consumption, hours of sleep before the session, and visual analogue scales relating to feelings of clear-headedness, drowsiness and tiredness (Williamson et al., 2001) were employed.

Procedure

At the practice session, participants were given a 15-minute practice drive in the simulator, and a profile on the SmartEye Pro system was established. The profile saves gaze tracking calibration information specific to each participant. The development of the profile enabled faster tracking of the participant's eye in the subsequent test session, and meant that considerable time was saved in test sessions. Several questionnaires were administered at the practice session (e.g. on demographics, usual sleep and wake time, usual and current caffeine intake etc), and instructions were provided on how to operate the actiwatch. A taxi voucher to transport the participant to the test session (which was usually the day after the practice session, and no more than two days later) was provided. Participants were instructed to come directly to the university on the day of the test session after waking, without performing any other usual morning activities such as going to the gym or walking the dog. Another taxi voucher was provided at the end of the evening test session, to transport the participants home. Transport away from the university at the end of the morning session, and to the university at the beginning of the afternoon session was not provided.

The test sessions were completed in the morning (between 07.30 and 09.30) and afternoon (between 16.30 and 18.30pm) of the same day. Pilot data we have collected indicated no substantial performance differences when conducting the morning or evening sessions first, given a prior practice session in the simulator. Completing test sessions on the same day saves considerable time and resources, particularly when examining sleep deprivation and the necessity to transport participants to and from the test venue.

In the test sessions, participants were asked to drive in the STISIM driving simulator for two 45 minute sessions at the times of their usual morning and evening commute to and from work. Half of the participants began driving in the morning in a simulator scenario which began with a speed zone of 70, which then changed to 80, and back to 70, alternating throughout the scenario. The other half began with a scenario that started at 80km/h and then changed to 70 and later back to 80 km/h. Participants were instructed to drive normally and obey the speed signs and regular road rules.

Results

Demographics

Table 1 shows the composition of the Groups by gender and average hours of sleep as measured by the act watch devices. The sample size for the actiwatch readings was reduced due to lack of participant compliance with use of the actiwatch and/or unavailability of data from the actiwatch in some cases.

Table 1. Sample demographics and time slept

	n	Males	Females	Average age (SD)	Average hours sleep before test session (SD)	Average self-rated hours of sleep before test session (SD)
Group 1 (0 hours sleep deprivation)	13	9	4	37.83 (8.5)	6.99 (1.38) n= 11	6.75 (.97) n=13
Group 2 (2 hours sleep deprivation)	14	7	7	40.54 (7.05)	5.9 (2.70) n=13	5.7 (1.33) n=14
Group 3 (4 hours sleep deprivation)	14	9	5	38.42 (5.85)	4.06 (1.08) n=10	4.47 (.75) n=14

A univariate ANOVA revealed that there was a significant effect of Group on hours of sleep as measured by the actiwatch devices $F_{(2, 33)} = 6.105$, $p = .006$. Post-hoc Tuckey tests indicated that this difference was between Groups 1 and 3 ($p = .004$), while the difference between group 2 and 3 was not significant ($p = .069$).

Similarly, there was a significant effect of Group on self-rated sleep time before the test session $F_{(2,40)}$ = 16.147, p = .000, with post hoc Tuckey tests showing significant differences between groups 1 and 2 (p =.041), 1 and 3 (p =.000), and 2 and 3 (p = .008).

However, analysis of hours slept recorded by the actiwatch devices indicated that two participants in Group 2 (2 hours sleep deprivation) had slept for more 10.42 and 11.32 hours respectively. Given this was more than the maximum time slept by Group 1 (0 hours sleep deprivation), and was inconsistent with the self-estimates of time slept by these participants (7 and 6.5 respectively), these participants were removed from the analysis.

This reduces the mean sleep time for Group B to 5.05 hours (SD = 1.69; n = 11). A significant main effect of Group is observed with these outliers removed ($F_{(2,31)}$ = 11.725, p = .000), though post-hoc Tuckey tests reveal there are still no significant differences between Group 2 and 3 (p= .267).

Ratings of tiredness, clear-headedness and drowsiness

Significantly higher ratings of tiredness were observed in the afternoon (m = 5.741, sd = .361) compared to the morning (m = 4.643, sd = .405), $F_{(1,36)}$ = 6.120, p = .018, though there was no significant effect of Group or an interaction effect between group and time of day. No significant differences between morning and afternoon sessions were observed for ratings of clear-headedness (time of day ns main effect $F_{(1,36)}$ = 3.800, p = .059) or drowsiness (time of day ns main effect $F_{(1,36)}$ = 3.137, p = .085).

Work hours and caffeine intake

There were no significant differences between the groups in the amount of time worked during the day before the afternoon session, ($F_{(1,36)}$ = .136, p = .874; Group 1 mean = 5.76; Group 2 mean = 6.00; Group 3 mean = 5.11).

There was a significant difference in the number of caffeinated drinks consumed between morning (mean .903, sem = .118) and afternoon sessions (mean 2.051, sem = .242) in the afternoon $F_{(1,28)}$ = 28.111, p = .000), however there were no significant differences between the groups, nor a significant interaction between group and time of day.

Driving performance

Analysis of the driving performance data attempted to understand whether:

- there was a difference between groups in the morning, and between groups in the afternoon; and
- there was a difference between the morning and the afternoon (across groups).

The dependent variables gained from the STISIM driving simulator included
Percent of speed limit and Mean Lane deviation.

Repeated measures ANOVAS 2(WS: “Time of day” morning vs afternoon) x 3(BS: “Group” 0hrs, 2hrs, 4 hrs sleep deprivation) were conducted.

Initially the data were separated into 5-minute bins throughout the 45-minute driving task, resulting in 9 separate time bins. For these analyses, performance was averaged across the bins to give an index of morning and afternoon performance.

Participants from Group 2 who did not comply with sleep instructions were excluded from the analysis as previously noted.

DV: Percentage of speed limit

A significant main effect of Group was observed on the percentage of the speed limit at which participants travelled ($F_{(2,36)} = 5.029$, $p = .012$). Tuckey tests showed the effect was between Groups 1 and 2 ($p=.016$) and between Groups 2 and 3 ($p=.037$).

Across morning and afternoon sessions, Group 2 (2 hours sleep deprivation) appear to be travelling slightly lower than the speed limit compared to those with no sleep deprivation, and those with 4 hours sleep deprivation, as shown in Table 2.

Table 2. Mean percentage of the speed limit for Groups 1,2 and 3 across morning and afternoon test sessions.

	Mean	SEM
Group 1: 0 hours sleep deprivation	101.139	1.377
Group 2: 2 hours sleep deprivation	95.313	1.433
Group 3: 4 hours sleep deprivation	100.347	1.327

DV: Mean lane deviation (absolute value)

For mean lane deviation, a significant main effect of Time of Day was observed ($F_{(1,36)}$ = 34.622, p = .000). A main effect of Group was also observed ($F_{(2,36)}$ = 8.976, p = .001), along with a significant interaction between these factors ($F_{(2, 36)}$ = 8.895, p = .001).

As shown in Table 3, this means that performance was significantly worse for all participants in the morning. Table 4 indicates that the most sleep deprived participants (Group 3) performed worse overall, across morning and afternoon sessions. Post hoc Tuckey tests revealed the differences are between Groups 1 and 3 (p= .001); and 2 and 4 (p = .017). The significant interaction between Time of Day and Group indicates that the participants with the most sleep deprivation are particularly impaired in the morning; though in the afternoon, all groups are performing similarly (see Figure 1).

Table 3. Mean lane deviation in the Morning and afternoon across sleep deprivation groups

Time of day	Mean	SEM
Morning	6.440	.871
Afternoon	1.294	.327

Table 4. Mean lane deviation by Sleep deprivation group, across morning and afternoon test sessions

	Mean	SEM
Group 1: 0 hours sleep deprivation	1.811	.849
Group 2: 2 hours sleep deprivation	3.153	.884
Group3: 4 hours sleep deprivation	6.639	.818

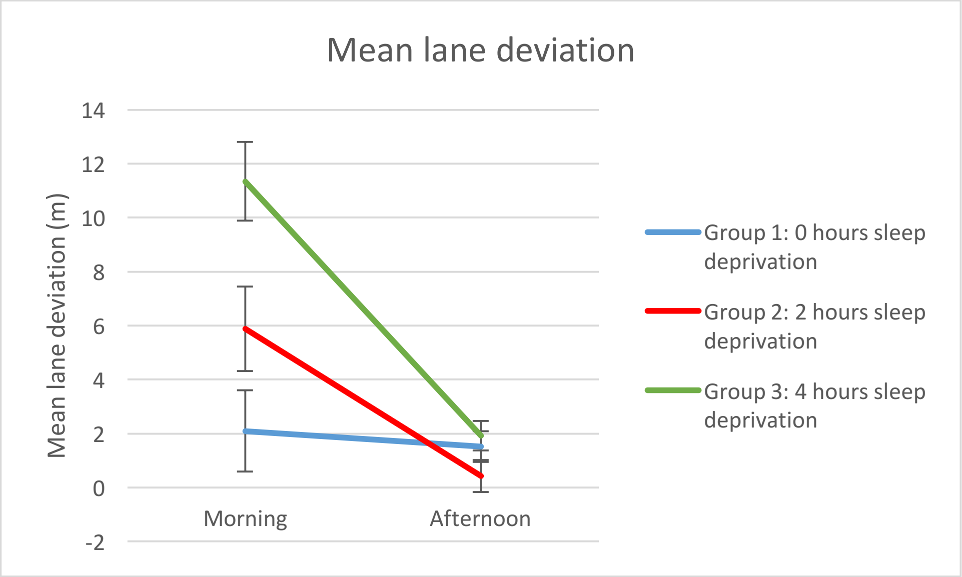

Figure 1. Mean lane deviation by group in the morning and afternoon

To examine the improvement in lane deviation performance in the afternoon, across both groups with sleep deprivation, we assessed caffeine intake between the morning and afternoon sessions. Caffeine was a possible explanation for this effect because, as reported above, a significant main effect of time of day was observed on the number of caffeinated drinks that participants observed. Across all groups, participants reported having consumed significantly more caffeinated drinks at the afternoon session than the morning session (average of .9 in the morning to 2.0 in the afternoon).

Total number of caffeinated drinks consumed on the test day was added to the analysis as a covariate. The covariate did not show any significant effects or interactions with the other factors, (Caffeine main effect F 1,35 = .632, p = .432; interaction of caffeine and time of day F (1,35)= .166, p = .686). The main effect of time of day remained (F (1,35) = .10.628, p =

.002), as did the main effect of group (F (2,35) = 9.166, p = .001), and the interaction between group and time of day (F (1,35) = 7.705, p = .002). This suggests that caffeine did not mediate the improvement of performance in the afternoon.

Smarteye data analysis

Analysis of the data from the Smarteye pro system aimed to understand whether

- there was a difference between groups in the morning, and between groups in the afternoon; and
- there was a difference between the morning and the afternoon (across groups)

The Dependent variables gained from the Smarteye Pro system were:

- Blink duration
- Pupil diameter
- PERCLOS

PERCLOS was calculated by first calculating the maximum eyelid opening distance, and then coding the number of times this distance was below 20% of the maximum (i.e. 80% closure). This was subsequently converted this to a time period, and percentage of each 5-minute time bin. Analyses presented here were based on PERCLOS averaged across the morning and afternoon sessions.

Repeated measures ANOVAS 2(WS: “Time of day” morning vs afternoon) x 3(BS: “Group” 0hrs, 2hrs, 4 hrs sleep deprivation) were conducted.

As previously discussed, Participants from Group 2 who did not comply with sleep instructions were excluded from the analyses. This meant that the total sample was N = 35, where Group 1 n = 12; Group 2 n= 10; Group 3 n= 13.

The exact n for each analysis changed somewhat depending on the amount of missing data. Some data was missing towards the end of the driving sessions (e.g. time bins 35-40minutes and 40-45 minutes) because some participants sped throughout the drive. In addition, small amounts of data were coded as missing due to failures of the SmartEye Pro system. Data from one session for each of two participants was corrupted and could not be logged in the

SmarteyePro software. These data have been send to the developers in Sweden for extraction and analysis.

No significant main effects of group or time of day, nor interactions were observed for pupil diameter, blink duration, or PERCLOS.

Figures 2-4 outline the mean values observed for these analyses, and highlight the lack of differences observed.

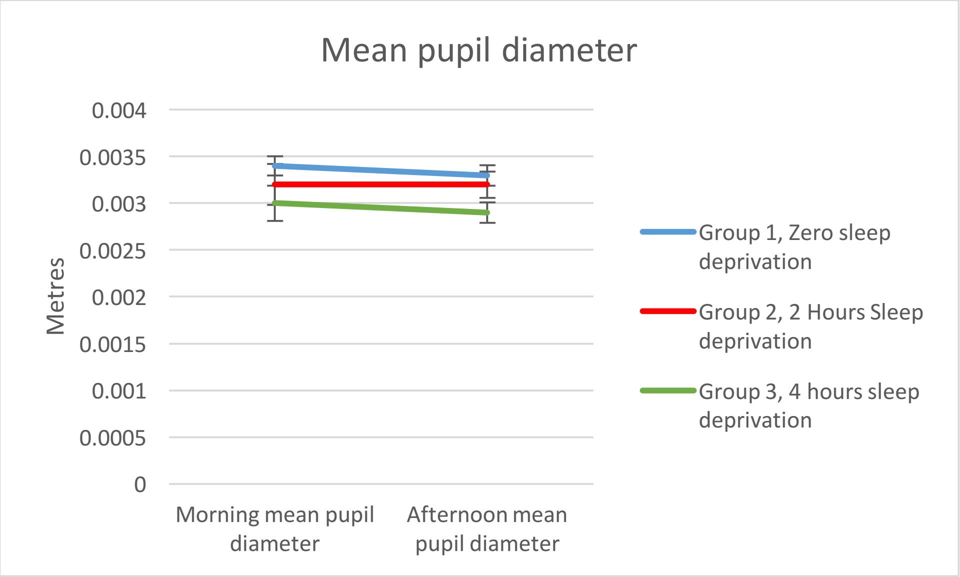

Figure 2. Mean pupil diameter by Group in the morning and afternoon test sessions.

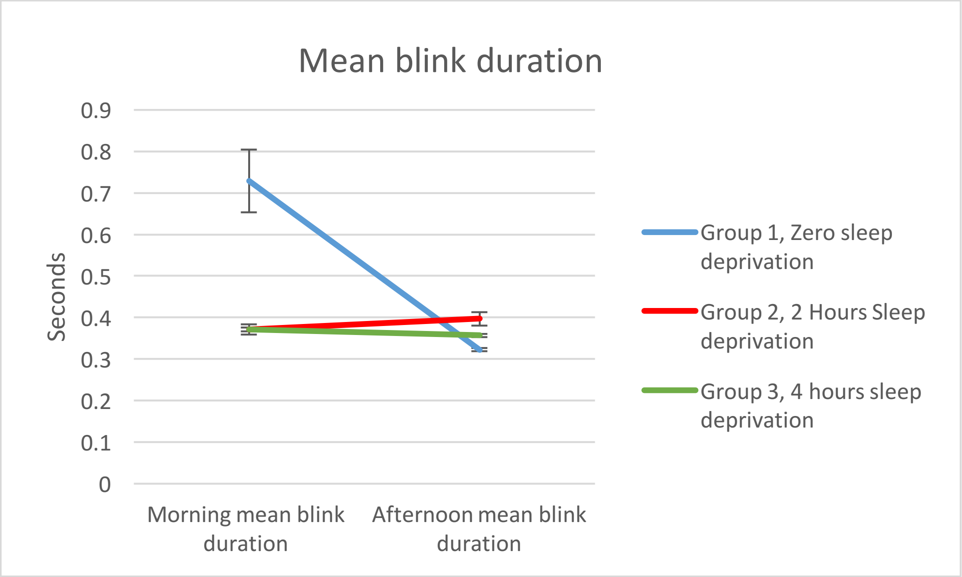

Figure 3. Mean blink duration by Group in the morning and afternoon.

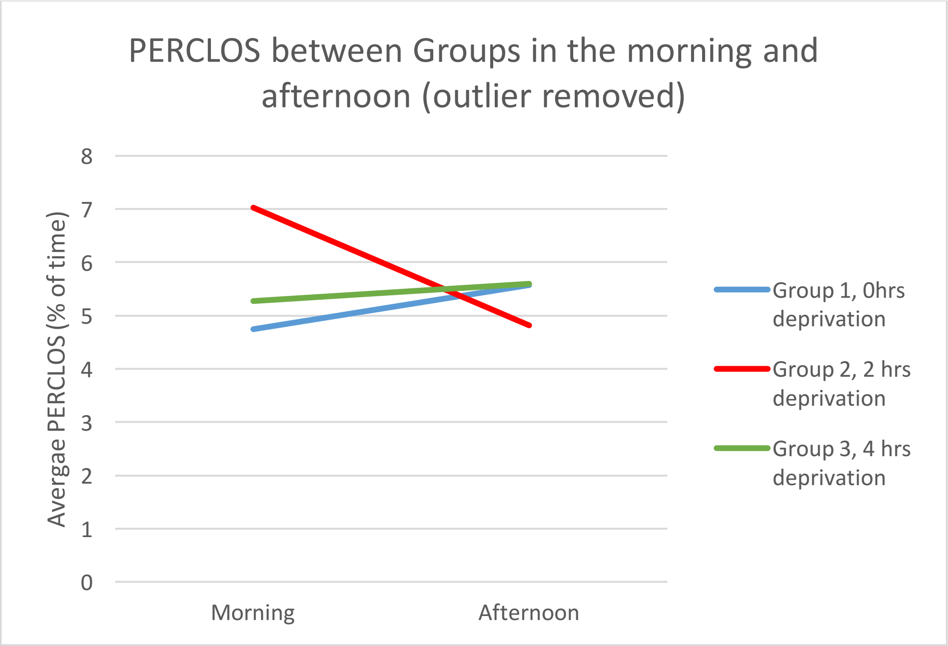

Figure 4. Mean PERCLOS by Group in the morning and afternoon with one outlier in Group 2 removed. (outlier was >65%).

Discussion

Driving performance

The main finding of this study was that sleep deprivation had an effect on driving performance, as indexed by lane deviation. This effect was particularly pronounced in the morning, soon after waking from a shorter than usual sleep. However, those who had experienced sleep deprivation the night before the test day, recovered their performance in the afternoon. Lane deviation in the afternoon was no different from that of participants who had had a full night's sleep. This recovery was not explained by caffeine intake during the day. Even though overall participants consumed more caffeinated beverages by the afternoon test session, this did not affect the lane deviation results. The recovery was also not explained by differences in the groups in terms of the hours that they worked on the test day, between test sessions, as there were no significant differences in hours worked on the test day.

These results are somewhat counter intuitive, in that it might normally be expected that performance decrements would be observed during the afternoon, when fatigue from the day's work might have an additional impact on any sleep deprivation experienced. Road crash data also suggests the early afternoon (Chipman & Jin, 2009) and early evening (BITRE, 2013; ACT Government 2016) to be times at which crashes are likely to occur. These statistics are influenced by the volume of traffic on the road at these times, and are not specific to fatigue related crashes.

The afternoon test session was outside of the period usually considered to be a low point of the circadian cycle (Chipman & Jin, 2009; May & Baldwin, 2009), which may explain the afternoon recovery, in that driving at that time occurred at a period of maximum alertness. It is possible that a practice effect contributed to the afternoon recovery (i.e. practice with the driving task led to improved performance), however results from our previous pilot work suggests that this is unlikely to be the case. Pilot data were collected from two groups

– one where the morning and afternoon sessions were performed on the same day, and one where the afternoon session was performed first, on one day, and the morning session was undertaken second, on the following day. Given the same practice session, no order effects were observed in driving performance. Performing both test sessions on the same day is considerably more practical, in terms of time, ensuring participants are sleep deprived, and likely compliance with sleep deprivation conditions.

A potential explanation for the poor performance in the morning is sleep inertia. Sleep inertia refers to a transitional phase between sleep and wakefulness characterised by impaired performance, vigilance and a desire to return to sleep (Trotti, 2016; Tassi et al 2000). While sleep inertia is known to be affected by sleep deprivation, it is controversial in terms of how long it is thought to last, which may depend on a range of other variables (Tassi et al., 2000). It remains a potential explanation for the impaired performance observed in the morning with sleep deprived participants. Further examination with cognitive and vigilance tests in sleep deprived and non-deprived participants, closer to waking times, and with additional psychophysical measurements (such as electroencephalogram (EEG)) may be required to explore this hypothesis.

While they may be somewhat counterintuitive, the observation of performance deficits with sleep deprivation in the equivalent of morning commuter driving is important.
Recent data from China support the results observed in our study, namely, that the morning commute is particularly prone to the effects of sleep deprivation. Zhang, Yau and Li (2016) analysed fatigue-related casualties in 21 cities of the Guandong province, an area with the highest rate of road accidents in China. The morning peak hours (7am-9am) were more likely to be associated with accidents due to fatigue than were evening peak hours (5pm-8pm) with odds ratios of 1.79 and .55 respectively. A similar pattern was found in relation to fatal or serious injuries, with respective odds rations of 1.84 and .11. These results parallel our findings of degraded performance in terms of lane deviation in the morning, following sleep deprivation. This means that early morning effects of sleep deprivation on regular, relatively short commuting trips should be further investigated.

The level of sleep deprivation employed in this study also emphasises the importance of these findings. Two hours sleep deprivation has been described as “mild” sleep deprivation (Mullington et al., 2009), and is certainly less than some of the levels of deprivation and sleep restriction employed in fatigued driving and sleep research (e.g. 3 hours of sleep from 23.00 to 1.00; Philip et al., 2005; 12 hours deprivation employed in Jackson et al, 2016). Two hours sleep deprivation equates to around 5-6 hours of sleep, and is consistent with “partial sleep deprivation” (Demos et al., 2016). Partial sleep deprivation is much more common than total sleep deprivation (i.e. 24 hours’ wakefulness), and may become chronic (Alhola & Polo-Kantola, 2007). That only 2 hours of sleep deprivation was required to observe significant impairments in driving performance in the morning is important due to the widespread nature of such deprivation in the community. Without imposing complex or severe restrictions on sleep, this study showed a significant driving impairment on commuter driving from a common degree of sleep disruption.

Eye tracking data

No significant effects were observed on indices of pupil diameter, blink duration, nor PERCLOS. These results are at odds with other findings in the field, for example, using electroencephalogram (EEG) devices which have found blink duration to be associated with sleepiness (eg. Akerstedt et al., 2010). A couple of potential explanations exist for these observations.

It may be that studies that have shown effects on these variables have done so on the basis of the combined effects of some sleep deprivation, time of day, and task-related fatigue. Confounding sleep related fatigue and task related fatigue is relatively common in sleep and driving research (May & Baldwin, 2009). For example, some studies have examined PERCLOS, blink duration, pupil diameter and other metrics in workers after a night shift (Wang & Xu, 2015). Others have not had direct comparability between sleep deprived and non-sleep deprived participants, in terms of the time of day at which test sessions were conducted, and the tasks performed between sleep and test (Daza et al., 2014). Accordingly, it may be that to observe an effect on these metrics, more than one type of fatigue may need to be employed, along with greater sleep deprivation, a longer task duration, or monotony (see Williamson et al., 2014).

Another alternative is that these measures are insensitive to the small changes that occur as a result of increasing drowsiness and fatigue. The effect of individual differences in response to sleep deprivation has been noted as an important issue in sleep research, and a particular issue in drowsiness detection (see Jackson et al., 2016). Jackson et al., identify the potential wide variation in responses and how this may affect drowsiness detection and measurement of performance impairment as an important area for future research.

Conclusions

The current study has demonstrated that drowsiness on commuter trips can be problematic in terms of driving performance with mild levels of sleep deprivation. This is important due to the degree of sleep deprivation at which performance impairments were observed being relatively widely experienced. Given that many drivers may think that they would be more likely to be tired in the evening after a long day at work, the observation that the impairments occurred in the morning is an important finding of this work. Additional investigation of psychophysiological measures may help understand the mechanisms accounting for these results further, in addition to examining issues in the sensitivity of eye-blink related metrics for assessing driver drowsiness.

References

ACT Government (2016). 2015 ACT Road crash report. Available from http://cdn.justice.act.gov.au/resources/uploads/JACS/PDF/2015-Crash-Report.pdf

Akerstedt, T. et al., (2010). Reaction of sleepiness indicators to partial sleep deprivation, time of day and time on task in a driving simulator – the DROWSI project. *Journal of Sleep Research, 19*, 298-309.

Alhola, P., & Polo-Kantola, P. (2007). Sleep deprivation: Impact on cognitive performance. *Neuropsychiatric Disease and Treatment, 3(5),* 553-567.

BITRE (2013). Australian Road Deaths Database. Retrieved March 1, 2013 from www.bitre.gov.au/statistics/safety/fatal_road_crash_database.aspx

BITRE 2016. Lengthy commutes in Australia. Research Report 144. Canberra: Bureau of Infrastructure, Transport and Regional Economics.

Boufous, S., & Williamson A. (2009). Factors affecting the severity of work related traffic crashes in drivers receiving a worker's compensation claim. *Accident Analysis and Prevvention,* 41, 467-473.

Bretzner, L., & Krantz, M. (2005). Towards low-cost systems for measuring visual cues of driver fatigue and inattention in automotive applications. *IEEE Inl Conf Vehicular Electronics and Safety, October 2005*, 161-164.

Brookshuis, K.A., & de Waard D. (2010). Monitoring drivers' mental workload in driving simulators using physiological measures. *Accident Analysis and Prevvention,* 42, 898-903.

Chipman, M., Jin Y, L. (2009). Drowsy drivers: The effect of light and circadian rhythm on crash occurrence. *Safety Science, 47*, 1364-1370.

Czeisler, C. A. et al., (2016). Sleep-deprived motor vehicle operators are unfit to drive: A multidisciplinary expert consensus statements on drowsy driving. *Sleep Health, 2*, 94-99.

Davenne, D., et al. (2011). Reliability of simulator driving tool for evaluation of sleepiness, fatigue and driving performance. *Accident Analysis and Prevention,* 45, 677-682.

Daza, I. G., et al., (2014). Fusion of optimised indicators from advanced driver assistance systems (ADAS) from driver drowsiness detection. *Sensors, 14*, 1106-1131.

De Rosario, H., et al. (2010). Controlled inducement and measurement of drowsiness in a driving simulator. *IET Intelligent Transport Systems,* 4, 280-288.

Demos, K.E. et al. (2016). Partial sleep deprivation impacts impulsive action but not impulsive decision-making. *Physiology & Behavior, 164*, 214-219.

Fell, D.L., & Black, B. (1997). Driver fatigue in the city. *Accident Analysis and Prevention,* 29, 463-469.

Geer, R., Jobes, D., & Tew, J. (1997). Incidence of automobile accidents involving anesthesia residents after on-call duty cycles. *Anesthesiology,* 87, 938.

Godley, S.T., Trigs, T.J. & Fildes, B.N. (2002). Driving simulator validation for speed research. *Accident Analysis and Prevention,* 34, 589-600.

Hanowski RJ et al. (2006). The 100-Car Naturalistic Driving Study: A Descriptive Analysis of Light Vehicle-Heavy Vehicle Interactions from the Light Vehicle Driver's Perspective. Washington DC: US Department of Tranportation.

Horne, J., & Reyner, L. (1999). Vehicle accidents related to sleep: A review. *Occupational and Environmental Medicine, 56*, 289-294.

Horrey, W.J., & Wickens, C.D. (2007). In-vehicle glance duration: Distribution, tails, and model of crash risk. *Transport Research Record, 2018*, 22-28.

Jackson, M. L., et al. (2016). The utility of automated measures of ocular metrics for detecting driver drowsiness during extended wakefulness. *Accident Analysis and Prevention, 87*, 127-133.

Kaplan, K.A., Itoi, A., & Dement, W.C. (2008). Awareness of sleepiness and ability to predict sleep onset: Can drivers avoid falling asleep at the wheel? *Sleep Medicine, 9*, 71-79.

Landstrom, U et al. (2010). Sound exposure as a measure against driver drowsiness. *Ergonomics,* 42, 927-937.

Marcus, C.L. & Loughlin, G. (1996). The effect of sleep deprivationon driving safety in house-staff. *Sleep,* 19, 763-766.

May, J.F., & Baldwin, C.L. (2009). Driver fatigue: The importance of identifying causal factors when considering detection and countermeasure technology. *Transportation Research Part F, 12*, 218-224.

McCartt, A.T, et al. (1996). The scope and nature of the drowsy driving problem in New York State. *Accident Analysis and Prevention,* 28, 511-517.

Mitchell, R., Driscoll, T., & Healey, S. (2004). Work-related road fatalities in Australia. *Accident Analysis and Prevention, 36*, 851-860.

Mullington, J. M. et al., (2009). Cardiovascular, inflammatory and metabolic consequences of sleep deprivation. *Progress in Cardiovascular Diseases, 51(4)*, 294-302.

NSW Centre for Road Safety (2016). Crash and Casualty Statistics. Available from http://roadsafety.transport.nsw.gov.au/statistics/interactivecrashstats/nsw.html?tabnsw=2

NSW Centre for Road Safety (2016a). Definitions and notes to support road crash data. http://roadsafety.transport.nsw.gov.au/downloads/definitions-notes.pdf

NSW RMS 2016. Don’t forget to stop, revive, survive. *Geared.* Accessed 20 July 2016. http://www.rms.nsw.gov.au/geared/your_driving_skills/staying_safe/driver_reviver.html

Philip, P. et al., (2005). Fatigue, sleep restriction and driving performance. *Accident Analysis and Prevention, 37*, 473-478.

Safe Work Australia (2015). Work-related Traumatic Injury Fatalities Australia 2014. Canberra: Safe Work Australia.

Safe Work Australia. (2012) *Compendium of workers' compensation statistics Australia 2009-10*. Canberra: Safe Work Australia.

Safework South Australia (2010). *Approved Code of Practice: Working hours*. Adelaide: Safework South Australia

Sagberg, F., Jackson, P., Kruger, H., et al. (2004). Fatigue, sleepiness and reduced alertness as risk factors in driving. Oslo: Institute of Transport Economics.

Sandberg, D. et al., (2011). The characteristics of sleepiness during real time driving at night – a study of driving performance, physiology and subjective experience. *Sleep, 34*, 1317-1325.

Scott, L.D., et al. (2007). The relationship between nurse work schedules, sleep duration and drowsy driving. *Sleep,* 30, 1801-1807.

Smolensky, M., et al. (2011). Sleep disorders, medical conditions, and road accident risk. *Accident Analysis and Prevention, 43*, 533-548.

Standing Committee on Transport (2010). National Road Saftey Strategy 2011-2020. Canberra: Department of Infrastructure and Transport.

Symmons, M.A., & Haworth, N.L. (2004). The contributions of speeding and fatigue to work-related road crashes. *Road Safety research, Policing and Education conference.* Perth.

Tassi, P., & Muzet, A. (2000). Sleep inertia. *Sleep Medicine Reviews, 4*, 341-353.

Trotti, L M. (2016). Waking up is the hardest thing I do all day: Sleep inertia and sleep drunkenness. Sleep Medicine Reviews, doi: 10.1016/j.smrv.2016.08.005

US Department of Transportation (2009). An Evaluation of Emerging Driver Fatigue Detection Measures and Technologies. FMCSA-RRR-09-005

Vadeby, A., et al. (2010). Sleepiness and prediction of driver impairment in simulator studies using a Cox proportional hazard approach. *Accident Analysis and Prevvention,* 42, 835-841.

Wang, X., & Xu, C. (2015). Driver drowsiness detection based on non-intrusive metrics considering individual specifics. *Accident Analysis and prevention.*

Wheatley, K. (1997). An overview of crashes in work-related driving. *Staysafe 36: Drivers as workers, vehicles as workplaces: Issues in fleet management.* Sydney: Parliament of NSW.

Williamson, A., & Boufous, S. (2007). A data matching study of the role of fatigue in work related crashes. *Transportation Research Part F,* 10, 242-253.

Williamson, A., et al. (2001). Developing measures of fatigue using an alcohol comparison to validate the efefcts of fatigue on performance. *Accident Analysis and Prevvention,* 33, 313-326.

Williamson, A., et al. (2011). The link between fatigue and safety. *Accident Analysis and Prevvention,* 43, 498-515.

Williamson, A., Friswell, R., Olivier, J., Grzebieta, R., (2014). Are drivers aware of sleepiness and increasing crash risk while driving? *Accident Analysis and Prevention, 70*, 225-234.

Young, K., et al. (2010). Intelligent speed adaptation - effects and acceptance by young inexperienced drivers. *Accident Analysis and Prevvention,* 42, 935-943.

Zhang, G., Yau, K.K.W., Zhang, X., & Li, Y. (2016). Traffic accidents involving fatigue driving and their extent of casualties. *Accident Analysis and Prevention, 87*, 34-42.