Heavy Vehicle Driver Fatigue Project

FINAL PROJECT REPORT (PUBLIC)

Prepared by the Cooperative Research Centre (CRC) for Alertness, Safety and Productivity for the National Transport Commission

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Executive Summary

The heavy vehicle driver fatigue project is the first international large scale project to validate alertness monitoring technology and use it to evaluate the impact of work-rest scheduling features on alertness and drowsiness in order to inform fatigue policy. Four different data sets were used including: two detailed instrumented vehicle studies conducted within the project involving more than 300 driver shifts; and collection and evaluation of retrospective alertness monitoring data from more than 150,000 shifts between 2015 and 2018 in conjunction with industry partners. This enabled evaluation of the impact of timing and duration of shifts, number and pattern of consecutive shifts, and duration and timing of rest breaks on alertness and drowsiness events, with consistent findings from the different project elements. The main findings were:

- Shifts longer than 12 hours were associated with at least a twofold increase in drowsiness events. This increase in risk occurred after 6-8 hours when on night shifts (starting in the afternoon to evening) and after 15 hours for day shifts starting before 9am
- The impact of shift duration was altered by the number of consecutive shifts. After 5 consecutive shifts the rate of drowsiness events doubled at 13 hours into the shift and tripled by 15 hours into the shift, but this was delayed for shorter shift sequences
- There was a modest increase in drowsiness events in the first 3 hours of the shift for early shifts starting between midnight and 6am (approximately 1.5 times the alert rate), but this then stabilised during day driving for shifts with a 3-6am start
- The greatest alertness was evident for shifts starting between 6-8am for up to 14 hours
- Driving at night was associated with impaired alertness (double the rate of drowsiness events between 10pm – 5am and triple from midnight – 3am)
- For night shifts there was substantial drowsiness after 8 or more hours of driving with a doubling of the drowsiness event rate, particularly after 6 or more shifts in a row
- Drowsiness was substantial during the first 1- 2 night shifts (first night shift effect), on long night shift sequences and with backward rotation of shifts (moving from night back to day or evening shifts)
- After long shift sequences of more than 7 shifts there was more than a doubling of drowsiness events for shorter rest breaks of 7-9 hours
- Nose-to-tail shifts with 7 hour breaks only enabled 5 hours of sleep, a duration previously associated with a 3-fold increased risk for motor vehicle accidents. There was increased drowsiness for the first segment of driving (first 90 minutes, prior to lunch break) compared

to an 11 hour break. There was a higher rate of EEG microsleep events during driving in the nose to tail schedule, but this effect was not significant, perhaps due to small sample of drivers and a low rate of microsleeps.

- Although there was no evidence of abnormal driving performance, a larger study may be required to assess the impact of nose-to-tail shifts in more detail, under different working conditions. This assessment was a single shift with a night time break and daytime driving and no restriction on caffeine intake. There may be greater drowsiness effects with consecutive nose-to-tail shifts given the restricted sleep obtained, and if the break occurred during the day.
- The threshold adopted to indicate ocular-based drowsiness events provided moderate accuracy to ensure a low false positive rate, but means that some drowsiness related events would not be identified. A doubling of the drowsiness event rate relative to driving in an alert state was used to indicate a substantial impairment in alertness, based on the doubling of accident risk at 0.05% BAC and was considered more accurate than relying on an absolute value.

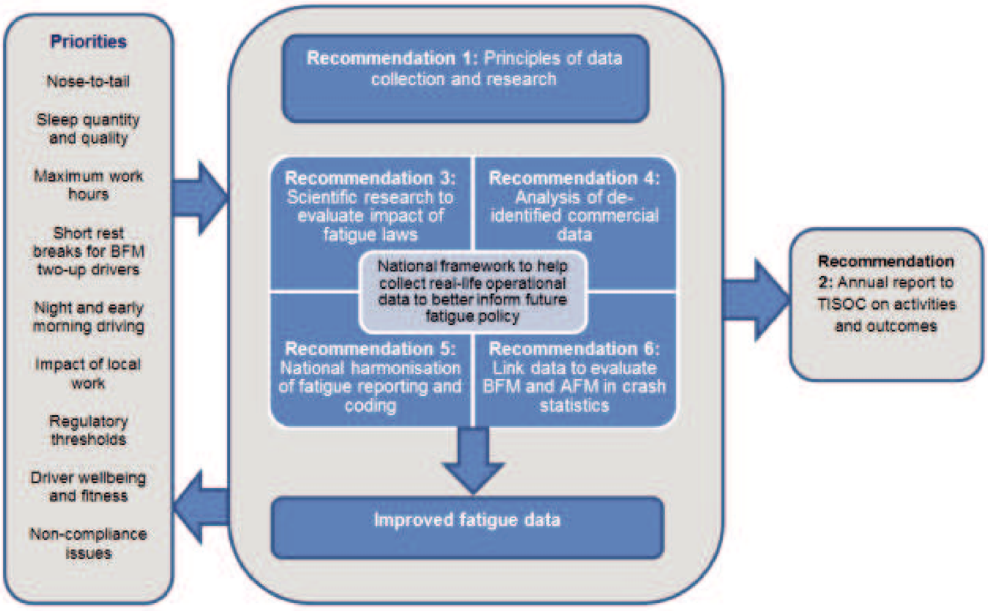
Introduction

In May 2016, a national framework was introduced with the objective of collecting real-life operational data to better inform future fatigue policy (National Transport Commission, 2016). A program of four projects were established to address priority fatigue issues.

The aim of the data framework is to build an ongoing evidence base to better understand and address the following issues and challenges:

1. Clarifying the contribution of heavy vehicle driver fatigue to road crashes
2. Heavy Vehicle National Law (HVNL) fatigue provisions have not been evaluated since their introduction in 2008
3. There is insufficient data to support future reforms
4. Alertness monitoring technology and existing commercial data can be better harnessed to support evidence-based policy and regulatory reform

Figure 1. Heavy Vehicle Fatigue Data Framework



The CRC for Alertness, Safety and Productivity (the Alertness CRC) was tasked with Recommendation 3: the scientific evaluation of the fatigue impact of current regulations (https://www.legislation.qld.gov.au/view/whole/html/inforce/current/sl-2013-0078) in the context of operational work schedules and the validation of the accuracy of alertness monitoring technology.

Goals

1. Analysis of existing research to
    a. Validate alertness monitoring tools and to identify research gaps
    b. Establish a link between alertness measure and actual safety risk (i.e. crash incidents and/or near misses)
2. A comparative analysis of the impact of nose-to-tail and conventional schedules on heavy vehicle driver alertness/fatigue (Phase 2a)
3. An assessment of heavy vehicle driver sleep quantity and quality in rest periods (Phase 2a)
4. An assessment of heavy vehicle driver alertness while driving in-vehicle related to their work schedules (Phase 2b)
5. Although not in the initial scope, an additional assessment of driver fatigue and mental health has been provided (Phase 2b)

A series of reports are available that detail the outcomes of each of these research projects

Phase 1 Report: Literature Review and Track Study

Phase 2a Report: Nose-to-tail Laboratory Study

Phase 2b Report (1): Alertness Monitoring Existing Data Part 1 (Seeing Machines)

Phase 2b Report (2): Alertness Monitoring Existing Data Part 2 (Optalert)

Phase 2b Report (3): Alertness Monitoring Field Study

Phase 2b Report (4): Fatigue and Mental Health Field Study

This report provides an integration of the findings across the research program and includes a discussion of the impact of work schedules on heavy vehicle driver fatigue.

Alertness Monitoring Technology - Evaluation and Validation

Goal 1. Phase 1 Report

The first phase of the project required identification and validation of alertness monitoring technology that could then be used to assess the impact of different work schedules on heavy vehicle driver alertness/drowsiness in their vehicles. This was undertaken via review of literature for alertness monitoring technology and validation of the chosen methods in comparison to driving impairment in an instrumented vehicle study.

To provide an evidence-based recommendation of alertness monitoring technology(ies) a range of devices with published validity findings were considered carefully. Information regarding their operational use were also considered for selecting them for application in heavy vehicles. Devices utilising ocular based evaluation of alertness were the only evidence-based technologies that met the scientific criteria, including validation in laboratory and field studies, commercial availability and suitability for use in the heavy vehicle industry. Laboratory based experiments and driving studies have found that drowsiness causes impairments in eye-blink parameters including slowed eye and eyelid movements, longer blink duration and episodes of prolonged eyelid closure that can last for more than 10 seconds [1-3]. These parameters are reliable predictors of drowsiness-related errors and impaired vigilance, correlating with simulated crashes [4-6]. To date, Australian heavy vehicle operators have successfully implemented both Optalert and Seeing Machines, which both utilise ocular based assessment of alertness, for the purpose of managing fatigue-related road safety risks.

Evaluation of the accuracy of ocular based alertness measures for detecting driver impairment was undertaken in comparison to the occurrence of out of lane driving events following sleep deprivation. Twelve drivers undertook two instrumented vehicle drives, one following 36 hours of sleep deprivation. The ability of ocular alertness measures to detect episodes of the driver drifting out of the lane when drowsy was evaluated. A range of ocular measures were able to detect drowsiness related out of lane events with moderate accuracy including blink duration measures and the Johns Drowsiness Score (JDS), with up to 82% correct classification. Cut-offs to indicate drowsiness events were chosen to be used in the field studies to provide a sensitivity of at least 50% for detecting out of lane events in the same minute and provided a specificity of 84%. Given these parameters, in the subsequent field projects (Phase 2a and Phase 2b reports) this means that some drowsiness related events would not be identified, however there would be a low false positive rate when these cut offs were reached.

Ocular based alertness monitoring technology, measured continuously, was used as the key measure to assess schedules in Phase 2. The data analysis expresses the rate per hour of drowsiness events. In addition to setting a cut off for indicating drowsy driving, a threshold needed to be set for indicating substantial impairment in alertness and increase in risk relative to alert driving. That is the increase in the rate of drowsiness events that is considered to be impaired when compared to the rate during alert driving. The risk for having an accident at a blood alcohol concentration (BAC) of 0.05% is approximately two times the risk at a BAC of 0.00%. Utilising this precedent, a doubling of the drowsiness event rate relative to driving in an alert state was used to indicate substantial impairment in alertness. As such, in phase 2b not only the effects of all factors of work/rest on driver alertness were examined, but also a cut off was set for substantial impairment in alertness.

Work Schedules

This section reviews the impact of different work schedule aspects on driver alertness/drowsiness (often referred to as fatigue), drawing upon the research and related reports listed above. Importantly this includes assessment of where these different schedule aspects interact to result in high risk scenarios. In describing schedule aspects that resulted in high levels of drowsiness/impaired alertness, an increase in drowsiness events of more than twofold compared to alert driving periods was used, based on the precedent that illegal blood alcohol concentrations of 0.05% increase crash risk by twofold [7].

These projects comprised:

Phase 2a Report: Nose-to-tail Laboratory Study: instrumented vehicle study assessing the impact of 7 hour break duration between shifts compared to 11 hours

Phase 2b Report (1): Alertness Monitoring Existing Data Part 1 (Seeing Machines): analysis of schedule factors that influence driver alertness utilising large existing alertness monitoring dataset

Phase 2b Report (2): Alertness Monitoring Existing Data Part 2 (Optalert): analysis of schedule factors that influence driver alertness utilising large existing alertness monitoring dataset

Phase 2b Report (3): Alertness Monitoring Field Study: instrumented vehicle study assessing the schedule factors that influence driver alertness

Nose-to-tail shifts

Goals 2 and 3. Phase 2a Report

A specific scheduling aspect that was addressed in the project was evaluation of the impact of nose to tail shifts on heavy vehicle driver fatigue and sleep in comparison to a conventional schedule. Currently, heavy vehicle national law permits drivers' to work back to back extended shifts that are up to 12-14 hours in duration and are separated only by a 7 hour rest break. This shift pattern is termed a nose-to-tail shift. Given the nature of a nose-to-tail shift, drivers may experience fatigue due to a combination of factors including inadequate sleep opportunity, driving for extended hours, or driving at times where alertness levels are naturally low (at night or in the early morning). To investigate these factors we assessed 13 heavy vehicle drivers during a simulated nose-to-tail shift schedule (two 13 hour shifts separated by a 7 hour rest break) and simulated alternative extended rest break shift schedule (two 13 hour shifts separated by an 11 hour rest break). During the simulated rest breaks for each shift schedule, sleep quality and quantity was recorded using activity monitors. During the simulated work periods that followed the rest break for each shift schedule, participants underwent 5 hours of alertness assessment in laboratory followed by 8 hours of alertness and performance assessment while driving an instrumented vehicle on a predetermined route in Victoria.

In summary the project found:

- The amount of sleep obtained in the nose-to-tail shift condition was substantially less (5 hrs during 7 hour break) than the extended rest break condition (6.5hrs during 11 hour break).
- During the laboratory component of the nose-to-tail schedule driver's reported being sleepier and had slower reaction times than during the extended rest break condition. These differences were not present during the on-road drive component.
- Ocular alertness measures were worse for the first drive segment (90 minutes prior to lunch break) in the nose-to-tail shift condition than the extended rest break shift condition. These differences did not extend into the second drive segment suggesting a restorative effect of the lunch break and consumed caffeine, which may act as countermeasures for the increased drowsiness in the nose to tail schedule and negate differences between the conditions. The relative role of each of these factors cannot be directly examined under the current project. Brain wave measures of alertness (microsleeps) did not clearly differ between the two shift schedules, possibly due to the small driver sample
- Driving performance as measured by adverse driving events scored by a qualified instructor did not differ between the two shift schedules, although the rate of events was low

During the 7-hour rest break of the nose-to-tail schedule, drivers obtained an average of 5 hours of sleep. Short sleep durations of 5 hours or less are associated with a 3-fold increased risk for motor vehicle accidents [8]. Further support for this comes from a prior study that surveyed truck drivers who had survived fatal fatigue-related crashes and found they had an average of 5.5 hours of sleep in the 24 hours prior to their accident [9]. Drivers need to undertake other activities during their rest break, including eating, showering and contacting family and friends and it also takes time to fall asleep, which is why sleep duration is substantially shorter than the break duration. These results are also consistent with the limited field evaluation of driver sleep. In driver schedules that allow an 8 hour break the average sleep duration is only 5 hours 18 minutes or 66% of the available time [10]. During the extended 11-hour rest break, drivers obtained an average of 6.5 hours of sleep. This was consistent with their habitual sleep which was monitored for ~two weeks during the study. There were no differences in self-reported or objectively measured sleep quality between the two shift conditions on the rest break.

Ocular alertness measures during the on-road drive were affected by shift schedule condition. During the first drive segment (90 minute period prior to the lunch break, eye opening was reduced by 10% and blink duration was increased by ~13% for the nose-to-tail schedule compared to the extended rest break schedule. A 37% increase in blink duration is associated with a four-fold increase in crash risk. Whether a 13% increase is associated with elevated crash risk is unknown and needs to be explored further. For drive segment 2 (3.5 hours of driving after lunch), there was no difference between eye opening and blink duration between the shift schedules. The improvement in alertness during the second drive segment after the nose-to-tail shift was likely attributable to the 45 min lunch break, where drivers were able to consume food and caffeine [11].

EEG microsleep measures of alertness during the on-road drive did not clearly differ between shift schedule conditions. While there did appear to be a higher rate of microsleeps in drive segment 1 for the nose-to-tail schedule than the extended rest break schedule, the effect was not significant, which may be attributable to the relatively low rate of occurrence for these events and small sample of drivers. Driving performance as measured by the occurrence of lane departure events, distraction events and all adverse driving events was no worse for the nose-to-tail shift than the extended rest break shift. Previous laboratory studies have demonstrated an increased amount of out of lane events when sleep is restricted to 5 hours compared to normal sleep [12]. There are a number of possible explanations for this discrepancy. Driving simulators over-estimate driving impairment compared to on-road driving [13], perhaps reflecting that people are more careful when driving on-road as a result of being aware of risk. In laboratory studies access to caffeine is restricted, but it was not restricted for this current project, which would help to mitigate the effects of impaired alertness but is consistent with real life operational situations. When divided by hours of driving, the rate of lane departures in this study was relatively low per hour of driving (~0.25), which is similar to the rate observed in healthy rested individuals during real on road driving (~0.66) [14], suggesting no substantial driving impairment in the drivers in this project. The relatively small sample size in this project may have also restricted the power to identify differences between the conditions.

This is the first study to assess the impact of simulated work scheduling on the duration and quality of sleep as well as alertness and driving performance in heavy vehicle drivers. The findings highlight that a nose-to-tail shift schedule adversely affects sleep quantity and some measures of alertness during a subsequent simulated work shift, when compared to a shift schedule with a longer rest break. Driver performance was not adversely affected in the nose-to-tail shift despite the shorter sleep duration. It appears that the short break (lunch break) and caffeine intake during the drive mitigated the impact of the short sleep duration on impaired alertness. Importantly this study only assessed the effects of a single nose-to-tail shift, with the rest/sleep period scheduled at night (the optimal time for sleeping) and the tail shift during the day (optimal time to maintain alertness). It has been demonstrated previously that recurrent restriction of sleep to 6 hours or less for two weeks results in a cumulative cognitive impairment that is equivalent to that observed following two full days of sleep deprivation [15, 16]. Given the restricted sleep obtained during the nose-to-tail shift, schedules should allow for adequate recovery between shifts and should avoid shift sequences with repeated nose-to-tail shifts. Future work should assess the cumulative impact on alertness and driving performance of shift schedules with more than one nose-to-tail shift and with different shift timing. It is noted that infrequent usage of a nose-to-tail shift for the purpose of avoiding driving during higher risk periods (such as at night) may result in lower overall risk for a particular journey.

Time of day

Goal 4. Phase 2b Reports 1,2,3

The body's circadian rhythm that regulates sleep and wake, markedly increases drowsiness (reduces alertness) at night to aid going to sleep. In people who sleep regularly at night this affect is usually most potent between approximately 2am and 6am – the circadian nadir. There is a second, less potent, impact on alertness in the early afternoon – the siesta period. The project reports from Phase 2b all support a substantial impact on alertness during night time driving. There was a doubling in the rate of ocular based drowsiness events (on average) when driving between midnight and 5am (Phase 2b Report 2). The lowest drowsiness event rates were between 6am to 8pm. This finding is supported by data in the Phase 2b Report 1, in which the number of fatigue events increased from 7pm, peaking at midnight and falling to the lower daytime levels by 7am. There also appeared to be an increase in fatigue events in the mid-afternoon in this data set, consistent with a "siesta period" impact. The field study data (Phase 2b Report 3) also supports this result with more than a doubling of drowsiness event rates between 11pm and 4am. The time of day impact on alertness is consistent with published research on crash risk demonstrating that driving between 2am and 5am increases the risk of a road crash by more than fivefold [8].

The time of day effect interacts with other schedule characteristics. The rate of drowsiness events was increased by more than 2.5 compared to the alert state when driving between midnight and 5am after more than 7 consecutive shifts and in some instance after 6-7 consecutive shifts (Phase 2b Report 2). Similar impacts were also evident in the alertness monitoring field study. A 2-fold increase in drowsiness events was evident between 10pm-midnight and 3-fold increase from midnight to

3am, mainly evident after driving for more than 6 hours or after 5 or more consecutive shifts (Phase 2b Report 3). Heavy vehicle drivers tend to have restricted sleep while working [17, 18] and it is likely that this interacts progressively with the impact of time of day influences on reducing alertness with more prolonged shift sequences. Shift sequences that included two shift transition types and backward rotation of shifts (from nights back to days) resulted in some particularly high drowsiness event rates when driving between midnight and 6am of more than 4 times the alert state (Phase 2b Report 2). Finally there was also some evidence that driving between midnight and 5am at the end of long shifts (10th-12th hours of the shift) could also result in very high drowsiness event rates of more than 3 times the alert state (Phase 2b Report 2). This is also consistent with expected impacts of prolonged driving on increased drowsiness and crash risk [19] interacting with time of day effects on impairing alertness.

Shift start time

Shift start time influenced alertness while driving, partly by determining whether driving occurred during the night/circadian low period, but this also interacted with other factors such as the impact of shift duration. The greatest alertness was evident for shifts starting between 6-8am for up to 14 hours (Phase 2b Report 2), while longer day shifts still resulted in substantial drowsiness (Phase 2b Report 3). There was a modest increase in drowsiness events in the first 1-3 hours of the shift for shifts starting between midnight and 6am (approximately 1.5 times the alert rate), but this then stabilised during day driving for shifts with a 3-6am start (Phase 2b Report 2). Analysis of existing alertness monitoring data (Phase 2b Report 1) supports these findings. The lowest frequency in fatigue events was for shifts starting between 6am-midday. There was a 19% increase in fatigue events for shifts starting between midday to 6pm (finishing in the late evening to over-night) and 28% increase for shifts commencing between 6pm to midnight (finishing over-night to early morning). These results are consistent with known circadian effects on alertness that promote wake from 6-8am until the mid-evening [20]. Similarly, greatest alertness for shifts starting between 6-8am (for up to 14 hours) is likely associated with the ability to sleep at night prior to the shift when the circadian rhythm of sleep propensity is high.

For night/evening shifts starting between 2pm to midnight, there was at least a doubling of the drowsiness event rate after more than 6 hours into the shift in the alertness monitoring field study (Phase 2b Report 2). While in the analysis of existing data, this increase in drowsiness occurred a little later, after 8 or more hours of driving with a doubling of the drowsiness event rate, particularly after 6 or more shifts in a row. This effect of time of day and longer shift duration on increasing drowsiness is consistent with deterioration in alertness due to the combined effect of the circadian nadir (night) and the effects of prolonged wake and task duration that both promote drowsiness [20]. Each of these factors also individually increase road crash risk, although in the absence of other influences shift duration does not usually increase crash risk until 12 hours of driving. [19, 21]

Shift duration

Goal 4. Phase 2b Reports 1,2,3

In the alertness-monitoring field study (Phase 2b Report 3) shifts longer than 12 hours were associated with at least a twofold increase in drowsiness events. This is consistent with published crash risk data showing an increase in crash risk after 12 hours of driving [19]. In assessing the impact of shift duration on drowsiness events there is a clear interaction with shift type, with earlier onset of events on night shifts in comparison to day shifts. In the analysis of existing alertness monitoring data (Phase 2b Report 1) there was a 1.5 times increase in risk of fatigue events in night shifts starting between 6pm to midnight compared to day shifts starting between 6am and midday. Fatigue events also occurred on average 100 minutes earlier.

Data from the alertness monitoring field study showed a doubling of drowsiness events after 6 hours when on night shifts (starting in the afternoon to evening) but that this was delayed until after 15 hours for day shifts starting before 9am (Phase 2b Report 3). Data from alertness monitoring existing dataset part 2 (Phase 2b Report 3) provided similar findings, with doubling of the drowsiness event rate after 8 or more hours of driving during night shifts, particularly after 6 or more shifts in a row. The greatest alertness was evident for shifts starting between 6-8am for up to 14 hours, supporting that longer shifts are safer during day shifts. These findings are consistent with known interactive effects of circadian influences on alertness (enhancing alertness during the day and promoting drowsiness at night) in conjunction with the effects of prolonged wake and task duration [20, 22].

In addition to the impact of prolonged shift duration on drowsiness there was a modest increase in drowsiness in shifts starting early in the morning, consistent with increased drowsiness at this time due to circadian effects. In the first 3 hours of the shift for shifts starting between midnight and 6am the rate of drowsiness events was increased to 1.5 times the alert rate (Phase 2b Report 2). This rate then stabilised towards the alert event rate during day driving for shifts with a 3-6am start, but remained modestly elevated for shifts starting between midnight to 3am.

Shift sequences

Goal 4. Phase 2b Reports 1,2,3

Different shift types (night vs day), the number of shifts in a row and rotation between shifts had an impact on alertness. The first night effect is a well described phenomenon. Prolonged wakefulness usually occurs as a result of sleeping during the night and the remaining awake for most or all of the day prior to the night shift. This can result in being awake for more than 24 hours by the end of the night shift and be combined with the drowsiness promoting effects of the circadian rhythm at night [23]. Driving at night was associated with moderately impaired alertness (1.7 – 2 times increased rate of drowsiness events between 11pm – 5am). Drowsiness was greater though during the first 1-2 shifts at these times (drowsiness event rate more than doubled, Phase 2b Report 2). Night shifts after longer shift sequences also result in greater drowsiness, with the drowsiness event rate more than doubled after more than 7 shifts in a row in the same dataset. In the alertness monitoring field study (Phase 2b Report 3) longer sequences of night shifts were also associated with a doubling of the drowsiness event rate, evident after 5 or more shifts for shifts starting between 6pm to midnight. Other field studies have demonstrated a predominance of drowsiness events during night driving in conjunction with restricted sleep of less than five hours during night shifts in long haul truck drivers [18]. Circadian effects make it difficult to obtain adequate sleep during night shifts that can have a cumulative effect over a sequence of night shifts that would explain progressive drowsiness over longer night shift sequences [15].

The body's circadian rhythm that sets the normal sleep wake cycle and promotes alertness during the day, delays more easily, moving the alertness-promoting period later in the day. This can result in partial shifting of the rhythm during night shift, although complete shifting of the rhythm is rare. Previous research has shown that the body adapts better to forward rotation of shifts, moving from day to evening and night shifts rather than moving from nights back to evenings or days in the same shift schedule [24, 25]. In the alertness monitoring field study, breaks resulting in backward rotation of shifts (moving from a night to a morning or afternoon shift) were associated with a four-fold increase in the rate of drowsiness events despite relatively long break durations (Phase 2b Report 3). This finding was also supported by analysis of shift sequences from the alertness monitoring existing dataset (Phase 2b Report 2). Shift sequences with 2 or more changes in shift type (e.g. day to night shift) and backward rotation of shifts (moving from night shifts back to day or evening shifts the following day) were associated with a doubling of drowsiness event rates and a 4-fold increase in drowsiness events when also driving at night. In this analysis longer day shift sequences had the lowest rate of drowsiness events and sequences with forward rotation from days to night shifts had an intermediate level of drowsiness.

Break influences

Goal 4. Phase 2b Reports 1,2,3 and Phase 2a

In the alertness monitoring existing dataset (Phase 2b Report 2) the major rest break duration was assessed by grouping the durations into 2 hour blocks, beginning from 7 hours up to 23 hours. The most common rest break duration between shifts was 9-11 hours (36%), followed by 11-13 hours (27%), 23-25 hours (10%) and then 13-15 hours (4%). The lowest drowsiness event rate was for rest breaks of 9-11 hours, but there was no significant difference compared to these other rest break lengths. Rest break durations between 7-9 hours were uncommon (<1%), as were rest breaks between 15 -17, 17-19, 19-21 and 12-23 hours (each <=1%) and hence it is difficult to comment regarding the effect of these rest breaks on drowsiness.

The combined impact of rest break duration and consecutive number of shifts was also compared using the ratio of the drowsiness score to most alert level (Phase 2b Report 2). All drowsiness ratio scores were similar for rest breaks over 9 hours irrespective of the number of consecutive shifts performed, apart from 7-9 hours after more than 7 consecutive shifts where there appeared to be 3 times the rate of drowsiness events compared to the alert state.

The combined impact of rest break duration and shift start time was also assessed (Phase 2b Report 2). For this analysis, the rate at which a drowsiness event occurred was compared between different rest break durations. This analysis revealed that rest break durations of 23-25 hours that started between 00:00 to 03:00 hours had a greater rate of drowsiness events. While this may seem unusual given the long duration of the rest break, it is likely that this particular shift type reflects the first night shift, after drivers have just come off a run of day shifts as discussed above under shift sequences. Similarly, shorter break durations of 9-11 hours prior to commencing night shifts between 17:00-21:30 were associated with higher drowsy event rates. There were no other significant differences found for the 9-11 hour, 11-13 hour or the 23-25 hour, outside of these start times.

In the alertness monitoring field study (Phase 2b Report 3) there was an increase in the drowsiness event rate to more than 4 times the alert event rate when rest lengths of 17-19 and 19-21 hours occurred before shift start times of 09:00-14:00 and 14:00-18:00 hours respectively. This likely reflects backward rotation of shifts (moving from a night shift to day or evening shift) as discussed above under shift sequences.

A key objective of the Phase 2a nose to tail study was to compare the effects of a 7 hour rest break between shifts (nose-to-tail) to an alternative rest break of 11 hours between shifts (extended rest break) on sleep, alertness and performance in heavy vehicle drivers. Drivers obtained an average of 5 hours of sleep during the nose-to-tail shift schedule (7 hour rest break) compared to an average of 6.5 hours during the 11 hour rest break. Sleep durations of 5 hours or less have been associated with a 3-fold increase risk for motor accidents [8]. Furthermore, heavy vehicle drivers who have survived fatal fatigue-related accidents have reported sleeping an average of 5 and half hours prior to their accidents (National Safety Transport Board, 1995). For optimal health, a good quality sleep of 7-9 h is recommended [26]. As shown drivers' in this study obtained substantially less sleep than this when restricted to a 7-hour break and time for eating, showering, relaxation (watching tv or using mobile phone) and contacting friends and family were accounted for. This amount of sleep is similar to previous reports of sleep duration in the heavy vehicle industry when operating under similar break durations.

The nose-to-tail shift schedule (7 hour break) was associated with greater driver reported sleepiness across the entire simulated shift, when compared to the extended rest break. In addition, driver's reaction times were worse for the nose-to-tail shift schedule, in the laboratory component, although this effect did not persist during the on road component. Reduced alertness while driving was evident in the nose-to-tail shift only during the first drive segment (for 90 minutes before the lunch break), when eye blink duration was considered. There were no differences in the number of total adverse driving events, lane departure events or distraction events as scored by the driving instructor, between the two different shift schedules.

The impact of minor rest breaks within shifts on sleepiness, alertness and driving performance.

A key objective of Phase 2a was to assess the impact of a short 45-minute lunch break within a shift, on sleepiness, alertness and driving performance. During the 45-minute lunch break drivers were able to consume food and beverages containing caffeine, although these were kept consistent between the conditions. A positive effect of this lunch break was observed for self-reported sleepiness, with driver's reporting feeling less sleepy following the lunch break when compared to immediately prior to the lunch break. When ocular alertness was considered, eye opening and blink durations were worse prior to the lunch break for drive segment 1 during the nose-to-tail shift, however following the lunch break, for drive segment 2 there was no longer a significant difference between conditions. These findings suggest a restorative effect of a break and consumed caffeine on alertness and sleepiness. This work highlights the potential benefit for short rest breaks on alertness and sleepiness, which is likely to be at least partially due to caffeine consumption [11, 27]. Future work should investigate different duration minor rest breaks and their placement within shifts. Additionally future work should separate the effects of the break by itself (e.g. not-driving) versus caffeine consumption by itself. As there were no differences in brain wave measures of alertness and adverse driving events of the drive segments (that separate the break), no positive effects of the minor 45 minute-lunch break on these variables can be inferred. However, a larger sample size may yield different results.

Mental health sub study

The demands of the transportation industry may expose heavy vehicle drivers to extended and irregular work hours and sleep disturbances. Evidence from other shift working industries (e.g., nursing, firefighting and law enforcement) have highlighted strong associations between sleep disturbances, certain work demands and mental health problems among personnel, but our understanding of how these common, yet modifiable factors, are related to the health and well-being of heavy vehicle drivers is limited. Therefore, the objective of this phase of the project was to determine if there are specific aspects of heavy vehicle drivers' sleep and work demands associated with mental health symptoms. This objective was addressed by combining sleep, work and survey data from participants in both Phase 2a: Nose-to-tail Laboratory Study and Phase 2b (3): Alertness Monitoring Field Study. A large proportion of the sample included in this phase screened positive for sleep disorders, most notably insomnia (24%) and sleep apnoea (48%). Over a quarter of drivers (28%) also screened positive for a mild risk of depression, while 8% screened positive for moderate to severe depression. Sixteen percent of participants had a mild risk of anxiety, and 8% had a moderate to severe risk of anxiety. Increased levels of sleep impairment were associated with a significantly greater risk of depression in heavy vehicle drivers, while increased insomnia symptom severity raised the risk of both depression and anxiety in this sample. Finally, increased years of experience working as a heavy vehicle driver was associated with a decreased depression and anxiety risk. Together, our findings support future research investigating whether sleep disorder screening, education and prevention strategies in the heavy vehicle industry, especially among less experienced drivers, are effective in reducing the risk of mental health issues in this workforce.

Conclusion

This sequence of projects has validated ocular based alertness monitoring technology, confirming its ability to identify drowsiness related driving impairment, and provided unique objective evidence regarding heavy vehicle driver schedule features that enable safe driving with high alertness levels and features that lead to high levels of drowsiness. The approach provided real life operational data that reflects current practice in order to inform future policy. The key features identified that impact on drowsiness are similar to those in the existing literature: time of day – highest alertness 6am-8pm, significant drowsiness 11pm-5am; shift duration – significant drowsiness after 12 hours; shift start time – lowest risk for 6am-midday starts, highest drowsiness for 6pm-midnight starts; sequential shifts - increasing drowsiness after more than 7 shifts in a row but earlier if combined with short breaks or night driving, and increased drowsiness with more rotation between shift types particularly backward rotation (e.g. nights back to days or afternoons). In addition to these individual factors it was clear that the interaction of each factor was important. For example, during day shifts there was no substantial drowsiness for up to 14 hours, however on night shifts starting in the afternoon to evening significant drowsiness was evident after 6 to 8 hours of driving. Several factors are likely to influence the drowsiness levels detected under different shift conditions and the interactions of these shift elements are important to consider. Greatest alertness for up to 14 hours on day shifts, for example, may be related to the time of day of shift start, longer rest break prior to shift, and/or the number of shift sequences in a row. In the study specifically evaluating a single nose to tail shift schedule with a between shift break duration of 7 hours, sleep duration was only 5 hours, a level known to increase crash risk. There was objective increase in drowsiness, however driving performance was not clearly impaired. This study assessed a single nose-to-tail shift schedule and sleeping at night whereas further work should assess multiple shift schedules and break timing as it has been shown that even modest sleep restriction of 6 hours across multiple days can result in cognitive deficits equivalent to severe sleep deprivation.

There are some limitations that should be considered. Most of the analysis of the impact of schedule features relied upon ocular based alertness monitoring technology. Based upon our review and previous assessments [28] this is the best available technology for continuous assessment of alertness/drowsiness. It had a moderate accuracy for detection of drowsiness related driving impairment in the validation study. It should be noted that the application of a doubling of the drowsiness event rate relative to driving in an alert state as an indication of impairment in alertness may not be the optimal threshold, but was considered more accurate than relying on an absolute value for drowsiness events. The majority of the analysis from all projects analysed the impact of schedule factors within the same driver and this helps to take into account any individual (driver related) influences on alertness/drowsiness. Recruitment for the Phase 2b projects were difficult despite the project team and steering committee employing a large range of strategies, in particular where this required instrumentation of company vehicles. The use of retrospective alertness monitoring datasets enabled analysis of large volumes of data, although it was not feasible to match all data with schedule information within the time frame of the project. This appears to be a promising avenue for assessing the impact of schedules on alertness/drowsiness. The available data provided a rich source of data for many schedule features, although there was a significant amount of missing data where the technology hadn't been used. It is also acknowledged that operators implementing alertness monitoring technologies have a safety focus and may not be representative of the broader population of heavy vehicle drivers. Analysis of shift sequences was challenging, given the very large number of different shift sequences (more than 70 in one dataset). The analysis of shorter major break durations (less than 9 hours) from the retrospective data and field monitoring study was difficult given relatively few breaks of this duration, although this was supplemented by detailed information from the nose to tail shift study. Finally it is not feasible to account for all confounding factors that may influence crash risk in addition to drowsiness, hence considering factors such as the influence of traffic density in interpreting the results is also important.

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Appendix

The Alertness CRC Personnel

Principal Investigators

Mark Howard, Institute for Breathing and Sleep
Shantha Rajaratnam, Monash University

Other Investigators

Clare Anderson, Monash University
Andrew Tucker, Monash University
Maree Barnes, Institute for Breathing and Sleep
Alexander Wolkow, Monash University

Project Leader

Tracey Sletten/Anna Clark, Monash University

Phase Leaders

Shamsi Shekari, Institute for Breathing and Sleep
Jen Cori, Institute for Breathing and Sleep
Caroline Beatty, Monash University
Brook Shiferaw, Institute for Breathing and Sleep
Alexander Wolkow, Monash University

Numerous Research Assistants, Students and Interns also provided vital contributions to this program of research.