Accident Analysis and Prevention 81 (2015) 8–13

Contents lists available at ScienceDirect

Accident Analysis and Prevention

journal homepage: www.elsevier.com/locate/aap

Real-time driver drowsiness feedback improves driver alertness and self-reported driving performance

Eugene Aidman[a,b,*], Carolyn Chadunow[a], Kayla Johnson[a], John Reece[c,d]

[a] Defence Science and Technology Organisation (DSTO), Land Division, Edinburgh, South Australia 5111, Australia
[b] University of Sydney, School of Psychology, Sydney, New South Wales 2006, Australia
[c] RMIT University, School of Health Sciences, Bundoora, Victoria 3083, Australia
[d] Australian College of Applied Psychology, Melbourne 3000, Australia

ARTICLE INFO

Article history:
Received 5 November 2013
Received in revised form 7 January 2015
Accepted 31 March 2015
Available online 29 April 2015

Keywords:
Driver fatigue
Drowsiness monitoring
Infra-red oculography
Feedback
Alertness
Performance ratings
Circadian phase
Military personnel

ABSTRACT

Driver drowsiness has been implicated as a major causal factor in road accidents. Tools that allow remote monitoring and management of driver fatigue are used in the mining and road transport industries. Increasing drivers' own awareness of their drowsiness levels using such tools may also reduce risk of accidents. The study examined the effects of real-time blink-velocity-derived drowsiness feedback on driver performance and levels of alertness in a military setting. A sample of 15 Army Reserve personnel (1 female) aged 21–59 ($M = 41.3$, $SD = 11.1$) volunteered to being monitored by an infra-red oculography-based Optalert Alertness Monitoring System (OAMS) while they performed their regular driving tasks, including on-duty tasks and commuting to and from duty, for a continuous period of 4–8 weeks. For approximately half that period, blink-velocity-derived Johns Drowsiness Scale (JDS) scores were fed back to the driver in a counterbalanced repeated-measures design, resulting in a total of 419 driving periods under "feedback" and 385 periods under "no-feedback" condition. Overall, the provision of real-time feedback resulted in reduced drowsiness (lower JDS scores) and improved alertness and driving performance ratings. The effect was small and varied across the 24-h circadian cycle but it remained robust after controlling for time of day and driving task duration. Both the number of JDS peaks counted for each trip and their duration declined in the presence of drowsiness feedback, indicating a dynamic pattern that is consistent with a genuine, entropy-reducing feedback mechanism (as distinct from random re-alerting) behind the observed effect. Its mechanisms and practical utility have yet to be fully explored. Direct examination of the alternative, random re-alerting explanation of this feedback effect is an important step for future research.

1. Introduction

Driver fatigue is a major causal factor in road accidents (Haraldsson and Akerstedt, 2001). Fatigue is also a construct that links factors such as time of day, time since waking, task duration and monotony, with safety-related outcomes (Ackerman, 2011; Williamson et al., 2011). Fatigue can result from sleepiness (drowsiness), boredom, and mental or physical exhaustion. From these causal factors, drowsiness is considered the most relevant aspect of fatigue when applied in the driving context. Driver drowsiness has been implicated in road accidents both within professional (Maycock, 1997) and general driving populations (Horne and Reyner, 1995a). Accidents caused by driver drowsiness can have a similar fatality rate to alcohol-related crashes (Pack et al., 1995).

Multiple factors contribute to drowsiness, such as long working hours (Fischer et al., 2000), lack of sleep (Dawson and McCulloch, 2005), and medical conditions (Smolensky et al., 2011). Lack of sleep is more prevalent in some populations, including junior doctors (Gander et al., 2007), submariners at sea (McLean et al., 2009) and 'fly-in fly-out' mining workers (Ferguson et al., 2010). Chronic sleep restriction is a known risk factor in driving (Williamson et al., 2011). It is also well established that the 24 h circadian rhythm is marked with peaks and troughs in alertness levels as evidence by studies incorporating both subjective and objective sleepiness measures (Monk et al., 1997; Wright et al., 2002). Task-related factors also contribute to driver drowsiness

---

[*] Corresponding author at: Defence Science and Technology Organisation (DSTO), Land Division, Edinburgh, South Australia 5111, Australia. Tel.: +61 873896844.
E-mail address: Eugene.aidman@dsto.defence.gov.au (E. Aidman).

http://dx.doi.org/10.1016/j.aap.2015.03.041

(Williamson et al., 2011). These factors may include driving duration (Folkard, 1997) and monotony (Thiffault and Bergeron, 2003), such as that experienced in highway driving (Horne and Reyner, 1995b).

The effects of drowsiness manifest in a reduced capacity to maintain vigilance (Johns et al., 2007). In the driving context this leads to observable changes in driver performance such as reduced capacity to maintain speed, distance between vehicles and lane-keeping (May and Baldwin, 2009), all of which increase the risk of road accidents (Adell et al., 2011).

With mounting evidence linking driver drowsiness to road accident risk, industry has responded with investment in driver monitoring tools aimed at mitigating this risk (Breuer, 2008; Kircher et al., 2002). These tools employ a range of methods including those based on (a) continuous driving time, (b) specific driver performance (e.g., steering) or (c) physiological response (e.g., eye metrics). Among the latter, eye and eyelid characteristics have been used to infer levels of drowsiness (Dinges and Grace, 1998). One of these tools, the Optalert Alertness Monitoring System (OAMS) (Johns et al., 2008a) utilises infra-red (IR) reflectance oculography to monitor eyelid movements. The system uses an IR emitter and sensor mounted on a spectacle frame to continuously measure eye blink velocity, from which levels of drowsiness are derived. The OAMS has been used for detection and monitoring of driver drowsiness in the mining (Caterpillar Global Mining, 2008) and road transport industries (Williamson et al., 2011; Smith et al., 2009), as well as for pilot drowsiness detection in aviation (Corbett, 2009).

OAMS has been used in commercial settings predominantly through the provision of drowsiness data to a central monitoring area. When a driver's drowsiness reaches a predetermined risk level, interventions (e.g., taking a mandatory break) can be implemented. Applications of this type come with a significant overhead in terms of monitoring and implementation cost. In addition, such interventions rely on fatigue detection rather than prevention. The current study explores the utility of real-time drowsiness feedback to drivers for fatigue prevention. Tucker (2012) has reported preliminary observational data indicating a reduction in an across-the-worksite average driver drowsiness associated with the provision of driver feedback during the staged rollout of OAMS across a number of mining sites. These data suggest that, at a group difference level, direct real-time driver feedback may reduce their drowsiness, compared to monitoring-only operation of OAMS. They do not, however offer an insight into how individual drivers would respond to such feedback. Our study is focused on this individual response and developing an understanding of the utility of real-time feedback to individual drivers potentially leading to a low cost strategy to improve driving outcomes for at-risk individuals.

Our study aims to examine the effectiveness of OAMS in improving driver functional state. It focuses on Australian Army Reserve personnel. For the majority of participants, an Army training weekend is normally preceded by a full-time working week and often a lengthy drive to the location of Army Reserve duty. In addition, members often report for duty on a weekday night, again involving the commute to and from the duty location. As a group Army Reservists are likely to work longer hours and have less sleep when on duty (Aidman et al., 2012a), potentially putting them at higher risk for drowsiness related driving accidents.

We hypothesised that provision of OAMS feedback would reduce both objective drowsiness and subjective sleepiness when compared to no-feedback condition. Feedback was also expected to improve driving performance ratings.

2. Method

2.1. Participants

This research was approved by the Defence Science & Technology Organisation Low Risk Human Research Ethics Review Committee prior to recruiting participants. Participants were members of an Australian Army Reserve regiment who volunteered to take part in a larger study (Aidman et al., 2012b) addressing driver fatigue, in exchange for duty time credit. All participants provided an informed written consent prior to participating.

Fifteen Army Reserve personnel (1 female) aged from 21 to 59 years ($M = 41.3$, $SD = 11.1$) self-selected as frequent drivers. They volunteered to have their drowsiness monitored with OAMS while commuting both in private and duty vehicles. Their rank ranged from Private (Sapper) to Lieutenant Colonel. Participants wearing prescription glasses were excluded.

2.2. Design

The study used a repeated-measures cross-over design to test the effect of OAMS feedback on objective drowsiness (Johns Drowsiness Scale scores), subjective sleepiness (Karolinska Scale scores) and self-rated driving performance (lane-keeping, headway and responsiveness). All participants drove with Optalert glassed on and continuous data recording by an in-vehicle OAMS. Approximately half the time they drove with the OAMS feedback switched on (Feedback On condition) and the other half with the feedback switched off (Feedback Off condition). The order of these conditions was counterbalanced with a single cross-over point in the design. Participants were randomly allocated to these conditions with the restriction to produce two groups of near-equal size. As a result, eight participants were allocated to the On-first condition (they begun their driving with feedback On, and the remaining seven participants started with feedback switched off (Off-first condition). At half-time mark of each driver's participation they crossed over to the alternative condition.

2.3. Materials

2.3.1. Johns Drowsiness Scale (JDS)

The OAMS comprises individually calibrated IR emitter and sensor mounted on spectacle frame and connected via a mini-USB cable to a data collection processor, and a dashboard indicator. The system (Johns et al., 2008a) continuously monitors eye and eyelid movement through IR oculography and generates, at one minute intervals, a drowsiness score based on previously validated regressions including relative velocities and duration of blinks and other eyelid closures (Johns et al., 2007, 2008a). The scores form the Johns Drowsiness Scale (JDS) (Johns et al., 2007) which has demonstrated good test-retest reliability (Johns et al., 2008b) and sensitivity/specificity in detecting cognitive performance decline caused by sleep deprivation (Johns et al., 2007), driving (Johns et al., 2008a) and aircraft operation (Corbett, 2009).

JDS scores range from 0 to 10, with higher scores indicating increasing drowsiness. A JDS score between 0 and 4.4 (inclusive) indicates a low risk level of drowsiness. A score between 4.5 and 4.9 (inclusive) indicates medium risk and JDS scores of 5.0 and above indicate a high risk (Johns et al., 2008a). In the feedback condition, the JDS scores were displayed on a 50 mm × 80 mm monochrome LCD screen attached to the dashboard immediately to the left of the visual arch of the steering wheel. This dashboard indicator also produced auditory and visual warnings when JDS scores reached the medium or high risk range. When a driver remained in the low risk range for 5 min, the indicator display blanked out but was able to be turned on by touching the screen. In the feedback-off condition, the dashboard indicator was switched off at all times.

2.3.2. Karolinska Sleepiness Scale (KSS)

Driver alertness was measure using a 10-point modified version of the Karolinska Sleepiness Scale (Kaida et al., 2007; Åkerstedt and Gillberg, 1990). The KSS is typically used as an instantaneous measure of sleepiness (Åkerstedt and Gillberg, 1990). The version utilised in this study had participants record their current level of alertness on a 10-point scale, which is a reverse of the Kaida et al. (2007) instrument, ranging from 1 ("extremely sleepy, fall asleep all the time") to 10 ("extremely alert"). At the end of each driving period participants were asked to record the start and end time of the drive, as well as their alertness level using the KSS.

2.3.3. Self-rated driving performance

Participants rated their driving performance on three 5-point Likert scales: lane keeping, headway and responsiveness to road events.

2.4. Procedure

Participants were individually fitted with a pair of OAMS glasses and given a Driving Alertness Journal, which incorporated the KSS, start and end times for each drive, as well as driving performance rating scales.

Participants were monitored with OAMS while driving, for a continuous period of 4–8 weeks. For approximately half that period, JDS scores were fed back to the driver via a dashboard display that also generated beeping sounds when the scores reached medium- and high-risk drowsiness levels. The remainder of driving tasks were performed with no feedback, while OAMS monitoring continued throughout. At the conclusion of the study, a total of 419 driving periods under "feedback" and 385 periods under "no-feedback" condition had been collected. The duration of these drive periods ranged from 1 to 180 min, with a mean drive length of just under half an hour (26.4 min; $SD = 24.6$). A linear mixed model analysis found no differences between the two conditions in drive duration, $F(1, 622.85) = 1.48$, $p = .46$, $\eta^2 < .01$, or time of day the drive was taken, $F(1, 650.44) = 1.18$, $p = .51$, $\eta^2 < .01$.

JDS scores were compared between two conditions (OAMS Feedback On versus Off), while controlling for time of day (to account for the known circadian variance in alertness) and drive duration (Tucker, 2012; Anderson et al., 2011). Repeated measured data were analysed with mixed linear model analyses using SPSS v.20 (IBM Corporation).

3. Results

3.1. Data preparation

Data from two participants had to be excluded due to equipment failure resulting in no reliable record of OAMS feedback status (On or Off). Similar equipment failure resulted in partial loss of feedback status for five more participants. Three of them completed feedback-On condition only and two completed feedback-Off only. These data were retained for our main analysis because the chosen method (linear mixed models) has the capacity to handle such cases with missing cells.

A total of 804 drive events was coded from 14 drivers. Each drive event was coded as to whether feedback was *on* or *off*, and the number of trials within each of these conditions for each driver was recorded and used as a fixed factor in the linear mixed model analyses reported below. The number of trials per driver in each condition ranged from 5 to 90. The minimum total number of driving events recorded by an individual driver was 10, with a maximum of 141 ($M = 57$).

The 804 drive events were distributed across time of day. Fig. 1 shows the distribution of drive events across the 24 h cycle. In this figure, x-axis values correspond to trip start times and midnight is represented as 0.

Data were checked for a range of assumptions underlying the chosen analyses. Measures of normality and homogeneity of variance were within tolerable bounds, and linearity is discussed below. Because each model involved covariates, the assumption of homogeneity of regression slopes was tested and was found to be met for all analyses.

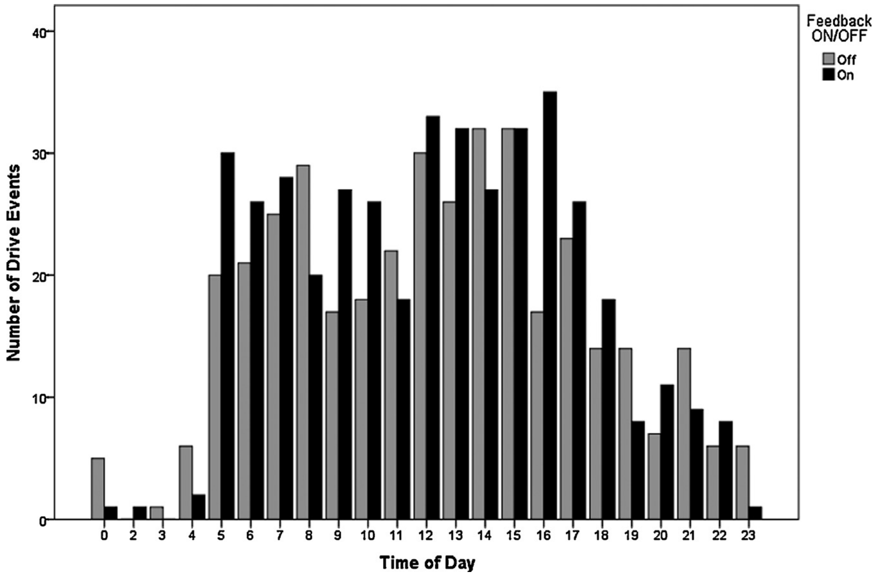

Fig. 1. Distribution of drive events for two conditions across time of day. *Note*: x-axis values correspond to trip start times.

3.2. Effects of real-time OAMS feedback on aggregated driver state and performance

The circadian effects on JDS-measured drowsiness can be seen in Fig. 2, with peaks in drowsiness during the early hours of the morning and gradually increasing throughout the day. Driver risk appears to be lowest during the day (between the hours of 7 am–5 pm).

A number of analyses were conducted that examined differences between feedback conditions, using univariate linear mixed model analyses. Given the repeated measures nature of the design used, and more importantly the unequal number of repeated driving periods each participant undertook, mixed models analysis was deemed to be the most appropriate analytical approach. As participants completed each feedback condition over multiple trials, both feedback condition and trial were entered as repeated fixed factors in the models. All analyses modelled the covariance structure using compound symmetry, which is the recommended approach for this design (Field, 2013), and that demonstrated superior model fit over any of the other covariance structure methods using both Akaike's information criterion and Schwarz's Bayesian criterion (Akaike, 1974). For all inferential tests reported below, the effect size η^2 is reported, along with its associated 95% confidence interval.

First, the order of conditions (On-first or Off-first) did not affect any of the outcome variables (all $Fs < 2.0$, $p > .1$). Consequently, the On-first and Off-first groups were combined for all subsequent analyses.

As task duration is known to influence the operator's drowsiness levels, the initial analysis included drive length (in minutes) as a covariate. There was no difference in drive length between the conditions. There was a significant effect of feedback on mean JDS scores, $F(1, 623.04) = 23.13$, $p < .001$, $\eta^2 = .04$, 95% CI [.01, .07], indicating that average drowsiness per drive was lower in the 'feedback on' condition ($M = 1.07$, $SE = 0.18$) compared with 'feedback off' ($M = 1.33$, $SE = 0.18$). The magnitude of this effect varied over the 24-h circadian cycle. During the daytime hours (when the majority of driving occurred) the effect peaked at around 11 am and 9 pm, and declined to almost no effect between 6 and 7 pm (see Fig. 1). Between the hours of 10 pm and 4 am there were insufficient driving periods to demonstrate a clear effect of feedback.

The observed decline in the mean JDS scores in the feedback condition, was largely accounted for by the second covariate, time of day. Time of day was entered using twenty-four hour time with midnight being entered as 0. When both task duration and time of day were entered as covariates in the model, the result was no longer significant. Time of day was used as a covariate, as it closely aligns with the normal circadian phase. The effects of circadian phase are known to be non-linear. Whilst our data confirm this non-linearity (see Fig. 1), our inspection of the residual plots (observed versus predicted values) revealed no marked non-linearity for any dependent measure. This confirmed the adequacy of mixed linear modelling for our data. The two-covariate model – controlling for task duration and time of the day – was applied to all subsequent analyses. First, we found that the most immediate indicator of risk – the maximum JDS score per driving session – was significantly lower in the 'feedback on' condition ($M = 1.97$, $SE = 0.21$), compared to the 'feedback off' condition ($M = 2.20$, $SE = 0.22$). The effect was small but significant: $F(1, 624.01) = 9.81$, $p = .002$, $\eta^2 = .02$, 95% CI[<.01, .04].

We also found the subjective appraisals of safe distance keeping to be significantly higher under the feedback condition, $F(1, 270.95) = 5.34$, $p = .02$, $\eta^2 = .02$, 95% CI[<.01, .06]. However, the effects of feedback on other appraisals of driving performance (lane-keeping and responsiveness) were not significant (see Table 1). The effect of feedback condition on KSS ratings was significant as well (Table 1), with participants rating themselves as more alert with feedback on, $F(1, 285.51) = 4.15$, $p = .04$, $\eta^2 = 01$, 95% CI[<.01, .05].

The duration of driving episodes did not differ between feedback and no-feedback conditions. Examination of free text entries in participant driving journals revealed no discernible thematic differences between the two conditions in the subjective experiences reported or strategies employed to maintain alertness.

3.3. Effects of real-time OAMS feedback on dynamic JDS metrics

The analyses presented so far, utilised aggregate characteristics of driving periods and showed that the presence of feedback had a significant impact on drivers' subjective ratings of their safe distance keeping and sleepiness. The presence of feedback also reduced the maximum JDS scores the drivers' reached in each driving session. In order to begin to understand the mechanism

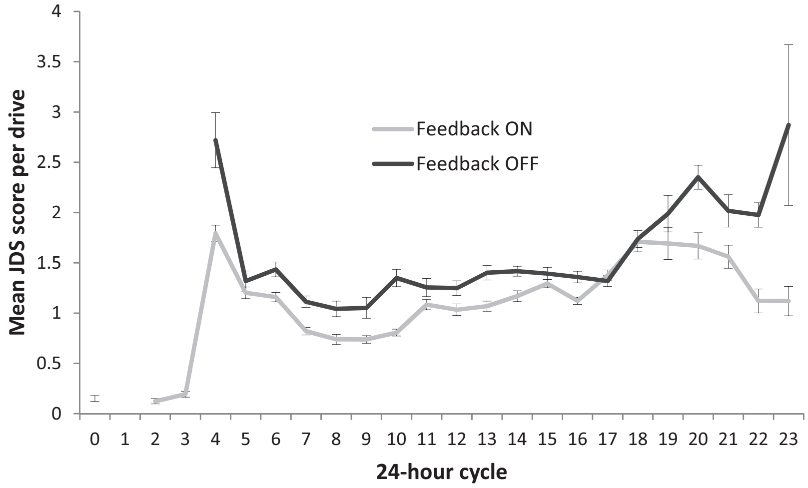

Fig. 2. The effect of feedback on levels of drowsiness (JDS scores) across the circadian cycle. Error bars indicate 95% CIs computed on data aggregated across all drivers. Larger CIs reflect reduced observations between 10 pm and 4 am. The effect peaked at around 11 am and 9 pm, and declined between 6 and 7 pm. *Note*: *x*-axis values correspond to trip start times.

Table 1
Drowsiness and performance metrics across two feedback conditions.

Measure	Feedback condition	
	On Mean[a] (SE) (*N*)	Off Mean[a] (SE) (*N*)
Lane keeping	4.43 (0.17) (167)	4.45 (0.17) (267)
Safe distance keeping	4.47 (0.18) (167)	4.60 (0.18) (267)
Responsiveness	4.44 (0.18) (168)	4.45 (0.18) (267)
Mean JDS	1.18 (0.19) (392)	1.34 (0.19) (326)
Maximum JDS	1.97 (0.21) (392)	2.20 (0.22) (326)
KSS	7.59 (0.32) (171)	7.30 (0.32) (282)
Number of JDS peaks	9.50 (0.66) (385)	10.49 (0.67) (317)
JDS peak duration (minutes)	12.43 (0.41) (386)	13.01 (0.43) (320)

[a] All descriptive values have been adjusted for the presence of driving duration and time of day as covariates. *N* refers to number of driving events contributing to each result.

behind this difference we further examined the differences between feedback conditions, by analysing the dynamics of JDS scores over time during individual drive periods. We defined JDS peaks as local maxima in the time series of a single trip (driving period). Given that JDS scores were recorded every 60 s, JDS peak duration was measured in minutes.

A significant feedback effect was found on the number of JDS peaks per trip, $F(1, 592.98) = 13.28$, $p < .001$, $\eta^2 = .02$, 95% CI[<.01, .05] and on JDS peak duration, $F(1, 555.59) = 4.77$, $p = .03$, $\eta^2 = .01$, 95% CI[<.01, .03] (See Table 1). These results indicate that the presence of feedback resulted in both reducing the number of peak JDS scores reached across a drive and reducing the JDS peak duration. This dynamic pattern is consistent with reduced entropy (Ivancievic and Aidman, 2007). And such entropy reduction is known to characterise feedback processes (Taub, 2010).

4. Discussion

Our study set out to examine the effectiveness of OAMS in improving driver functional state in the context of a field trial. Overall, our results show a significant effect of OAMS feedback: its presence was consistently associated with reduced peak drowsiness (lower maximum JDS scores), improved self-reported alertness (reduced sleepiness in KSS) and drivers' own ratings of headway. The effects are small but remain significant after controlling for known confounds, such as circadian phase (time of day as a proxy) and time on task (time since the start of each drive). This effect remained unaffected by the potential artefact of the cross-over design – the order of conditions (On-first or Off-first). This indicates that the protocol utilised in our study produced a transient effect that is unlikely to persist beyond the feedback episode.

Our finding is consistent with Optalert's own trial results (Tucker, 2012) showing that the introduction of feedback and warnings resulted in 28% fewer medium risk warnings and 41% fewer high risk warnings when compared against the baseline, no-feedback condition.

The results confirm the predicted effects of OAMS feedback on reducing drowsiness (JDS peak scores), self-reported alertness (KSS), and improving driving performance appraisal (safe distance ratings). The magnitude of this effect varied over the 24-h circadian cycle, predictably peaking between 22:00 and 04:00 when alertness levels are at their lowest in the circadian cycle (Wright et al., 2002). The same effect declined to almost zero in between 18:00 and 19:00 – a time window when alertness levels are typically high (Monk et al., 1997). This result should be interpreted cautiously however, as data from this study indicated an unexpected increase in drowsiness in the early evening. As well as this, the JDS data did not show the expected increases in alertness in both the early afternoon and the early morning that would be expected due to circadian phase. This may be partly due to the small number of data points collected in the night-time hours.

The important question of why the feedback condition produced these effects, remains open. The active ingredient of our feedback condition that reduced drowsiness (JDS) and improved alertness (KSS) and performance appraisals, is yet to be explained. The most optimistic explanation would suggest a genuine feedback effect: the driver's awareness of their own functional state, enhanced by the OAMS, may have enabled them to apply their own means of adjusting their level of alertness. Alternative explanations include placebo effects and simple re-alerting effects of any display change that draws the driver's attention in addition to their routine tasking. The Hawthorn effect can be discounted as our participants were always aware of the fact they were being monitored – both in feedback and no-feedback conditions. The re-alerting mechanisms of such feedback have yet to be fully examined. It is possible that it is the continuous provision of feedback that explains the difference. Alternatively, invitations to update *t* the feedback screen when it goes blank after several minutes of low JDS readings may have produced a re-alerting effect. Our field study had no capacity to answer this question in full, as it afforded no control over the driver action in respect of the feedback display. For this question to be addressed, future studies will have to enforce greater control both over the mode of feedback provision and over the driver response. However, our analysis of the dynamics of JDS scores across individual driving periods offer a preliminary answer. We counted the number of JDS peaks per trip and measured each peak's duration. If the observed difference in the average drowsiness levels (mean JDS scores over a driving period) was due to a genuine feedback effect then, according to biofeedback models (Taub, 2010) JDS peak duration should be shorter, indicating feedback-driven entropy reduction. Our findings confirm that expectation, suggesting that a genuine feedback mechanism was likely at play in reducing drowsiness under the feedback condition.

Our sample size was rather small. We partially compensated for it with a cross-over design whereby each participant experienced both feedback and no-feedback conditions. In addition, the amount of control over participants action was limited, which is typical in field study contexts. We had no influence on when they drove and for how long. As a result our data were distributed unevenly across the complete 24-h cycle, with a relatively small number of observations in late evening and early morning hours and no data coverage between 1 and 4 am. This is representative of non-operational driving patterns but requires caution in generalising our findings to continuous operations, such as those in the mining industry. Variation in drive duration was also quite substantial – from a few minutes to nearly three hours. We accounted for this by including drive duration as a co-variate in all our analyses. However, both circadian phase and drive duration are likely to moderate the effect of OAMS feedback, and as such would benefit from a more targeted analysis with a more deliberate manipulation of drive duration and timing. This analysis would help answer important questions such as how the feedback effect changes with increasing drive duration and what time of day it is most/least pronounced.

Confirming the preliminary conclusion about the feedback mechanism responsible for our main finding would require ruling out a placebo effect (the effect of mere awareness of being monitored). This will require additional experimentation that might include presenting numbers, unrelated to eye blinking, that drivers believe reflect their drowsiness. Such experimentation seems worth pursuing in future research.

The effect of OAMS feedback on both drowsiness and driving performance ratings was robust and statistically significant, which supports, in principle, the capacity of OAMS to generate improvement in both drowsiness and performance as a stand-alone system. However, the relatively small size of this effect leaves open the question of the system's practical utility as a behaviour change agent. The practical benefits that OAMS feedback confers still need to be examined against alternative means of driver state monitoring.

Given that the purpose of OAMS is to provide alerts at higher levels of driver drowsiness, observation of a feedback effect on drowsiness and performance measures at low levels of OAMS-measured drowsiness is promising. Future research should replicate the study over night-time hours (e.g., between 10 pm and 4 am) when drivers are expected to be most drowsy, and incorporate long drives, where monotony of the task would be expected to induce drowsiness. These conditions would more closely replicate those found in military continuous operations and allow investigation of the utility of OAMS as a behaviour change agent in more dangerous and realistic contexts. To examine the generalizability of our findings, they also need to be replicated with different driving populations (such as road freight, taxi and mining industries) that have different risk profiles and levels of formal regulation.

Acknowledgements

The authors thank Warren Lewis, Dana Michalski, Gary Coombs and Philip Jacques for assistance with data collection; John Stewien and Elaine Lee for their help with data processing; Andy Tucker for advice on JDS score interpretation and Justin Fidock for commenting on earlier drafts of this paper.

References

Cognitive Fatigue: Multidisciplinary Perspectives on Current Research and Future Applications. In: Ackerman, P.L. (Ed.), American Psychological Association, Washington, D.C.

Åkerstedt, T., Gillberg, M., 1990. Subjective and objective sleepiness in the active individual. Int. J. Neurosci. 52, 29–37.

Adell, E., Várhelyi, A., Fontana, M.d., 2011. The effects of a driver assistance system for safe speed and safe distance – a real-life field study. Transp. Res. C: Emerging Technol. 19, 145–155.

Aidman, E., Chadunow, C., Johnson, K., 2012. Effects of real-time drowsiness feedback on driver fatigue and performance in Army Reserve personnel. Paper presented at Defence Human Sciences Symposium, November 2012; Adelaide.

Aidman, E., Chadunow, C., Johnson, K., Coombs, G., Fidock, J., 2012b. Driver Fatigue in an Army Reserve Regiment: A Multi-Method Field Study with Experimental Manipulation. DSTO-TR-2759. Defence Science & Technology Organisation, Edinburgh, South Australia, pp. 1–63.

Akaike, H., 1974. A new look at the statistical model identification. IEEE Trans. Autom. Control 19, 716–723.

Anderson, C., Czeisler, C., Lockleys, S., 2011. Driving home after the night shift: awareness of drowsiness and distractibility. J. Sleep Res. 20, 36.

Breuer, J., 2008. Attention assist: Don't fall asleep. Daimler Tech. Report.

CaterpillarGlobalMining, 2008. Operator Fatigue Detection Technology Review. Caterpillar, Peoria, IL.

Corbett, M., 2009. A drowsiness detection system for pilots: Optalert. Aviat. Space Environ. Med. 80, 149.

Dawson, D., McCulloch, K., 2005. Managing fatigue: it's about sleep. Sleep Med. Rev. 9, 365–380.

Dinges D.F., Grace R., 1998. PERCLOS: a valid psychophysiological measure of alertness as assessed by psychomotor vigilance. Federal Highway Administration Office of motor carriers, Tech. Rep. MCRT-98-006.

Ferguson, S.A., Baker, A.A., Lamond, N., Kennaway, D.J., Dawson, D., 2010. Sleep in a live-in mining operation: the influence of start times and restricted non-work activities. Appl. Ergon. 42, 71–75.

Field, A., 2013. Discovering Statistics: Using IBM SPSS Statistics. Sage, London.

Fischer, F.M., de Castro Moreno, C.R., da Silva Borges, F.N., Louzada, F.M., 2000. Implementation of 12-h shifts in a Brazilian petrochemical plant: impact on sleep and alertness. Chronobiol. Int. 17, 521–537.

Folkard, S., 1997. Black times: temporal determinants of transport safety. Accid. Anal. Prev. 29 (4), 417–430.

Gander, P., Purnell, H., Garden, A., Woodward, A., 2007. Work patterns and fatigue-related risk among junior doctors. Occup. Environ. Med. 64, 733–738.

Haraldsson, P., Akerstedt, T., 2001. Drowsiness-greater traffic hazard than alcohol. Causes, risks and treatment. Lakartidningen 98, 3018–3023.

Horne, J., Reyner, L., 1995a. Sleep related vehicle accidents. BMJ 310, 565–567.

Horne, J., Reyner, L., 1995b. Driver sleepiness. J. Sleep Res. 4, 23–29.

Ivancievic, V., Aidman, E.V., 2007. Life-space foam: a medium for motivational and cognitive dynamics. Physica A 382, 616–630.

Johns, M.W., Tucker, A., Chapman, R., Crowley, K., Michael, N., 2007. Monitoring eye and eyelid movements by infrared reflectance oculography to measure drowsiness in drivers. Somnologie-Schlafforschung Schlafmedizin 11, 234–242.

Johns, M.W., Chapman, R., Crowley, K., Tucker, A., 2008a. A new method for assessing the risks of drowsiness while driving. Somnologie 12, 66–74.

Johns, M.W., Crowley, K.E., Chapman, R.J., Tucker, A.J., Hocking, C.A., 2008b. The test-retest reliability of an ocular measure of drowsiness. Sleep 31, A118.

Kaida, K., Åkerstedt, T., Kecklund, G., Nilsson, J.P., Axelsson, J., 2007. Use of subjective and physiological indicators of sleepiness to predict performance during a vigilance task. Ind. Health 45, 520–526.

Kircher, A., Uddman, M., Sandin, J., 2002. Vehicle Control and Drowsiness. Swedish National Road and Transport Research Institute, Stockholm.

May, J.F., Baldwin, C.L., 2009. Driver fatigue: the importance of identifying causal factors of fatigue when considering detection and countermeasure technologies. Transp. Res. F: Traffic Psychol. Behav. 12, 218–224.

Maycock, G., 1997. Sleepiness and driving: the experience of UK car drivers. Accid. Anal. Prev. 29 (4), 453–462.

McLean, A., Grech, M., Elischer, P., 2009. Collins class submarines: a study examining the issues of sleep, fatigue and performance. DSTO Publication DSTO-TR-2341: 1–32.

Monk, T., Buysse, D., Reynolds III, C., Berga, S., Jarrett, D., et al., 1997. Circadian rhythms in human performance and mood under constant conditions. J. Sleep Res. 6, 9–18.

Pack, A.I., Pack, A.M., Rodgman, E., Cucchiara, A., Dinges, D.F., et al., 1995. Characteristics of crashes attributed to the driver having fallen asleep. Accid. Anal. Prev. 27, 769–775.

Smith, S.S., Horswill, M.S., Chambers, B., Wetton, M., 2009. Hazard perception in novice and experienced drivers: the effects of sleepiness. Accid. Anal. Prev. 41, 729–733.

Smolensky, M.H., Di Milia, L., Ohayon, M.M., Philip, P., 2011. Sleep disorders, medical conditions, and road accident risk. Accid. Anal. Prev. 43, 533–548.

Taub, E., 2010. What psychology as a science owes neal miller: the example of his biofeedback research. Biofeedback 38, 108–117.

Thiffault, P., Bergeron, J., 2003. Monotony of road environment and driver fatigue: a simulator study. Accid. Anal. Prev. 35, 381–391.

Tucker, A., 2012. Personal communication: email correspondence received November 26, 2012.

Williamson, A., Lombardi, D.A., Folkard, S., Stutts, J., Courtney, T.K., et al., 2011. The link between fatigue and safety. Accid. Anal. Prev. 43, 498–515.

Wright, K.P., Hull, J.T., Czeisler, C.A., 2002. Relationship between alertness, performance, and body temperature in humans. Am. J. Physiol.-Regul. Integr. Comp. Physiol. 283, R1370–R1377.