Psychophysiological changes associated with self-regulation of sleepiness and cessation from a hazard perception task

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Abstract

The relationship between a driver's ability to identify increasing sleepiness and ceasing driving when sleepy is relatively unexamined. Several studies suggest that drivers have some ability to identify increasing levels of sleepiness. However, whether that identification of sleepiness leads to drivers being able to self-regulate and cease driving has not been examined. This study assessed the capacity of drivers to identify sleepiness and to self-regulate their own simulated driving cessation. Twenty-six young adults completed a validated hazard perception simulated task when moderately sleep deprived after a 05:00 wake up. Participants were instructed to stop driving if they thought they were too sleepy to drive safely on the road. Physiological (EEG, EOG, and ECG) and subjective (Karolinska Sleepiness Scale) measures were used to examine self-regulation of simulated driving cessation. The behavioural validity of the participants' subjective sleepiness was then examined with a 30 minute nap opportunity. All participants ceased the task on average after approximately 40 minutes (range = 12.5-73 mins). No participant was judged to have experienced any microsleeps or fallen asleep. Subjective sleepiness and EOG-based blink duration measures increased significantly from the beginning of the drive to the end of the simulated driving episodes. During the nap opportunity 23 of the 26 participants were able to achieve sleep onset. The results suggest that moderately sleep deprived individuals can identify increasing sleepiness and then take action to cease a hazard perception task. Potentially, on-road drivers could benefit from better elicitation of subjective sleepiness and their self-regulation of driving cessation.

Keywords: driver sleepiness; awareness; physiological sleepiness; subjective sleepiness; nap break

Introduction

Sleep deprivation has been shown to have a number of detrimental neurobehavioural outcomes. Specifically, sleep deprivation decreases alertness (Åkerstedt & Gillberg, 1990; Kribbs & Dinges, 1994), impairs cognitive functions (Jackson et al., 2013), and reduces psychomotor performance (Dinges et al., 1997). Sleep-related crashes have been estimated from case-control studies to constitute approximately 20% of all fatal and severe road crashes (Connor et al., 2001; Kecklund, Anund, Wahlström, & Åkerstedt, 2012). It is likely that sleepiness also contributes to a significant proportion of less severe crashes or crashes assigned to other risky driving behaviours. The lack of an objective post-crash measure for sleepiness (equivalent to blood alcohol content) means that the exact contribution of sleepiness to crash risk remains uncertain. Efforts to reduce the incidence of sleep-related crashes are largely reliant on drivers self-regulating their behaviour.

Several physiological indices have been proposed as suitable indicators of an individual's sleepiness level. Assessing cortical arousal levels via electroencephalography (EEG) is one promising indicator, with increased power in the alpha (8-13 Hz) and theta (4-8 Hz) EEG frequency bands indicative of increases in sleepiness (Kecklund & Åkerstedt, 1993). Several ocular indices (including blink rate and blink duration) have been investigated for their utility as a measure of sleepiness via electrooculography (EOG). Increases in blink duration appear to be a reliable indicator of greater sleepiness (Ingre, Åkerstedt, Peters, Anund, & Kecklund, 2006). Another potential physiological indicator of sleepiness can be derived from cardiac function via electrocardiography (ECG). Longer beat-to-beat intervals (the R-R interval) have been found to reflect increased sleepiness (Tran, Wijesuriya, Tarvainen, Karjalainen, & Craig, 2009). Currently, the use of physiological indices via technology to monitor the driver's sleepiness is not wide spread or widely implemented with

the majority of the driving population. In the absence of a technology to monitor drivers' sleepiness level, the individual driver must assess their own sleepiness levels.

In order for a driver to take an appropriate action when sleepy (i.e., to stop driving), drivers need to have awareness of their level of sleepiness. The correspondence between self-awareness of sleepiness (i.e., subjective sleepiness) and objective physiological measurements can be inconsistent. Several studies have shown that subjective sleepiness and physiological measures of electroencephalography (i.e., alpha and theta EEG bands) have positive associations (Åkerstedt & Gillberg, 1990; Kaida et al., 2006). In contrast, other studies have found no correspondence between subjective and physiological measures of sleepiness (Biggs et al., 2007; Tremaine et al., 2010). These inconsistencies are potentially due to situational contexts (i.e., social interaction, task demands) that vary between studies – social interactions and task demands can facilitate increases in arousal and can affect subjective ratings of sleepiness (e.g., Åkerstedt, Kecklund, & Axelsson, 2008).

Bonnet and Moore (1982) have shown that perceptions of the transition between the states of sleepiness and sleep are rather imprecise, and even some highly sleep restricted individuals (2 hours of sleep) can have a limited ability to predict sleep onset during a sleep inducing task (Kaplan, Itoi, & Dement, 2007). Reyner and Horne (1998) examined whether moderately sleep restricted participants (5 hours of sleep) could accurately judge their likelihood falling asleep during a simulated drive. It was found that the correspondence between subjective ratings of the likelihood of falling asleep and objective likelihood determined from EEG recordings were far from precise. Specifically, on 18% of the occasions when participants rated their subjective sleepiness as very great, paradoxically they reported being unlikely or very unlikely to fall asleep. Yet, shortly after the rating, a brief sleep episode occurred. These data suggest that the ability to predict sleep onset is unreliable when high levels of subjective sleepiness are being experienced. Moreover, drivers are likely

to be past the point of impairment when they experience these high levels of sleepiness (Kribbs & Dinges, 1994).

The instructions given to participants (i.e., the perceived purpose of the task) may have an effect on actual task performance. When sleep deprived participants are instructed to complete a driving task, it is often found that they will apply extra effort to remain awake during periods when they are 'fighting' sleep onset due to their sleep deprivation and the lowered arousal levels from tedious driving scenarios (e.g., Thiffault & Bergeron, 2003). In essence, when a participant's motivation is to complete a driving task, this can lead to increased effort to remain awake by fighting sleep onset until the task is completed. A number of studies have used this paradigm, which examines driving performance during periods of extreme sleepiness. However, little is known about driver's ability to monitor their sleepiness levels and then choose to cease driving before they reach such extreme levels of sleepiness. The capacity to judge sleepiness and the association between sleepiness and driving safety at lower levels of sleepiness has not been examined.

The first aim of this study was to examine if participants could identify increasing sleepiness and then make a decision to cease a hazard perception task before unintended sleep onset occurred. The second aim of this study was to examine changes in subjective and physiological measures with cessation from a hazard perception task. The third aim was to examine the behavioural validity of the participants' subjective sleepiness by examining their 'napability' (i.e., their ability to nap upon request).

Methods

Participants

Participants were recruited into the study by an email sent via the University student intranet. Participants were excluded from participating if they were a shift worker, had travelled overseas in the past month, had a habitual bedtime later than 12 midnight, had any

significant health problems or a sleep disorder, took prescription medications or illicit drugs, drank more than three cups of coffee per day and/or more than two standard drinks of alcohol per day, had sleeping difficulties (Pittsburgh Sleep Quality Index score of < 5: Buysse, Reynolds, Monk, Berman, & Kupfer, 1989), or had excessive daytime sleepiness (Epworth Sleepiness Scale of > 10: Johns, 1991).

Overall, 26 participants (19 females and 7 males) took part in the study. The mean age of participants was *M* = 23.77 years (*SD* = 2.32; range = 20-28). On average the participants usual weekday bedtime was 22:29 (*SD* = 39.00 mins) and usual weekday wake-time was 06:52 (*SD* = 51.00 mins) and thus the average normal weekday sleep duration for the participants was *M* = 508.27 minutes (*SD* = 41.81; range = 420-585 mins) as assessed by the Sleep Timing Questionnaire (Monk et al., 2003). All participants had a valid driver's licence with a mean duration of licensure being *M* = 5.65 (*SD* = 2.46; range = 2-10) and all participants were current drivers. Participants were compensated 100 AUD for taking part the study, regardless of the duration of their participation.

Materials

The data collection was separated into two stages: participant intake and the collection of psychophysiological data. The participant intake stage utilised two questionnaires for screening of participants (Pittsburgh Sleep Quality Index and the Epworth Sleepiness Scale). The remaining measures were utilised for the data collection during the hazard perception task.

Pittsburgh Sleep Quality Index. The Pittsburgh Sleep Quality Index (PSQI; Buysse et al., 1989) assesses subjective sleep quality during the preceding month. The questionnaire utilises 19-items that are summed to produce a global PSQI score (range of 0-21), where higher scores indicate poorer sleep quality. A global PSQI score of less than five is recommended as a cut-off point between 'good' and 'bad' sleepers (Buysse et al., 1989). The

PSQI has demonstrated a high level of reliability and satisfactory validity (Carpenter & Andrykowski, 1998).

Epworth Sleepiness Scale. The Epworth Sleepiness Scale (ESS; Johns, 1991) is a measure of excessive daytime sleepiness. Participants must rate the likelihood of dozing or falling asleep in eight different situations. The ratings scale is from 0 = would never doze to 3 = high chance of dozing. The responses to the eight items are then summated (range: 0-24) to generate a total score with higher scores indicative of greater daytime sleepiness. A score below 10 is considered to be within the normal range of individual without a sleep disorder (Johns, 1991). The ESS has adequate reliability and validity as a measure of excessive daytime sleepiness (Johns, 1991).

Sleep Timing Questionnaire. The Sleep Timing Questionnaire (STQ; Monk et al., 2003) is a self-report, single-administration questionnaire that assesses the habitual sleep timing of an individual. Measures of an individual's habitual bedtime (good night-time, GNT) and habitual wake-time (good morning time, GMT) are produced from the questionnaire for the week nights and weekend nights respectively. The reliability and validity (compared with wrist actigraphy) of the STQ was be shown to be adequate (Monk et al., 2003). On the night before testing the participants recorded the time they fell asleep with a simple sleep log.

Karolinska Sleepiness Scale. The Karolinska Sleepiness Scale (KSS; Åkerstedt & Gillberg, 1990) is a self-report measure of the individual's current level of subject sleepiness. The KSS is a nine-point Likert scale with higher scores indicative of higher levels of subjective sleepiness. The KSS is a reliable and valid measure of subjective sleepiness, when compared with objective physiological measures (Kaida et al., 2006).

Signs of Sleepiness Questionnaire. After examination of the relevant peer reviewed literature regarding signs of sleepiness, nine signs of sleepiness were selected for the signs of

sleepiness questionnaire (SoSQ). The nine signs of sleepiness included physical and psychological signs (i.e, yawning, slow eye blinks, frequent eye blinks, difficulty keeping eyes open, difficulty concentrating, changing position frequently, slower reactions, head nodding, mind wandering). Participants rated the importance of each of the sign of sleepiness as an indicator of their level of sleepiness on a seven-point Likert scales from 1 (not important) to 7 (very important).

Physiological sleepiness. The physiological sleepiness levels of participants were monitored with electroencephalography (EEG), electrooculography (EOG), and electrocardiography (ECG). The physiological data was recorded by an ambulatory Somté polysomnographic recorder (Compumedics Limited), and data were sampled at 256 Hz. The EEG recording locations were C3 and O1 paired with A2; the EOG electrodes were placed 1cm above and below the left eye; the ECG signal was recorded from a two-lead montage with one electrode placed five cm below the right clavicle and the second electrode placed on the V6 location (i.e., left midaxillary line).

Hazard Perception test. A hazard perception test (HPT) was used as the driving stimulus for this study. The driving skill of hazard perception is the ability to recognise potential traffic conflicts that could result in a crash unless action is taken by the driver (Horswill & McKenna, 2004). Hazard perception requires the individual to actively and continuously scan the road environment for traffic situations that could be potentially hazardous (Underwood, Phelps, Wright, van Loon, & Galpin, 2005). Hazard perception is regarded as an important driving skill as it has criterion validity with actual on-road crashes; with faster hazard perception associated with decreased crash frequency (e.g., Drummond, 2000; Pelz & Krupat, 1974; Pollatsek, Narayanaan, Pradhan, & Fisher, 2006). Hazard perception is a multicomponent and a high-order cognitive skill (Horswill & McKenna, 2004) that has been found to correlate with on-road driving performance (Wood, Horswill,

Lacherez, & Anstey, 2013), and is impaired by sleepiness (Smith, Horswill, Chambers, & Wetton, 2009).

Prior to undertaking the HPT each participant watched an instructional video with two examples of 'typical' traffic conflicts. Traffic conflicts were defined as "situations in which a collision or near miss between you and another road user/s might occur, unless you took some type of evasive action such as steering or braking." The HPT is a video-based test of actual footage recorded from the driver's perspective during the daytime. Participants watched the recorded footage and were instructed to use the computer mouse to "click on the road user(s) that you believe may be involved in a future traffic conflict with your vehicle." In total, the HPT used in the study contained 45 hazards during the two hours of simulated driving. Due to the extended length of time required for this study, several video clips did not contain any traffic conflicts. Hazard events were approximately evenly distributed over the two hours of the test, however, the duration between every hazard was never the same. That is, the inter-stimulus-interval was different between all hazards. This was to ensure that participants could not anticipate the appearance of a hazard with, for instance, a fixed duration between hazards. This method is consistent with other established tests of alertness (e.g., the Psychomotor Vigilance Test (Dinges & Powell, 1985; Wilkinson & Houghton, 1982), Mackworth's "Clock Test" (Mackworth, 1948)). The video footage was displayed to participants on a 17 inch, 4:3 ratio aspect LCD monitor that was situated directly in front of them. The refresh rate of the LCD monitor was 60 Hz.

Procedure

The research protocol was given ethical approval by the University Human Research Ethics Committee and all participants gave their informed written consent prior to participation in the study. On the day of testing, participants awoke at 05:00 to induce mild sleepiness and abstained from ingesting any caffeine or alcohol until completion of the

testing session. This abstinence of caffeine or alcohol was verbally confirmed by the participant before testing began. Participants were randomly assigned to undertake the testing during the morning (n = 13; 9 females and 4 males, starting at 09:00) or in the afternoon (n = 13; 10 females and 3 males, starting at 14:00).

Upon arrival at the laboratory, participants had the EEG, EOG, and ECG electrodes attached. Before starting the hazard perception task, participants were instructed to "*stop when you think you would be too sleepy to drive safely on the road*". Before starting the hazard perception task, the participants completed the SoSQ and their subjective sleepiness was assessed with the KSS. The points where subjective sleepiness ratings were obtained and the sections of physiological recordings used in the analyses can be seen in Figure 1. After the participants received the standardised instructions, the experimenter left the room – each participant completed the testing alone. The maximum duration the task could run for was 2 hours. Participants were not told the maximum duration that the task to minimise any anticipation effects. The testing room was temperature controlled (23ºC), light controlled (410 lx), and was devoid of all time cues, and participants were instructed to remove their watches and turn off their mobile phones.

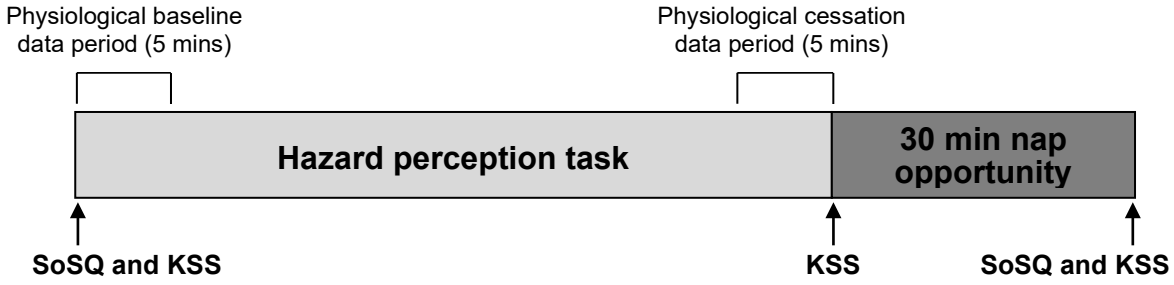

Figure 1. Overview of the time points of data collection. Note that the duration of the hazard perception task varied between participants. EEG and EOG were continuously recorded during the hazard perception task and the 30 min nap opportunity.

When the participant chose to cease the driving task, they communicated to the experimenter via a microphone in the laboratory room that they wanted to cease the task. The experimenter noted the duration of the task, then re-entered the laboratory, administered the KSS, and then advised the participant they now had a "nap opportunity". Participants were instructed to remain seated in the chair used during the hazard perception task, rest their head on the back of the chair, and keep their eyes closed during the whole of the nap opportunity. The angle of the chair was maintained at 105 degrees. Participants were not told of the duration of the nap opportunity, which was restricted to thirty minutes. At the end of the nap opportunity, the experimenter re-entered the laboratory room, re-administered the SoSQ and the KSS for the last time and removed the electrodes.

Data Acquisition

The physiological data was continuously recorded from the participants during the driving task and the nap opportunity. The physiological data was inspected by an experienced polysomnographer (CNW) for artefact. During the driving task any 30 second epoch that contained artefact of any sort was excluded from the spectral analysis. The EEG (C3-A2 and O1-A2 electrode pairings) and EOG recordings were visually scored during the driving task utilising standard sleep onset criteria (i.e., Iber & American Academy of Sleep Medicine, 2007) and for episodes of microsleeps (i.e., 3-15 seconds of theta activity). The entire simulated driving period for each participant was visually scored for microsleeps and sleep onset, with the nap opportunity visually scored for sleep onset latency, duration, and sleep staging.

The EEG, EOG, and ECG derived indices were computed during the five minutes of baseline and cessation recordings (see Figure 1). These data points were chosen as the duration of simulated driving varied between each participant and the duration was also consistent with previous work (e.g., Åkerstedt et al., 2013). Spectral analysis of EEG

obtained during the driving session utilised the electrode pairing of O1-A2. A 0.3 Hz high pass filter and a 30 Hz low pass filter were applied to the physiological data, as per current recording guidelines (Iber & American Academy of Sleep Medicine, 2007). The absolute power (μV^2) was determined for each 30 second epoch for the frequencies of alpha (8-13 Hz) and theta (4-8 Hz). The absolute power for each 30 second epoch was then averaged across the five minute baseline and cessation periods. A 10 Hz low pass filter was applied to the EOG data. The EOG signals were scored as blinks if they were greater than 100 μV in amplitude and were visually confirmed as blinks on the EOG trace. The index of blink duration, measured in milliseconds (ms) was extracted from the data, measured as the duration at half blink amplitude. The left eye EOG trace was used for all analyses. The cardiac beat-to-beat interval, measured in milliseconds (ms) was extracted from artefact-free ECG data with a peak detection algorithm (Tarvainen et al., 2014) that produced the index of mean R-R.

Statistical Analyses

The first aim, could participants identify increasing sleepiness and then make a decision to cease a hazard perception task before unintended sleep onset occurred, was evaluated via visual scoring of the EEG and EOG recordings. The second aim, examining the changes in subjective and physiological measures with cessation from a hazard perception task, utilised a series of 2 x2 repeated measures ANOVAs with the first factor being baseline and cessation data and the second factor being the time of testing (morning or afternoon). Participants also rated the importance of nine signs of sleepiness as indicators of their perceived level of sleepiness prior to and after ceasing the driving task, any change in the importance of the ratings were evaluated with paired-samples *t*-test. The third aim, the behavioural validity of the participants' subjective sleepiness by examining their 'napability' was evaluated with visual scoring of the EEG and EOG recordings.

Results

Sleep Prior to Testing

In total, the amount of sleep obtained prior to testing was approximately 6.50 hours (M = 390.96; SD = 39.12 minutes) and the amount of sleep debt the participants were experiencing was approximately 2 hours (M = 117.31; SD = 36.75 minutes). No significant difference was found between the duration of sleep prior to the morning (M = 387.69, SD = 38.17) and afternoon testing session (M = 394.23, SD = 41.32), $t(24) = -0.42$, $p = .68$. Similarly, no significant difference was found between the morning (M = 125.38, SD = 34.31) and afternoon testing session participants (M = 109.23, SD = 38.67), $t(24) = 1.13$, $p = .27$ for the amount of sleep debt. As such, the estimated need for sleep between the morning and afternoon participants was considered equivalent.

Sleepiness and Cessation of the Task

All participants choose to cease the hazard perception task on average, after approximately 40.00 minutes (M = 36.13; SD = 17.70; range = 12.50-73.00). An independent samples t-test was performed to examine if any circadian effects influenced the duration of driving. No significant difference was found between the morning (M = 34.58, SD = 14.47) and afternoon durations of driving (M = 37.69, SD = 20.92), $t(24) = -0.44$, $p = .66$.

Visual inspection of the EEG and EOG data revealed that none of the participants could be judged to have fallen asleep by current sleep staging criteria (i.e., Iber & American Academy of Sleep Medicine, 2007) or having experienced any microsleeps (i.e., between 3-15 seconds of theta activity) before the point of driving cessation. However, three of the 26 participants did display some identifiable signs of increased sleepiness (e.g., long eyelid closures that were less than 2 seconds in duration) that occurred on average, after 27.67 minutes (SD = 13.55, range = 13.50-40.50) from starting the task. These three participants average duration of performing the task was 40.00 minutes (SD = 16.02, range = 23.50-

55.50); these three participants continued with the task for on average 12.33 minutes (*SD* = 2.52, range = 10.00-15.00) following the first observation of signs of sleepiness. At the end of testing two of the three participants reported that they might have fallen asleep during the hazard perception task, with the third participant unsure if they had fallen asleep. It was reported by these three participants that they "pushed" themselves to maintain wakefulness prior to ceasing the hazard perception task, as they believed that they had not completed enough of the task. However, they did acknowledge that they were aware of their high level of sleepiness.

Subjective and Physiological Data

Table 1 displays the mean and standard deviations of the study variables and the repeated measures ANOVAs results. The level of subjective sleepiness increased significantly from the beginning of the simulated drive to cessation of the task, this was a large effect. Figure 2 shows the increase in subjective sleepiness from baseline to cessation of driving for every participant. A significant increase in blink duration was also found from baseline to cessation, but the effect size was smaller in magnitude than the subjective sleepiness effect size. No significant change was found for EEG absolute theta and alpha power, ECG R-R index, or with of the baseline-cessation and time of day interactions. Table 2 displays the bivariate correlations between the change values from baseline to cessation for the subjective and physiological data. Two moderate sized correlations were observed – the first between EEG Theta power change and EEG Alpha power change and the second between EOG blink duration change and EEG alpha power change. A small correlation was observed between the KSS change and EOG blink duration change – the smaller size of this correlation is possibly influenced by a limitation of range, as it can be seen in Table 2 the range of change scores for the KSS values was 3-1.

Table 1.

Means, standard deviations (SD) of the subjective and physiological data and 2 x 2 ANOVA statistics

			ANOVA					
			Baseline-cessation (within factor)		Time of testing (between factor)		B-C x ToT	
Data source	Baseline Mean (*SD*)	Cessation Mean (*SD*)	*F*	η_p^2	*F*	η_p^2	*F*	η_p^2
Subjective Sleepiness								
KSS	6.65 (0.69)	8.15 (0.46)	**134.21****	.85	2.04	.08	.09	.01
Physiological Sleepiness								
EEG Theta power (μV^2)	11.85 (1.87)	11.25 (2.26)	4.13	.15	2.61	.10	2.54	.10
EEG Alpha power (μV^2)	10.98 (2.50)	11.62 (3.95)	1.48	.06	3.19	.09	2.39	.10
EOG blink duration (ms)	102.89 (13.17)	117.30 (25.01)	**9.84****	.29	0.99	.04	1.65	.06
ECG R-R (ms)	835.15 (108.01)	847.76 (113.12)	0.08	.01	0.30	.01	0.58	.02

* < .05, ** < .01; B-C x ToT, baseline-cessation x time of testing

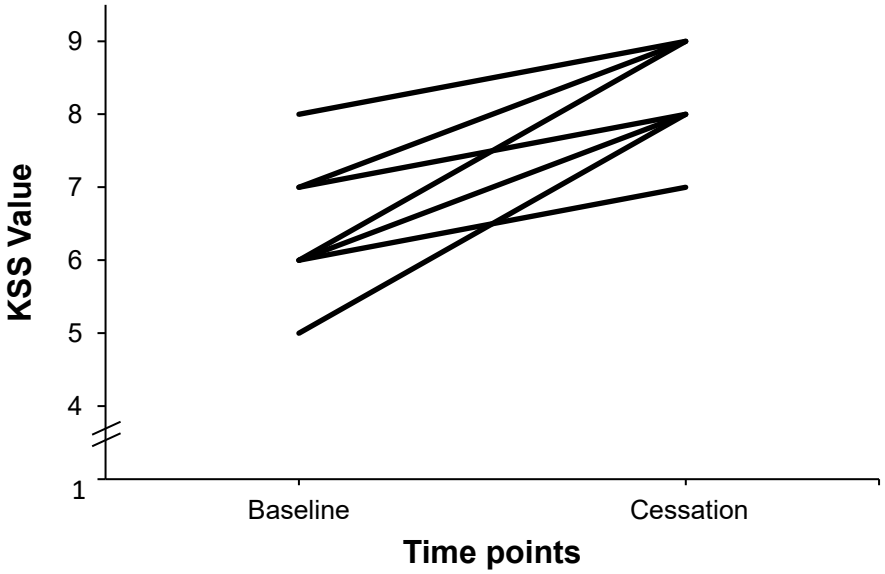

Figure 2. Subjective sleepiness scores at baseline and cessation time periods for all 26 participants. Note many participants had identical subjective sleepiness values, hence the number of viewable lines.

Table 2.

Bivariate correlations between the change values for the subjective and physiological data

Data source	1.	2.	3.	4.	5.
1. KSS Δ	-				
2. EEG Theta power Δ	-.25	-			
3. EEG Alpha power Δ	.13	**.49****	-		
4. EOG blink duration Δ	**.11***	-.06	**.35***	-	
5. ECG R-R Δ	.13	.11	.24	.07	-

* < .05, ** < .01; Δ, change in data value from baseline to cessation

Signs of Sleepiness

Participants rated the importance of nine signs of sleepiness as an indicator of their level of sleepiness prior to and after ceasing the driving task. Figure 3 displays mean scores for the importance of the nine signs of sleepiness. It can be seen in Figure 3 that ratings of the importance of slow eye blink, frequent eye blinks, difficulty concentrating, changing

position, slower reactions, mind wandering, and being easily distracted as indicators of sleepiness significantly increased from before the driving task to after the task.

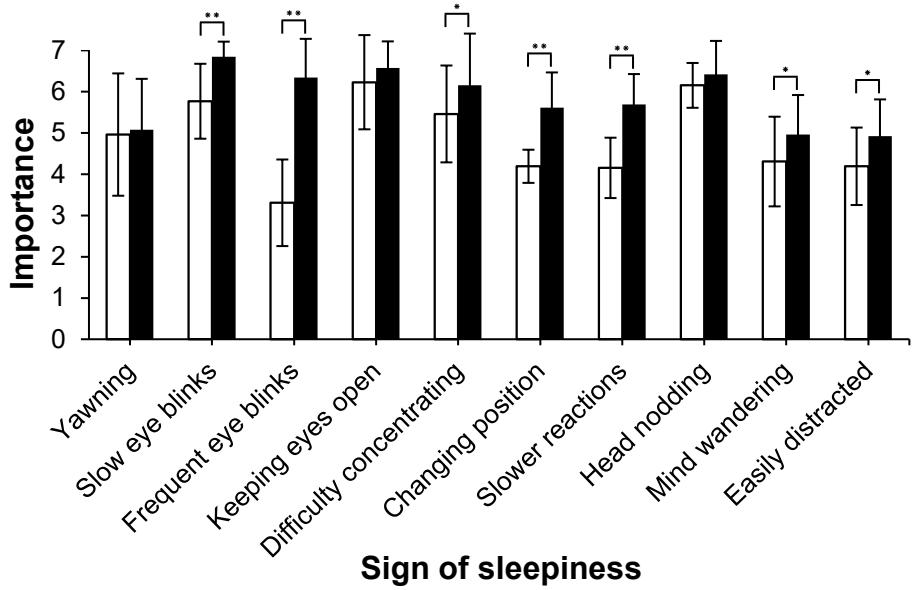

Figure 3. Importance of the nine signs of sleepiness as an indicator of their level of sleepiness prior to (white bars) and after ceasing the driving task (black bars). Error bars represent standard deviation.

$^{*} < .05$, $^{**} < .01$

Thirty Minute Nap Opportunity

Data from the thirty minute nap opportunity for 23 of the 26 participants are presented in Table 3, as three of the participants were not able to achieve sleep onset. The EEG and EOG data was scored for sleep onset latency, duration, and sleep staging. On average, the sleep onset latency was 8.61 mins, with the nap mostly comprised of NREM 2 stage of sleep. A significant reduction in subjective sleepiness assessed via the KSS, was found from driving cessation ($M = 8.17$, $SD = 0.50$) to after the nap ($M = 6.96$, $SD = 1.82$), $t(22) = 2.99$, $p = .007$ for participants who could achieve sleep onset. No statistical difference was found between participants tested in the morning or afternoon for the variable of sleep onset latency ($t(21) = .63$, $p = .54$), sleep duration ($t(21) = .45$, $p = .66$), NREM1 ($t(21) = .51$, $p = .62$), NREM2 ($t(21) = 1.04$, $p = .31$), or NREM3 ($t(21) = -1.37$, $p = .19$).

Table 3.

Sleep Staging Data for the Thirty Minute Nap Opportunity (n = 23)

		Sleep time (% of total)			
SOL (*SD*)	Duration (*SD*)	NREM 1	NREM 2	NREM 3	REM
8.61 (7.78)	15.09 (8.11)	24.33	67.39	8.28	-

Note. SOL = Sleep onset latency (min); NREM = Non-Rapid Eye Movement; REM = Rapid Eye Movement

Discussion

The main finding from this study was that all participants chose to cease the hazard perception task before unintended sleep onset occurred. After mild sleep restriction, the participants reported *moderate* subjective sleepiness at the start of the task. The participants' subjective sleepiness increased during the driving sessions to a *high level* of subjective sleepiness prior to driving cessation (corresponding KSS anchor of *'sleepy, some effort to stay awake'*). This level of subjective sleepiness is estimated to be associated with a 15 times greater likelihood of having a sleep-related crash on the road (Åkerstedt, Connor, Gray, & Kecklund, 2008). Participants appeared able to identify increases in subjective sleepiness, and were all able to cease the hazard perception task before unintentional sleep onset occurred. None of the participants were judged to have fallen asleep by standard sleep staging criteria (i.e., Iber & American Academy of Sleep Medicine, 2007) during the hazard perception task prior to cessation; that is, there were no sudden sleep attacks or microsleeps.

Subjective sleepiness increased during the driving session for each participant. This increase in subjective sleepiness as well as the increase in blink duration over the duration of the hazard perception task is consistent with previous research (Ingre et al., 2006; Sandberg et al., 2011). No significant changes in EEG or ECG indices of sleepiness were found, which was contrary to previous work (e.g., Kecklund & Åkerstedt, 1993; Tran et al., 2009). One potential explanation for the discrepancy between the subjective and the EEG and ECG data could be the level of sleepiness the participants were experiencing at the beginning of the test

session. That is, the physiological defined sleepiness could have already been relatively high as the participants were moderately sleep deprived and therefore, would not have changed considerably. The participants' subjective sleepiness ratings at the beginning of the task could have been erroneous, possibly due to increased arousal levels from interacting with the experimenter. Previous research has demonstrated that verbal interaction can mask sleepiness by increasing arousal (Åkerstedt, Kecklund, et al., 2008). Notwithstanding the possible effects of verbal interaction, the significant increase of blink duration corroborates the subjective sleepiness results, as well as the correlation between the KSS change and EOG blink duration change variables.

The discrepancy between the physiological and subjective measures deserves examination. No statistical changes were observed in the EEG or ECG measures, even though statistically significant increases were observed with the subjective sleepiness and blink duration index. The EEG defined transition from wakefulness to sleep is characterised by a slowing of the oscillatory cortical activity from high frequency beta waves (13-30 Hz) to alpha waves (8-13 Hz) and then theta waves (4-8 Hz) during sleep onset and light sleep/non-REM 1 sleep (Hasan, Broughton, Ogilvie, & Harsh, 1994; Iber & American Academy of Sleep Medicine, 2007). However, the EEG changes associated with increasing sleepiness is less clear (Lal & Craig, 2001) and the correspondence with other physiological measures is also uncertain. Support for this notion is provided from previous research that has demonstrated increases of subjective sleepiness during a 30 minute simulated drive, but no significant increase in EEG indices (Gillberg, Kecklund, & Åkerstedt, 1996). Considered together, it is possible that that increases of sleepiness will manifest differently for different physiological measures.

It is likely that the instructions and the task set given to participants might have had an effect on the participant's awareness of their sleepiness and decision-making. The instruction

that participants received prior to driving was to “stop when you think you would be too sleepy to drive safely on the road”. The participants’ only task in this study was to monitor their sleepiness levels while completing the simulated driving task. As previously discussed no participant could have been judged to have fallen asleep by standard sleep scoring criteria nor were any mircosleeps observed. Additionally, it was found that the ratings of importance as indicators of certain signs of sleepiness increased from prior to after the simulated driving task. This suggests that participant might have been more conscious of these signs of sleepiness during the simulated drive and thus the greater awareness might have assisted the participants with deciding when to cease the driving task.

Driving a vehicle is a task oriented activity that typically involves getting from location A to location B. Previous work suggests that motivation to reach a destination is a common reason drivers cite for continuing to drive when they are aware of their own high sleepiness levels (Nordbakke & Sagberg, 2007; Watling, Armstrong, Obst, & Smith, 2014). It is possible that this motivation might obscure or bias a driver’s decision-making processes. It has previously been suggested that sleepy drivers consider the signs of sleepiness as negligent (Dinges, 1995) and thus often fail to recognise the seriousness of driving while sleepy (Horne & Reyner, 2001). In this study, reaching a destination was not an explicit requirement of the task and it was observed that all participants reported increases in subjective sleepiness and were able to choose to cease the hazard perception task before a high level of sleepiness was reached.

The duration of driving before cessation was relatively short, with most participants stopping within one hour. Similar results have been reported with an on-road night-time driving study with participants stopping driving prematurely after 43 mins due to high levels of sleepiness (Åkerstedt et al., 2013). Survey data suggests one third of drivers report having briefly fallen asleep within one hour of beginning driving (Pennay, 2008). Current road safety

campaigns recommend drivers take a break after every two hours of driving. The current data suggests that drivers can experience significant sleepiness levels well within this limit, and drivers may need to be better informed about such rapid onset of sleepiness – particularly when driving in rural locations. Whereas, dynamic and ever changing driving situations, such as urban locations can partially attenuate sleepiness due to the mental stimulation they provide. The footage used in the current study was of urban locations - less stimulating footage, such as a rural location, could lead to a quicker onset of sleepiness, and thus a shorter duration of driving before cessation is appropriate. Another factor that needs to be considered when interpreting the duration of driving results is the lower arousal levels that laboratory conditions invoke compared to on-road situations (Philip et al., 2005). This effect from laboratory conditions could have contributed to the obtained results.

The behavioural validity of the participants' subjective sleepiness was established with 23 of the 26 participants able to achieve sleep onset during the nap break. That is, approximately 90% of participants displayed a high level of 'napability' at the end of the hazard perception task. The average duration of sleep onset latency (i.e., 8.61 mins) suggests that participants were genuinely sleepy. That is, mean sleep onset latencies determined from the Multiple Sleep Latency Test (Carskadon et al., 1986) for the age range of 20-29 are 10.40 minutes (Arand et al., 2005), with sleep onset latencies less than 5 minutes indicative of pathological sleepiness (Carskadon et al., 1986). However, sleep onset latencies that are within as 5-10 minutes are considered in a grey area of pathological sleepiness (Carskadon & Dement, 1981; Littner et al., 2005). The majority of the nap sleep time was comprised by the lighter sleep stages of NREM1 and NREM2 with a small amount of NREM3 sleep occurring during the nap. Waking from a nap during slow-wave sleep (i.e., NREM3 sleep stage) can lead to experiencing sleep inertia which is the transient impairment of cognitive functioning (Muzet, Nicolas, Tassi, Dewasmes, & Bonneau, 1995). The small amount of NREM3 sleep

did not appear to overly affect the subjective sleepiness ratings after the nap, as subjective sleepiness levels significantly reduced from before to after the nap.

A limitation of the current study was the lack of a performance measure for the simulated driving task. Moreover, an inherent limitation of the driving stimulus pertains to the lack of overt feedback the participants receives during the Hazard Perception test. Vehicle based driving simulators allows the driver to receive feedback via their positioning of the vehicle on the road. It is possible that an individual's decision to cease driving due to sleepiness could be based on perception of their driving performance or levels of subjective sleepiness or both. Another limitation of the current study was the lack of a comparison condition. Future work could consider varying and comparing the type of instruction given to participants and how this manipulation of instruction affects participants' awareness of sleepiness, task performance, and physiological sleepiness. Such manipulations of the task instruction could provide a better understanding of participants' awareness of sleepiness in the context of driving. Replicating (and or extending) the current study paradigm to on-road driving with the appropriate safety protocols could be especially insightful.

Driver sleepiness contributes substantially to fatal and severe crashes. The current study asked drivers to monitor their own sleepiness levels and then to cease driving when they thought it appropriate. The key finding was that all participants decided to cease the hazard perception task when they thought they were too sleepy to drive safely. The greatest change in sleepiness was observed in the subjective rating. The physiological measure of blink duration showed less change based on effect sizes, and no significant change was found for the EEG or ECG physiological indices. The possibility that better elicitation of subjective sleepiness could improve accuracy of self-regulation should be pursued. The current findings are encouraging as they demonstrate that, in certain circumstances, moderately sleep deprived

individuals can identify increasing sleepiness and then take action to cease a hazard perception task.

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