Too sleepy to drive: self-perception and regulation of driving when sleepy

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Abstract

Background: Sleepiness is a direct contributor to a substantial proportion of fatal and severe road cashes. A number of technological solutions designed to detect sleepiness have been developed, but self-awareness of increasing sleepiness remains a critical component in on-road strategies for mitigating this risk. In order to take appropriate action when sleepy, drivers' perceptions of their level of sleepiness must be accurate.

Aims: This study aimed to assess capacity to accurately identify sleepiness and self-regulate driving cessation during a validated driving simulator task.

Participants: Participants comprised 26 young adult drivers (20-28 years). The drivers had open licenses but no other exclusion criteria where used.

Methods: Participants woke at 5am, and took part in a laboratory-based hazard perception driving simulation, either at mid-morning or mid-afternoon. Established physiological measures (including EEG) and subjective measures (sleepiness ratings) previously found sensitive to changes in sleepiness levels were utilised. Participants were instructed to 'drive' until they believed that sleepiness had impaired their ability to drive safely. They were then offered a nap opportunity.

Results: The mean duration of the drive before cessation was 39 minutes (±18 minutes). Almost all (23/26) of the participants then achieved sleep during the nap opportunity. These data suggest that the participants' perceptions of sleepiness were specific. However, EEG data from a number of participants suggested very high levels of sleepiness prior to driving cessation, suggesting poor sensitivity.

Conclusions: Participants reported high levels of sleepiness while driving after very moderate sleep restriction. They were able to identify increasing sleepiness during the test period, could decide to cease driving and in most cases were sufficiently sleepy to achieve sleep during the daytime session. However, the levels of sleepiness achieved prior to driving cessation suggest poor accuracy in self-perception and regulation. This presents practical issues for the implementation of fatigue and sleep-related strategies to improve driver safety.

Introduction

Occupational road crashes have been identified as the most common cause of injury and fatalities in the workplace (National Institute for Occupational Health and Safety, 2004; Safe Work Australia, 2012b). Accordingly, the personal (Mitchell, 1997), organisational and community costs (Safe Work Australia, 2012a) associated with occupational road crashes are considerable. Sleep-related crashes contribute substantially to the overall incident rates of fatal and severe road crashes (Connor et al., 2002) with driver sleepiness similarly being a prominent factor with occupational crashes (Harrison, Mandryk, & Frommer, 1993).

In recent years it has been acknowledged that driver sleepiness is an important risk factor for vehicle crashes in the occupational settings. This acknowledgement has led to the establishment of sleepiness countermeasures at the organisational level of the heavy vehicle sector including: regulated driving hours, Fatigue Management programs, and the Chain of Responsibility legislation. In contrast, the light vehicle sector has limited resources with which to mitigate sleep-related crashes. Moreover, many organisations have limited scope with risk management frameworks which are important to mitigate occupational road safety risks (Rowland, Watson, & Wishart, 2006). As such, education and awareness programs have by and large been the main countermeasure utilised for light vehicle driver sleepiness. Education and awareness campaigns typically involve imparting sleep knowledge and the heightened levels of crash risk associated with sleepy driving to the individual so they can monitor their own behaviour.

The ability, or inability, of a driver to detect increasing sleepiness is a factor in sleep-related crashes. At the individual driver level a number of technological solutions designed to detect sleepiness have been developed and are used mostly by the heavy vehicle sector. However, self-awareness of increasing sleepiness remains a critical component in on-road strategies for mitigating this risk. In order to take appropriate action when sleepy, drivers' perceptions of their level of sleepiness must be accurate. As such, it is important to understand driver's awareness of increasing levels of sleepiness – their ability to self-regulate.

Several studies suggest that drivers may not be able to make accurate decisions regarding their level of sleepiness. For example, although drivers report being able to drive for up to 5.4 hours before reporting subjective sleepiness (McCartt, Ribner, Pack, & Hammer, 1996), up to one third of drivers have fallen asleep at the wheel during trip durations of less than one hour (Pennay, 2008). Additionally, approximately 60% of drivers continue to drive even when they are feeling sleepy or fatigued (Vanlaar, Simpson, Mayhew, & Robertson, 2008). Such behaviours could be expected from an under-recognition of sleepiness signs (e.g., Kaplan, Itoi, & Dement, 2007) and/or an under-appreciation of the dangers of a sleep-related crash (e.g., Reyner & Horne, 1998). Considered together, these reports may suggest a significant gap between perception of sleepiness, driving behaviours, and the ability to self-regulate.

A number of studies have found that perceptions of sleepiness (i.e., subjective sleepiness) have significant and positive relationships with physiological measures (e.g., Dorrian, Lamond, & Dawson, 2000; Kaida et al., 2006). Additionally, subjective ratings of sleepiness have been found to have a positive relationship with simulated driving incidents (Reyner & Horne, 1998) as well as predicted sleepiness levels and on-road sleep-related crashes (Åkerstedt, Connor, Gray, & Kecklund, 2008). However, other studies have found inconsistent relationship between subjective ratings and physiological measures (e.g., S. N. Biggs et al., 2007; Hoch et al., 1992;

Tremaine et al., 2010). These inconsistencies between the two measures are possibly due to individuals having a limited awareness of the physical sleepiness signs such as droopy eyelids, increased blinking, wandering thoughts (e.g., Kaplan, et al., 2007). Sleepiness also impairs cognitive functioning which could possibly affect self-awareness of sleepiness levels.

Another factor that could influence the likelihood of perceiving sleepiness is the intrinsic circadian rhythm of an individual. The circadian rhythm of an individual has a sinusoid function during a 24 hour period, which results in low sleep propensity during the day (i.e., ascending phase) and the highest sleep propensity typically during night-time hours (i.e., descending phase) (Richardson, Carskadon, Orav, & Dement, 1982). The descending phase of the circadian rhythm typically begins in the afternoon and is characterised as the post-lunch dip in circadian function (Carskadon & Dement, 1992). As such, the descending circadian phase could lead to higher sleepiness levels in the afternoon.

The Current Study

The role of sleep-related crashes is substantial with occupational crashes. As awareness of sleepiness levels is an important component of driver behaviour change, determining capacity to accurately identify sleepiness and then to self-regulate driving cessation is necessary for reducing sleep-related crashes. This study aimed to assess capacity to accurately identify sleepiness and self-regulate driving cessation during a validated driving simulator task.

Method

Design

An experimental design was utilised with participants being randomly assigned to complete the testing during a morning session (i.e., 09:00 start) or an afternoon session (i.e., 14:00 start).

Participants

In total, 26 participants (19 females and 7 males) completed the study. The participants had a mean age of 24 years (*SD* = 2; range = 20-28). Participants reported an average vehicle licensure of six years (*SD* = 2.46; range = 2-10). Additionally, the sample reported having driven an average of 14,028.01 kilometres per year over the last three years (*SD* = 14,028.01; range = 1,040-70,000). Altogether, six participants reported having a crash (i.e., where they were the driver and there was damage to property or persons) in the last three years. All participants were paid $100 AUD for partaking in the study.

Materials

Karolinska sleepiness scale. The Karolinska Sleepiness Scale (KSS; Åkerstedt & Gillberg, 1990) is a self-report measure of the level of subjective sleepiness an individual is experiencing. The KSS has been found to be a sensitive and reliable measure of sleepiness (Gillberg, Kecklund, & Åkerstedt, 1994; Kaida, et al., 2006) which has been validated against physiological measures (van den Berg, Neely, Nilsson, Knutsson, & Landström, 2005). Individuals are required to indicate on a nine point Likert scale how sleepy they are currently feeling. Higher scores are indicative of higher levels of subjective sleepiness.

Physiological sleepiness. Electroencephalography (EEG) and electrooculography (EOG) were utilised by the current study to measure physiological sleepiness levels. The software that was utilised to score the physiological data was the Profusion PSG 3 v3.4 (Build 345) software (Compumedics, Melbourne, Victoria, Australia). The EEG and EOG recordings were sampled at 256 Hz (i.e., 512 samples per second) with 0.3 Hz high pass filter and a 30 Hz low pass filter. Recording epochs of 30 seconds were utilised in accordance with standard physiological recordings and sleep medicine practices (Atkinson, 2007; Rechtschaffen & Kales, 1968).

The utilised EEG recording sites were: C3, C4, A1, and A2; electrode placement utilised the 10-20 system derivations. The central (i.e., C3 and C4) and occipital (i.e., O1 and O2) electrodes were referenced the contralateral electrode site of A1 or A2. These six electrodes sites utilised Ag-Al electrodes. The EOG recording sites used were the standard sleep study placement for EOG electrodes. That is, the right eye electrode was placed approximately one cm lateral and one cm dorsal to the outer corner of the eye (outer canthus), with the left eye electrode placed one cm lateral and one cm ventral the outer canthus. Self adhesive electrodes were used for the EOG, and ground recording sites.

Driving Stimulus. The driving stimulus for this study was the Hazard Perception test (HPT). Hazard perception has been described as the skill to anticipate traffic situations that may result in a crash or near miss (Horswill & McKenna, 2004; McKenna & Crick, 1991). The HPT is a video-based reaction time latency measure designed to measure this ability that has been developed in previous work (i.e., Horswill et al., 2008; Smith, Horswill, Chambers, & Wetton, 2009). Quicker hazard perception identification is the only driving skill that has a consistent relationship with decreased crash incidences and is an important driving skill (Horswill & McKenna, 2004). Due to the varying durations of the driving task by the participants, the hazard perception data could not be used as dependent variable.

Procedure

A recruitment email was sent via the QUT intranet and was posted on various QUT online notice boards inviting participants to take part in the current study. The recruitment email explained the inclusion and exclusion criteria and gave a concise description of the experimental procedure. Those participants that wished to take part in the study were asked to sign a written consent form. Participants were instructed to wake up at 05:00 on the day of testing and they were also instructed not to ingest any form of caffeine or alcohol until completion of the testing session.

On the day of testing, the participant was met by the experimenter at the QUT's Kelvin Grove campus. EEG and EOG electrodes were then attached to the participant. Prior to beginning the HPT, the participant's subjective sleepiness was assessed with the KSS. All participants were verbally instructed to, "Stop when you think you *would be* too sleepy to drive safely on the road". After receiving this instruction the participants began the HPT.

When the participants chose to end the HPT session, they spoke into a microphone to let the experimenter know they wished to take a break. The duration of time that had elapsed for the HPT was noted by the experimenter. The experimenter then entered the testing room and administered the KSS, then instructed the participants that they now had an opportunity to nap. During this nap opportunity the participants were asked to remain in their chair with their eyes closed. After thirty minutes the experimenter re-entered the testing room, re-administered the

KKS for the last time and removed the electrodes. The participants completed the hazard perception testing session and the nap opportunity alone in the noise- and temperature-controlled environment. All time cues were removed from the testing room.

Data Acquisition

Physiological recordings. The EEG recordings during the HPT were visually inspected for signs of sleep (alpha and theta activity, slow rolling eye movements, extended eye closures) and micro sleeps by an experienced polysomnographer. In addition, the EEG nap data was scored for its sleep stages according to the Rechtschaffen and Kales (1968) criteria. The C3-A2 paring of electrodes was utilised for the scoring of sleep stages.

Results

Manipulation Check

Subjective sleepiness. To assess whether the 05:00 wake-up on the testing day induced any subjective daytime sleepiness in the participants, the means of the KSS prior to testing were inspected. The mean KSS at the beginning of testing was 6.65 (SE = 0.135), where the relevant points on the KSS scale were labelled as "some signs of sleepiness" (= 6) and "sleepy, no effort to stay awake" (=7). This level of KSS suggests that the sample was experiencing a degree of sleepiness prior to beginning the simulated drive.

Increasing levels of sleepiness. A paired samples *t*-test was performed to determine if the subjective sleepiness levels increased from the beginning of testing to the time immediately prior to the break. The paired samples *t*-test revealed that subjective sleepiness levels increased from the beginning of testing (M = 6.65, SE = 0.135) to prior to the break (M = 8.15, SE = 0.464), $t(25) = -11.802$, $p < .001$.

Self-regulation of Sleepiness Levels

It was found that on average participants stopped the task after approximately 40 minutes (M = 38.346, SD = 18.385, range = 15-76). To determine if the duration was mediated by any circadian effects an independent samples *t*-test was performed. It was found that equal variances could not be assumed across the groups, $F(1, 24) = 4.289$, $p = .049$. With unequal variances accounted for, it was found that there was no significant difference between the morning duration (M = 36.462, SE = 4.049) and afternoon duration (M = 40.231, SE = 6.098), $t(20.859) = -0.515$, $p = .612$.

Visual scoring of the EEG data revealed that no participant could be judged to have fallen asleep by standard criteria (i.e. more than 30 seconds of continuous Stage 1 sleep) before stopping for a break. However, three of the 26 participants did display high levels of sleepiness (e.g., head nodding, micro sleeps). These three participants requested their breaks on average 12.333 minutes (SD = 2.517, range = 10-15) following these microsleep events. At the end of testing two of the three participants reported that they believed they had fallen asleep during the task, with the third participant being unsure if they had fallen asleep. It was reported by these three participants that they pushed themselves to maintain wakefulness in the minutes leading up to ceasing driving as they believed that they had not completed enough of the driving task.

Thirty Minute Nap Break Data

Nap break polysomnography data. Complete EEG data was obtained for all participants during the nap break. This data was scored for sleep onset latency, duration, and sleep stages according to Rechtschaffen & Kales (1968) rules for sleep staging and can be found in Table 1. Data for the 23 of 26 participants who were determined to have fallen asleep during the nap opportunity is reported in the table.

Table 1. Sleep Staging Data for the Thirty Minute Nap Break.

		Sleep time (% of total)				
SOL (*SD*)	Duration (*SD*)	Stage 1	Stage 2	Stage 3	Stage 4	REM
8.609 (7.781)	15.087 (8.113)	24.333	67.389	6.803	1.476	-

Note. Table only includes 23 participants data as scored by Rechtschaffen & Kales (1968) rules for sleep staging. SOL = Sleep onset latency (min); REM = Rapid Eye Movement.

Discussion

The aim of the current study was to determine how effectively drivers could identify their sleepiness levels and self-regulate their need to stop for a break. The results suggested that the sample subjectively experienced high levels of sleepiness during the testing sessions, and all requested a break within 76 minutes of driving. The majority of participants were then able to fall asleep during the nap break.

Effects of Awareness Levels of Sleepiness

The key finding from this study is that all of the participants decided to cease driving and take a break from the driving task. A number of studies describe that drivers have a reasonable ability to judge their sleepiness levels (e.g., Kaplan, et al., 2007; Reyner & Horne, 1998); yet, it is also noted in the literature that there are individual differences regarding the accuracy of determining sleepiness level. In addition, the transition from low levels of sleepiness to high levels of sleepiness and finally into sleep is a subtle progression, and the awareness of these varying levels is also likely to vary between individuals (Bonnet & Moore, 1982). Consistent with this we found that some participant's EEG data suggested brief sleep episodes (i.e., microsleeps) prior to driving cessation. These behaviours could possibly be attributed to under-recognition of sleepiness signs and/or an under-appreciation of the progression of high sleepiness to falling asleep. However, these participants that experienced microsleeps reported fighting to maintain wakefulness to complete the driving task. This suggests that the two participants did in fact perceive an extreme level of sleepiness but increased their *drive* for wakefulness to ensure meeting assumed task demands.

Most of the participants ceased driving before one hour had elapsed, with the longest duration being 76 minutes. Our data suggests that drivers can experience very significant levels of sleepiness which occurred within the commonly promoted 'stop and revive' time-based recommendation of two hours of driving before taking a break. Participants reported a high level of subjective sleepiness after a relatively moderate level of sleep restriction provided by early wake time that morning. Similar levels of sleep restriction are commonplace for many people in modern society (National Sleep Foundation, 2008). It is possible that the simulated environment per se could have contributed to the relatively short duration of completion of the task in the current study. Laboratory conditions have been noted to invoke lower arousal levels than those experienced during on-road conditions (Philip et al., 2005).

Accurate self-perception of sleepiness is a critical consideration for the timely use of a driver sleepiness countermeasure. The self-perceptions of sleepiness for certain types of occupational drivers may be masked by occupational demands. For instance, occupations that involve higher levels of activity (i.e., courier drivers) may mask true levels of sleepiness. That is, increases in the levels of activity can lead to a transient reduction in subjective sleepiness (e.g., Gillberg, Kecklund, Göransson, & Åkerstedt, 2003; Sallinen et al., 2008) levels. The effects of activity on cognitive measures are however equivocal, with studies showing that activity can facilitate better cognitive functioning or have no effect at all (LeDuc, Caldwell, & Ruyak, 2000; Sallinen, et al., 2008). Considered together, increases in activity levels may mask sleepiness levels for certain types of occupational drivers – this may leave drivers with an erroneous subjective perception of their sleepiness level. Future research should explore this possible issue.

It is believed that a proactive and positive safety culture could lead to a reduction in the incidents of vehicle crashes in the occupational setting (Rowland, et al., 2006). Moreover, the importance of establishing a positive safety culture for influencing employees' safety behaviours has been noted in other occupational settings (e.g., S. E. Biggs, Davey, & Freeman, 2012; Dingsdag, Biggs, & Sheahan, 2008). As driver education is the most common sleepiness countermeasure utilised in the light vehicle occupational setting, it is possible that a positive safety culture that encourages drivers to stop driving when they feel too sleepy to drive safely on the roads, could have road safety benefits.

There are several limitations of the current study that require consideration when evaluating the results. The Hazard perception data could not be used in the analysis for current study. Including a measure of driver performance could further explain the moments when a driver decides to cease driving. The obtained results were from young adults which may not necessarily be generaliseable to more mature drivers as some studies have shown that older drivers have reduced impairment levels on some performance tasks than younger drivers (Campagne, Pebayle, & Muzet, 2004; Philip et al., 2004). This study was carried out under laboratory conditions and as such may have contributed to the lowered arousal levels experienced by the participants. Future studies should incorporate an on-road driving design to examine this issue.

In conclusion, driver sleepiness contributes substantially to vehicle crashes in the occupational settings. The main finding from the current study was that all participants had capacity to perceive increasing sleepiness and self-regulate their behaviour to take a break. The majority of the participants were then able to achieve some sleep. Maintaining a positive workplace safety culture that encourages its employees to utilise driver sleepiness countermeasures is a vital consideration for occupational road safety.

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