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Specific sleepiness symptoms are indicators of performance impairment during sleep deprivation

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ABSTRACT

Drivers are not always aware that they are becoming impaired as a result of sleepiness. Using specific symptoms of sleepiness might assist with recognition of drowsiness related impairment and help drivers judge whether they are safe to drive a vehicle, however this has not been evaluated. In this study, 20 healthy volunteer professional drivers completed two randomized sessions in the laboratory – one under 24 h of acute sleep deprivation, and one with alcohol. The Psychomotor Vigilance Task (PVT) and a 30 min simulated driving task (AusEdTM) were performed every 3–4 h in the sleep deprivation session, and at a BAC of 0.00% and 0.05% in the alcohol session, while electroencephalography (EEG) and eye movements were recorded. After each test session, drivers completed the Karolinska Sleepiness Scale (KSS) and the Sleepiness Symptoms Questionnaire (SSQ), which includes eight specific sleepiness and driving performance symptoms. A second baseline session was completed on a separate day by the professional drivers and in an additional 20 non-professional drivers for test–retest reliability. There was moderate test–retest agreement on the SSQ ($r = 0.59$). Significant correlations were identified between individual sleepiness symptoms and the KSS score (r values 0.50–0.74, $p < 0.01$ for all symptoms). The frequency of all SSQ items increased during sleep deprivation (χ^2 values of 28.4–80.2, $p < 0.01$ for all symptoms) and symptoms were related to increased subjective sleepiness and performance deterioration. The symptoms "struggling to keep your eyes open", "difficulty maintaining correct speed", "reactions were slow" and "head dropping down" were most closely related to increased alpha and theta activity on EEG (r values 0.49–0.59, $p < 0.001$) and "nodding off to sleep" and "struggling to keep your eyes open" were related to slow eye movements (r values 0.67 and 0.64, $p < 0.001$). Symptoms related to visual disturbance and impaired driving performance were most accurate at detecting severely impaired driving performance (AUC on ROC curve of 0.86–0.91 for detecting change in lateral lane position greater than the change at a BAC of 0.05%). Individual sleepiness symptoms are related to impairment during acute sleep deprivation and might be able to assist drivers in recognizing their own sleepiness and ability to drive safely.

1. Introduction

Sleep deprivation is associated with impaired alertness and psychomotor performance (Akerstedt and Folkard, 1995; Howard et al., 2007; Jackson et al., 2008; Van Dongen et al., 2003) and is implicated in 20% of heavy vehicle accidents (Akerstedt, 2000; Neville et al., 2000). Ideally drivers should be able to determine when they have reached a degree of sleepiness that is dangerous for driving and then make an appropriate decision to stop driving. Some individuals are poor at predicting when sleep onset is imminent, fail to realize that they have briefly fallen asleep, or continue to drive despite recognizing sleepiness due to an under appreciation of its' risks (Connor et al., 2002; Itoi et al., 1993; Mitler et al., 1997; Nabi et al., 2006; Reyner and Horne, 1998). Methods for assisting drivers to recognize dangerous levels of sleepiness may help them to determine when they are not safe to drive.

Subjective sleepiness questionnaires record an individual's perception of their instantaneous sleepiness level using a numerical rating (Akerstedt and Gillberg, 1990; Hoddes et al., 1973) or visual analog scale (Monk, 1987) to indicate feelings ranging from extremely awake to extremely sleepy. The individual must have insight into their experience of sleepiness and be able to distinguish it from other factors which might produce similar symptoms such as physical fatigue.

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Changes in subjective sleepiness occur during sleep deprivation and the circadian nadir (Babkoff et al., 1991; Gillberg et al., 1996). Moderate correlations have been found between subjective sleepiness scales and changes in vigilance, reaction time and lane drifting whilst driving following sleep deprivation (Gillberg et al., 1994; Horne and Baulk, 2004; Ingre et al., 2006b). It is also related to increased alpha and theta activity on electroencephalography (EEG) during sleep deprivation (Horne and Baulk, 2004). However, increased accident risk is present even at low levels of sleepiness on subjective scales, when individuals may still consider themselves fit to drive (Connor et al., 2002).

An alternative to simply asking people whether they are sleepy or alert is to ask about specific symptoms of sleepiness that they experience. The Tiredness Symptom Scale (Schulz et al., 1991) and the Accumulated Time with Sleepiness Scale (Gillberg et al., 1994) use symptoms of sleepiness to assess subjective sleepiness level, rather than an individual's judgment of whether they are sleepy or not. A small number of studies have assessed the occurrence of sleep-related symptoms during driving (Nilsson et al., 1997) and vigilance tasks (Gillberg et al., 1994; Itoi et al., 1993). Drivers notice specific symptoms related to sleepiness and driving performance as they become sleepier, such as "wandering thoughts", "difficulties keeping eyes open" and "difficulty concentrating" (Gillberg et al., 1994; Herscovitch and Broughton, 1981; Nilsson et al., 1997). Symptom frequency increases with increasing hours awake; however the relationship between individual symptoms and performance varies (Sallinen et al., 2012). There is also significant individual variation in the correlation between cognitive function, self-perceived performance and subjective sleepiness following sleep-restriction, with overall moderate correlations (Sallinen et al., 2012). Nevertheless drivers frequently notice specific sleepiness symptoms prior to episodes of falling asleep whilst driving (Nordbakke and Sagberg, 2007). However, it remains unclear whether any specific sleepiness symptoms are better predictors of performance than standard subjective evaluations of overall levels of sleepiness and if so, which symptoms are most useful.

In the laboratory, participant performance on tasks following alcohol consumption can be compared to performance on tasks following other risk factors, such as sleep deprivation, to determine the level of deterioration and how it compares to the known performance decrease caused by alcohol. Comparison of performance deterioration due to sleepiness with performance deterioration caused by measured concentrations of alcohol consumption is one means of determining whether a particular level of sleepiness is likely to increase accident risk. This method has been utilized to determine that performance on a variety of tasks after 24 h awake is similar to performance at a BAC of 0.08–0.10% in a non-sleep-deprived state (Dawson and Reid, 1997; Lamond and Dawson, 1999; Williamson et al., 2001).

This study evaluated specific symptoms as markers of sleepiness and performance impairment. It examined changes in a subjective sleepiness scale, the Sleepiness Symptoms Questionnaire (SSQ), during 24-h of sleep deprivation and the relationship of specific sleepiness symptoms to simulated driving and psychomotor performance in professional drivers.

2. Methods

2.1. Participants

Twenty professional drivers were recruited by advertisement through newspapers and the Victorian Transport Workers Union newsletter. An initial interview was organized to collect baseline information, gain consent and practice the tasks. Drivers were reviewed by a physician and those with contraindications to sleep deprivation (e.g. epilepsy, diabetes, psychiatric disorders), who had symptoms of a sleep disorder, medical condition or were on drugs that might affect neuropsychological performance (e.g. neurological diseases, psychotropic medications) were excluded. An additional 20 non-professional drivers were recruited using the same criteria to collect data for test–re-test reliability and discriminant validity (comparing baseline sleepiness symptoms in all participants with and without chronic sleepiness). The study was approved by the Human Research Ethics Committee at Austin Health and written informed consent was obtained from all participants.

2.2. Design

Professional drivers undertook two sessions in the sleep laboratory at the Austin Hospital, with a randomized, crossover design. One session consisted of a period of sleep deprivation, and the other session involved testing at a blood alcohol concentration (BAC) of 0.05%, as outlined below. The alcohol session was used to benchmark when performance was severely impaired in the sleep deprivation session. Participants completed a sleep diary for one week prior to the test sessions to document their hours of sleep and sleep/wake patterns. Prior to each test session, drivers had at least 7 h sleep, were required to wake at 07:00 and presented to the laboratory by 08:30. Taxi transport was provided to and from the laboratory. A calibrated Alcometer (model SD_400; Lion Laboratories, Glamorgan, UK) was used to confirm that no alcohol was consumed before the sessions. This instrument has an accuracy of ±10%.

2.2.1. Sleep deprivation condition

Participants undertook a 30 min, divided attention, simulated driving task at 09:00, 12:00, 16:00, 20:00, 24:00 (17 h awake), 03:00 (20 h awake) and 06:00 (23 h awake) in a soundproofed room in dim light. Objective indicators of sleepiness were recorded throughout the driving task (EEG, slow eyelid closure) and after the driving task (during the Psychomotor Vigilance Task (PVT)). Subjective sleepiness (Karolinska Sleepiness Scale (KSS)) and sleepiness symptoms (SSQ) were recorded immediately after the driving task, prior to the PVT. Participants stayed awake in the sleep laboratory until 07:00 am the following day, and were allowed to partake in passive activities, such as reading or watching videos. They refrained from drinking caffeinated beverages throughout the 24 h testing period.

2.2.2. Alcohol condition

Participants undertook a 30 min, divided attention, simulated driving task at baseline (BAC of 0.00%) and following alcohol consumption (BAC of 0.05%). Participants consumed standard measures of vodka given orally in orange juice or soft drink to reach a BAC of between 0.05% and 0.055%. Blinding to the presence of alcohol was not attempted as other authors have shown that participants can determine whether or not they have received alcohol (Lamond and Dawson, 1999). However, participants were blinded to the dose of alcohol and their BAC. Oral rinses (H_2O) were used after drinking to remove mouth alcohol. Approximately 15 min after each alcohol dose, breath alcohol level was measured using the calibrated Alcometer. Following the testing session, participants remained in the sleep laboratory until their BAC returned to 0.00%. This session was used to define when participants had severe driving or psychomotor impairment during sleep deprivation, defined as equivalent or worse than the mean performance at a BAC of 0.05%.