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# The utility of automated measures of ocular metrics for detecting driver drowsiness during extended wakefulness

Melinda L. Jackson[a,b], Gerard A. Kennedy[a,c], Catherine Clarke[d], Melissa Gullo[d], Philip Swann[e], Luke A. Downey[f,g], Amie C. Hayley[f], Rob J. Pierce[a], Mark E. Howard[a,*]

[a] Institute for Breathing and Sleep, Department of Respiratory and Sleep Medicine, Austin Health, Australia
[b] RMIT University, School of Health Sciences and Health Innovations Research Institute, Bundoora, Australia
[c] Cairnmillar Institute, Melbourne, Australia
[d] College of Arts, Victoria University, Victoria, Australia
[e] Department Road Safety, Vic Roads, Victoria, Australia
[f] Centre for Human Psychopharmacology, Swinburne University, Victoria, Australia
[g] Cambridge Health Alliance, Cambridge, MA, USA

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ABSTRACT

Slowed eyelid closure coupled with increased duration and frequency of closure is associated with drowsiness. This study assessed the utility of two devices for automated measurement of slow eyelid closure in a standard poor performance condition (alcohol) and following 12-h sleep deprivation. Twenty-two healthy participants (mean age = 20.8 (SD 1.9) years) with no history of sleep disorders participated in the study. Participants underwent one baseline and one counterbalanced session each over two weeks; one 24-hour period of sleep deprivation, and one daytime session during which alcohol was consumed after a normal night of sleep. Participants completed a test battery consisting of a 30-min simulated driving task, a 10-min Psychomotor Vigilance Task (PVT) and the Karolinska Sleepiness Scale (KSS) each in two baseline sessions, and in two randomised, counterbalanced experimental sessions; following sleep deprivation and following alcohol consumption. Eyelid closure was measured during both tasks using two automated devices (Copilot and Optalert™). There was an increase in the proportion of time with eyelids closed and the Johns Drowsiness Score (incorporating relative velocity of eyelid movements) following sleep deprivation using Optalert ($p < 0.05$ for both). These measures correlated significantly with crashes, PVT lapses and subjective sleepiness ($r$-values 0.46–0.69, $p < 0.05$). No difference between the two sessions for PERCLOS recorded during the PVT or the driving task as measured by the Copilot. The duration of eyelid closure predicted frequent lapses following sleep deprivation (which were equivalent to the average lapses at a blood alcohol concentration of 0.05% – area under curve for ROC curve 0.87, $p < 0.01$). The duration of time with slow eyelid closure, assessed by the automated devices, increased following sleep deprivation and was associated with deterioration in psychomotor performance and subjective sleepiness. Comprehensive algorithms inclusive of ocular parameters may be a better indicator of performance impairment following sleep loss.



## 1. Introduction

Drowsiness is the transient state between wakefulness and sleep, during which a reduction in vigilance (alertness, attentiveness) and performance is often observed (Corsi-Cabrera et al., 1996; Anund et al., 2008). Increasing drowsiness can be particularly detrimental to performance when undertaking tasks that demand sustained levels of attention, such as driving a motor vehicle. Driver drowsiness is believed to be a leading cause of motor vehicle accidents throughout the world (Connor et al., 2001; Åkerstedt et al., 2010). Therefore, the detection of drowsiness as a countermeasure for combating driver fatigue has important implications for driver safety. Currently, there is a lack of reliable objective measures for assessing drowsiness in awake individuals in real time, and there is little distinction of efficacy between these available devices. As such, the aim of the current study is to assess the utility of two measures of eye closure in predicting driving deterioration caused by sleep deprivation, and in comparison to alcohol consumption.

* Corresponding author at: Institute of Breathing & Sleep, Austin Health, Heidelberg, Victoria 3184, Australia.
*E-mail address:* mark.howard@austin.org.au (M.E. Howard).

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Several physiological parameters have potential as markers of drowsiness. Increased alpha and theta power density in the electroencephalogram (EEG) has been demonstrated in awake yet drowsy subjects during driving and other activities (Kecklund and Åkerstedt, 1993; Cajochen et al., 1995; Mitler et al., 1997). Increases in alpha and theta power density in the EEG frequently coincide with performance decrement during monotonous tasks (Akerstedt and Gillberg, 1990), and are considered to increase monotonically as a function of prior wakefulness (Dijk et al., 1990). Changes in heart rate variability (Fairclough and Graham, 1999) and saccadic eye movements (Cajochen et al., 1999; Russo et al., 2003) have also been observed in individuals who are sleep deprived. These latter two parameters have shown promise as objective markers of drowsiness as they can be implemented relatively unobtrusively and processed on a real time basis. Such non-intrusive, continuous methods that are sensitive to increased periods of drowsiness may be useful for alerting drivers and potentially reducing sleep-related road accidents.

Eye and eyelid movements have shown promise as a simple non-invasive indicator of drowsiness. While normal blink duration is less than 200 ms, periods of eye closure lasting more than 500 ms have been termed "slow eyelid closures" (Morris and Miller, 1996; Sirevaag and Stern, 2000). Slow eyelid closure occurs prior to sleep onset on EEG, and is therefore recognised as a leading indicator of drowsiness (Santamaria and Chiappa, 1987). Changes in frequency, amplitude and duration of blinks, and episodes of slow eyelid closure, as assessed by electrooculogram (EOG) (device used to measures the existing resting electrical potential of the retina in the eye), have been identified in sleepy participants under a variety of conditions (Wierwille and Ellsworth, 1994; Morris and Miller, 1996; Caffier et al., 2003; Åkerstedt et al., 2010), however, technical issues regarding device utility, such as the reproducibility and practicality of these observations in highly-controlled experimental conditions to those of real-life driving scenarios often impede device reliability during on road driving tasks. A number of technologies and procedures have been developed to monitor drowsiness in drivers and provide early warning signals. Several automated devices measure episodes of slow eyelid closure and other ocular metrics to detect drowsiness. One of these devices, the Copilot, assesses the percentage of eyelid closure (PERCLOS) over the pupil, and is based on monitoring of infrared light reflected from the retina (Dinges and Grace, 1998; Grace et al., 1999). PERCLOS was first defined by Wierwille and Ellsworth (1994) as the proportion of time that the eyelid covers more than 80% of the pupil over a 1 min time interval (Wierwille and Ellsworth, 1994). PERCLOS has been shown to increase in drowsy subjects, and strong associations between PERCLOS and deficits in several performance measures, such as poorer driving ability, vigilance and psychomotor performance have been observed (Wierwille and Ellsworth, 1994; Wierwille, 1999; Chua et al., 2014; Jackson et al., 2015). This system has been validated in preliminary on-road driving studies (Tijerina et al., 1999) and with tasks of sustained attention, such as the Psychomotor Vigilance Test (PVT) (Dinges and Grace, 1998; Mallis, 1999). PERCLOS values correlate with lane departures during simulated driving in sleep deprived drivers (Kozak et al., 2005), and increased blink duration is reflective of behavioural lapses on the PVT (Jackson et al., 2015). In a study comparing PERCLOS against EEG algorithms, eye blink software, and head-nodding technology, PERCLOS was found to be superior to the other techniques in detecting drowsiness (Dinges and Grace, 1998; Mallis, 1999). More recently, PERCLOS has been found to be associated with variability in both vigilance performance (PVT) and variation in lane position in a simulated driving task completed by sleep deprived professional truck drivers (Jackson et al., 2015). This indicates that eyelid closure appears to be a promising method for indicating driver drowsiness in real-time (Ftouni et al., 2013) and is both sensitive to the effects of sleep deprivation and related to decrements in driving performance.

Alternate ocular metrics to the PERCLOS assessment have also been evaluated, including eyelid movements (including the duration, velocity and amplitude of eyelid closure and re-opening) by measuring infrared light reflected from the eyelids using sensors set in glasses (Caffier et al., 2003; Johns et al., 2007). These devices have demonstrated increased blink duration (Caffier et al., 2003; Johns et al., 2007) and altered velocity and amplitude of eyelid closure and re-opening (Caffier et al., 2003; Johns et al., 2007) in sleep deprived participants. The Optalert device uses a small light emitting diode (LED) below and in front of the eye, offering accurate measures of eye and eyelid movement and position. Predictive algorithms have revealed associations between errors of omission on a reaction time task and increased lane crossings during simulated driving tasks (Johns et al., 2007). Increased eyelid closing and reopening time (during blinks and episodes of prolonged eyelid closure) (Caffier et al., 2003; Johns et al., 2007) and reduced amplitude of eyelid opening (Morris and Miller, 1996; Johns et al., 2007) have also been demonstrated in drowsy subjects.

These measures have utility as proxy indicators of driver alertness and subsequent performance deficits. At present, there is a paucity of research assessing the utility of automated measures of ocular movement as indicators of performance impairment in drowsy subjects. The measurement of PERCLOS has traditionally been used to assess drowsiness; however, new devices with more complex algorithms have now been developed. It is currently unknown whether different drowsiness detection devices have different sensitivities, and whether differential effectiveness is evident between these measures. Large and random individual differences in response to sleep loss are often observed in assessments of drowsiness/sleepiness (Van Dongen et al., 2004), performance of attentional tasks and within ocular measures designed to assess drowsiness, such as blink parameters (Ingre et al., 2006). Therefore, it is necessary to assess and compare individual variations in automated ocular measures during sleep loss. As such, this study evaluated changes in ocular metrics measured following extended wakefulness using two different devices – Copilot and Optalert. The utility of automated measurement of slow eyelid closure for detecting subjects with severe performance impairment, equivalent to or worse than that shown at a blood alcohol concentration of 0.05% in a non-sleep deprived state was also evaluated; used to provide a comparison for the level of impairment observed after sleep deprivation to a quantifiable level of impairment due to alcohol. Reference measures of performance were obtained from baseline sessions completed prior to each experimental condition. The aim of this study is to determine whether newer algorithms of drowsiness detection are superior to PERCLOS.

## 2. Materials and methods

### 2.1. Participants

Twenty-two healthy volunteers (three men and 19 women) were recruited from advertisements at Victoria University, Melbourne. The mean age of the participants was 20.8 years (SD 1.9 years, range 18–26 years). All participants held a current driver's license, and had an average alcohol intake of less than five standard drinks per day for men and less than three standard drinks per day for women. Individuals were excluded from the study if they reported the following: (1) medical conditions or medication usage that were a contra-indication to drinking alcohol or undertaking sleep deprivation; (2) previously diagnosed sleep disorder or