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# The efficacy of objective and subjective predictors of driving performance during sleep restriction and circadian misalignment

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ABSTRACT

Fatigue is a significant contributor to motor-vehicle accidents and fatalities. Shift workers are particularly susceptible to fatigue-related risks as they are often sleep-restricted and required to commute around the clock. Simple assays of performance could provide useful indications of risk in fatigue management, but their effectiveness may be influenced by changes in their sensitivity to sleep loss across the day. The aim of this study was to evaluate the sensitivity of several neurobehavioral and subjective tasks to sleep restriction (SR) at different circadian phases and their efficacy as predictors of performance during a simulated driving task. Thirty-two volunteers (M ± SD; 22.8 ± 2.9 years) were time-isolated for 13-days and participated in one of two 14-h forced desynchrony protocols with sleep opportunities equivalent to 8 h/24 h (control) or 4 h/24 h (SR). At regular intervals during wake periods, participants completed a simulated driving task, several neurobehavioral tasks, including the psychomotor vigilance task (PVT), and subjective ratings, including a self-assessment measure of ability to perform. Scores transformed into standardized units relative to baseline were folded into circadian phase bins based on core body temperature. Sleep dose and circadian phase effect sizes were derived via mixed models analyses. Predictors of driving were identified with regressions. Performance was most sensitive to sleep restriction around the circadian nadir. The effects of sleep restriction around the circadian nadir were larger for simulated driving and neurobehavioral tasks than for subjective ratings. Tasks did not significantly predict driving performance during the control condition or around the acrophase during the SR condition. The PVT and self-assessed ability were the best predictors of simulated driving across circadian phases during SR. These results show that simple performance measures and self-monitoring explain a large proportion of the variance in driving when fatigue-risk is high.



## 1. Introduction

Demand for 24-h access to services and goods has led to an increase in the number of employees engaged in shiftwork (Mcmenamin, 2007). Despite its economic benefits, shiftwork has social and public health costs. Shift workers, especially those who work at night, are among the most fatigued demographic in society, frequently obtaining inadequate durations of sleep, and working in conflict with their body clocks (Åkerstedt, 2003). Insufficient sleep, extended wakefulness, and working during the circadian nadir are associated with an increased risk of workplace and motor vehicle accidents (Folkard et al., 2006; Philip and Åkerstedt, 2006). An estimated 20% of on-road accidents are attributed to fatigue (Horne and Reyner, 1995). Given the necessity of driving for many shift workers, whether it is for the purpose of commuting or a requirement of the job itself (e.g., trucking, mining, courier and postal services), this demographic is particularly susceptible to accidents on the road (Akerstedt et al., 2005). Thus, the ability to assess risk and predict driving impairment on the job is of great importance in fatigue management.

For an assay of performance to be an effective and convenient predictor of drowsy driving, it must be sensitive to fatigue-inducing factors (e.g., sleep restriction and time of day), demonstrate a strong

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association with a relevant driving performance metric, and should be portable, affordable, and brief (Balkin et al., 2004; Dorrian et al., 2005). A simple neurobehavioral task or subjective assessment of alertness or one's capacity to perform could meet all these criteria. Indeed, these tasks are often used in the laboratory and in the field as proxies for "real-world" functioning on the basis that they capture basic constructs required for the performance of complex tasks (Basner and Dinges, 2011; Jackson et al., 2013) and are highly responsive to sleep and circadian processes (Balkin et al., 2004; Kosmadopoulos et al., 2014a; Lamond et al., 2006; Van Dongen et al., 2004; Zhou et al., 2011).

Neurobehavioral tasks requiring vigilance, speed and memory, as well as self-reflective subjective assessments of sleepiness, have all been associated with driving performance (Ingre et al., 2006; Szlyk et al., 2002). Recent studies conducted both on-road and with laboratory-based simulators have indicated that sustained attention during a psychomotor vigilance task (PVT), following 24 h of total sleep deprivation, is strongly positively associated with driving performance – more so than other laboratory tasks (Baulk et al., 2008; Jackson et al., 2013; Jongen et al., 2015). While critical for a safe commute, it is not necessarily evident that psychomotor vigilance would constitute the best predictor of drowsy driving at all times of day. Shift workers, generally, tend to be chronically sleep-restricted, rather than totally sleep-deprived (>24 h) and are employed around the clock, not just during the day. Notwithstanding individual differences in performance (Van Dongen et al., 2004), driving, neurobehavioral tasks, and subjective assessments all vary in their resilience to sleep and circadian manipulation depending on their duration, difficulty and complexity (Balkin et al., 2004; Burke et al., 2015; Matthews et al., 2012b; Schmidt et al., 2007; Zhou et al., 2012). Thus, the driving performance of shift workers and any given assay used to predict it may not have consistently strong associations, following partial sleep restriction, at all times of day.

The aim of this study was twofold: First, to establish the sensitivity of a simulated driving task, several commonly-used neurobehavioral tasks, and subjective measures of sleepiness and self-assessed performance ability to circadian phase and sleep dose; and, second, to determine how well these neurobehavioral and subjective measures predict simulated driving performance at different circadian phases and sleep durations. To accomplish this, two forced desynchrony protocols, one with sleep restriction and one without, were employed.

## 2. Materials and methods

### 2.1. Participants

Participants were 32 healthy males with a mean (±SD) age of 22.8 (±2.9) years and body mass index (BMI) of 22.3 (±2.1) kg/m$^2$. Volunteers were required to pass a screening process that involved an interview, questionnaires, and a week of wrist actigraphy. Exclusion criteria included smoking, excessive consumption of caffeine or alcohol, physical or medical disorders, irregular sleep patterns, or transmeridian travel/shiftwork in the previous two months. For a week before admission, participants were required to maintain consistent bedtimes between 22:00 h and 00:00 h and sleep durations of 7–9 h per night, verified by activity monitors (Actical; Philips Respironics, Bend, Oregon, USA) and sleep diaries (Kosmadopoulos et al., 2014b).

#### 2.1.1. Ethics

The study was conducted in accordance with the Declaration of Helsinki and guidelines of the National Health and Medical Research Council of Australia. All participants provided informed written consent prior to admittance into the study and were remunerated with an honorarium for their involvement. The Central Queensland University Human Research Ethics Committee approved the protocol.

### 2.2. Apparatus and measures

#### 2.2.1. Simulated driving task

Driving was assessed using the York Driving Simulator (YDS; York Computer Technologies, Kingston, Ontario), conducted on a desktop computer, with a wheel mounted to the desk and acceleration and brake pedals fixed to the floor. The simulation was 10 min in duration and emulated a night-time rural drive on a single carriageway, two-lane road with target speeds of 100 km/h on straight sections alternating with target speeds of 80 km/h on winding sections. Participants were required to overtake a single car appearing 7 min into the task. Participants were instructed to keep as close to the speed limit as possible and to stay within the left lane (standard in Australia). Performance was expressed as the standard deviation of lateral position (SDLAT) within the lane, with increased variability indicative of worse performance, as it is sensitive to fatigue (Matthews et al., 2012a). Lateral position was calculated as the distance in metres from the centre point of the car to the centre of the road.

#### 2.2.2. Neurobehavioral performance measures

Three measures of fatigue and neurobehavioral function were selected for their potential utility as predictors of SDLAT in operational settings. The first of these was the Psychomotor Vigilance Task (PVT), a 10-min simple response time task performed on a portable electronic hand-held unit (PVT-192, Ambulatory Monitoring Inc., Ardsley, New York, USA) (Dorrian et al., 2005). The PVT has minimal learning effects and measures sustained attention, requiring constant vigilance to detect stimuli presented at random intervals. Increased mean response times on the PVT indicate reductions in the ability to sustain attention. The mean reciprocal response time (RRT; $ms^{-1} \times 10^{-3}$) was derived as the performance metric as it has been shown to be the most sensitive to partial sleep deprivation (Basner and Dinges, 2011). The Serial Addition/Subtraction Task (SAST) was included as a cognitive throughput measure capturing changes in sustained attention and declarative working memory (Darwent et al., 2010; Destefano and Lefevre, 2004). Conducted on a desktop computer, performance was determined by the number of addition and subtraction sums correctly answered in 5 min. The final task was the Digit Symbol Substitution Test (DSST), a cognitive throughput measure dependent on processing speed, memory, and visuomotor coordination (Joy et al., 2004). A different version of the DSST was used in each test session to minimize learning effects. Performance was determined by the number of correct digit-symbol pairs created in 90 s.

#### 2.2.3. Subjective measures of sleepiness, alertness, and self-assessed ability

Subjective sleepiness was measured using a 9-point Karolinska Sleepiness Scale (KSS) (Akerstedt and Gillberg, 1990). This scale requires participants to rate how sleepy they feel, from 1 = "Extremely alert" to 9 = "Very sleepy, great effort to keep awake, fighting sleep", with intermediate levels labelled in 1-unit increments. Alertness and self-assessed ability to perform were assessed using 100 mm visual analogue scales (VAS). The question, "How alert do you feel?" (VAS Alert) was anchored left-to-right by the statements "struggling to remain awake" and "extremely alert and wide awake". Similarly, the question, "how well do you think you will perform?" (VAS Performance) was anchored with "extremely poorly" and "extremely well".