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Performance awareness: Predicting cognitive performance during simulated shiftwork using chronobiological measures

Drew M. Morris, MS, June J. Pilcher, PhD *, Joseph B. Mulvihill, M.D., Melissa A. Vander Wood, MS

Department of Psychology, Clemson University, Clemson, SC, USA

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ABSTRACT

Physiological tracers of circadian rhythms and a performance awareness index were examined as predictors of cognitive performance during two sleep deprivation conditions common to occupational shiftwork. Study 1: Thirty-three sleep-deprived participants completed a simulated nightshift. Study 2: Thirty-two partially sleep-deprived participants completed a simulated dayshift. A standardized logic test was used to measure cognitive performance. Body temperature and heart rate were measured as chronobiological indices of endogenous circadian rhythms. Performance awareness was calculated as a correlation between actual and perceived performance. These studies demonstrated a parallelism between performance awareness and the circadian rhythm. Chronobiological changes were predictive of performance awareness during the simulated nightshift but not dayshift. Only oral temperature was a significant independent predictor. Oral temperature predicted an individual's awareness of their own performance better than their own subjective awareness. These findings suggest that using circadian rhythms in applied ergonomics may reduce occupational risk due to low performance awareness.

1. Introduction

Endogenous circadian rhythms are intrinsically connected with cognitive performance and applied ergonomics through alertness (Van Dongen and Dinges, 2000). This relationship is significant when considering the effects of shiftwork scheduling on the sleep/wake cycle and the detrimental effects resulting from sleep deprivation (Pilcher and Huffcutt, 1996). As a result, circadian rhythms are of utmost importance when considering on-the-job safety and may be used to mitigate occupational risks (Costa, 1996).

Cognitive performance can fluctuate across a work shift due to circadian rhythms. Periods of poor cognitive performance occur as a result of a nonlinear interaction between the pressure to sleep, the need to stay awake, and biological rhythms (Van Dongen and Dinges, 2003). This results in a cognitive performance low, or *circadian decrease*, when the hormone melatonin increases and body temperature decreases during nightshift hours (Wyatt et al., 1999). In the case of repeated nightshifts, further cognitive performance decrements are also associated with sleep deprivation following sustained wakefulness during the circadian decrease (Monk et al., 1985; Olds and Clarke, 2010). Not surprising then, the circadian decrease and occupational risk during nightshift are commonly correlated (Folkard et al., 2006; Wojtczak-Jaroszowa and Jarosz, 1987), and sleep deprivation during the circadian decrease limits work-related attention, memory, vigilance, motivation, and subjective perceptions (Odle-Dusseau et al., 2010; Pilcher et al., 2007). Indeed, occupational safety research and circadian rhythm research exist as concomitant fields when exploring cognitive performance.

Because of the effect of circadian rhythms on cognitive performance, methods of tracking biological changes in a non-invasive manner could be advantageous to the field of applied ergonomics. Literature shows that core temperature and heart rate changes can be used as indices of endogenous circadian rhythms (Krauchi and Wirz-Justice, 1994; Walker et al., 2009), and could be applied to an occupational setting as a tracer of dangerous cognitive decrement. Furthermore, circadian changes in core body temperature has been shown to parallel occupational risk factors such as alertness, sleepiness, serial search ability, and general cognitive performance (Burgess et al., 2003; Darwent et al., 2010; Dijk et al., 1992; Monk et al., 1985; Wyatt et al., 1999). Cardiac activity has also

* Corresponding author. Department of Psychology, 418 Brackett Hall, Clemson University, Clemson, SC 29634-1355, USA.
E-mail address: jpilche@clemson.edu (J.J. Pilcher).

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been shown to parallel occupational risk factors like attention, but has not been proposed within an occupational setting (Van Eekelen et al., 2004; Walker et al., 2009). Such a parallel relationship between overt biological markers and occupational risk is an important topic for the workforce at large.

This relationship may be more important when considering the exacerbating effects of sleep deprivation on cognitive performance during shiftwork. Shiftwork schedules can cause partial sleep deprivation (i.e., insufficient/limited sleep at night) during the dayshift and more severe total sleep deprivation (i.e., no sleep at night) during a nightshift when day sleep is difficult, and may influence the biological circadian cycle (Daan et al., 1984; McClelland et al., 2013). Sleep deprivation holistically limits cognitive and motor performance and can even impact brain operational capacity after recovery days of normal sleep (Belenky et al., 2003; Morris, et al., 2015; Pilcher et al., 2015a; Pilcher et al., 2015b). Importantly, research also suggests that sleep deprivation impacts metacognition, limiting an individual's awareness and understanding of their own cognitive decrements (Odle-Dusseau et al., 2010). As a result, sleep deprivation must be considered when addressing occupational risks related to circadian rhythms.

Poor cognitive performance impacts both employee and employer (Eatough et al., 2011), largely due to degradation in monitoring vigilance during sleep deprivation. Laboratory simulations of shiftwork have shown high variability in tasks requiring monitoring vigilance between dayshift and nightshift due to partial sleep deprivation (Sauer et al., 2003). In addition, an employee's awareness of their own performance (i.e., self-monitoring) can have a significant effect on the quality of their work as well as their own safety within the work place (Slovic, 1978; Stanton et al., 2001). Research has explored the parallel relationship between circadian rhythms and cognitive performance, but has not done so in direct comparison to the two basic types of occupational sleep deprivation: total deprivation during nightshift work and partial deprivation during dayshift work (Pilcher and Huffcutt, 1996). Research has also demonstrated the effects of occupational sleep deprivation on metacognition, but has not shown the parallel relationship with circadian rhythms that other cognitive measures have (Dorrian et al., 2000; Dorrian et al., 2003; Monk et al., 1985). This relationship between the circadian cycle and an employee's metacognition would be important to occupational safety and productivity but remains enigmatic. If this relationship exists, the potential to predict performance awareness using physiological circadian rhythm markers may also exists, which could be used to reduce occupational risk (Folkard et al., 2006; Knauth, 1996; Monk et al., 1996).

The authors propose *performance awareness* as a metacognitive index to better understand the impact of circadian rhythms and sleep deprivation on occupational work. The performance awareness index is based on perceived task performance and actual task performance, the former sharing a metacognitive relationship with the latter. High performance awareness does not necessarily equate to good task performance, but rather a high awareness of actual task performance, either good or bad. This is an important distinction which suggests personal performance may only have the potential to be self-corrected during times of high performance awareness. Previous studies have used a correlational approach to index self-awareness and distraction, but have not used it to assess changes in awareness (Horrey et al., 2008). These studies have, instead, focused on the existence of performance awareness denoted by the significance of the correlation. Moreover, this method has not been used to assess performance difference related to the circadian rhythm or shiftwork.

Two common types of sleep deprivation, total sleep deprivation during a simulated nightshift and partial sleep deprivation during a simulated dayshift, were used in two separate laboratory studies. We hypothesize that individuals will lose the ability to accurately gauge self-performance in parallel with both types of sleep deprivation, resulting in low performance awareness scores. However, we anticipate those in the total sleep deprivation condition will show a greater degree of performance awareness degradation. We also hypothesize that physiological measures of heart rate and oral temperature will be significant predictors of performance awareness in both shift conditions. Both cognitive performance and physiological changes have been shown to parallel the circadian rhythm which suggests that one should be able predict the other.

2. Method

2.1. Study 1

2.1.1. Participants

A sample of thirty-three volunteers (22 males and 11 females) with a mean age of 20.57 (SD = 2.70) participated in a simulated nightshift under sleep deprivation conditions. Participants were screened using a questionnaire prior to testing to ensure they were in good mental and physical health, native English speakers, and had no history of sleep disorders. The procedure was explained prior to participation and individuals received monetary compensation ($150) for their participation over two days. The study was approved by the institutional review board and all participants signed an informed consent before beginning the study.

2.1.2. Procedure

Participants used a wrist-worn actigraph and sleep diary to record their daily activity and sleep times three days prior to the laboratory measures. On the night before the first testing day, participants were instructed to go to bed between 11:30 PM and 1:00 AM and sleep for 8 h. Participants were called by a researcher at a prearranged time between 8:00 AM and 9:00 AM to ensure they were awake. Participants were to refrain from alcohol use the day before the first testing day. Participants reported to the campus laboratory and were transported to the off-campus laboratory by research assistants. Participants reported to the laboratory at 9:30 AM on the first day of the study, concluded the simulated work shift at 12:00 PM on the second day and left the laboratory at 1:30 PM (Table 1). Participants experienced approximately 28 h of sleep deprivation. Participants were tested in groups of four and were

Table 1
Study 1 timetable.

Day 1	
9:30 a.m.–10:30 a.m.	Arrival at off-campus lab
10:30 a.m.–11:30 a.m.	Training Session I
11:30 a.m.–2:15 p.m.	Lunch break
2:15 p.m.–4:15 p.m.	Training Session II
4:15 p.m.–4:45 p.m.	Break
4:45 p.m.–5:30 p.m.	Subjective measures (e.g., global sleep quality, mood)
5:30 p.m.–6:30 p.m.	Dinner break
6:30 p.m.–10:30 p.m.	Testing Session I and physiological measures
10:30 p.m.–11:00 p.m.	Break
11:00 p.m.–12:00 a.m.	Testing Session II and physiological measures
Day 2	
12:00 a.m.–3:00 a.m.	Testing Session II continued
3:00 a.m.–3:30 a.m.	Break
3:30 a.m.–7:30 a.m.	Testing Session III and physiological measures
7:30 a.m.–8:00 a.m.	Break
8:00 a.m.–12:00 p.m.	Testing Session IV and physiological measures
12:00 p.m.–12:30 p.m.	Lunch break
12:30 p.m.–1:30 p.m.	End-of-study activities
1:30 p.m.	Transport to residence