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Performance on a simple response time task: Is sleep or work more important for miners?

Sally A. Ferguson*, Gemma M. Paech, Jillian Dorrian, Gregory D. Roach, Sarah M. Jay

Centre for Sleep Research, University of South Australia, GPO Box 2471, Adelaide, SA 5001, Australia

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ABSTRACT

The purpose of the current study was to investigate the impact of work- and sleep-related factors on an objective measure of response time in a field setting. Thirty-five mining operators working 12-h shift patterns completed daily sleep and work diaries, wore activity monitors continuously and completed palm-based psychomotor vigilance tests (palmPVT) at the start and end of each shift. Linear mixed models were used to test the main effects on response time of roster, timing of test, sleep history and prior wake. The time at which the test occurred was a significant predictor of response time ($F_{3,403.4} = 6.72$, $p < .01$) with the end of night shifts being associated with significantly slower response times than the start of night shifts, and the start or end of day shifts. Further, the amount of sleep obtained in the 24 h prior to the test was also a significant predictor of response time ($F_{3,407.0} = 3.05$, $p < .01$). The results suggest that, as expected, the end of night shift is associated with changes in response time indicative of performance impairments. Of more interest however is that immediate sleep history was also predictive of changes in response time with lower amounts of prior sleep related to slower response times. The current data provides further evidence that sleep is a primary mediator of performance, independent of roster pattern.

1. Introduction

Shiftwork, particularly night work, is associated with an increased risk for incident and accident (Akerstedt, 1995; Dinges, 1995). Specific features of shiftwork patterns that are thought to contribute to increased risk include extended shifts, night work and consecutive shifts. For example, the risk of a fatal accident increases significantly beyond 9 h at work (Nachreiner et al., 2000), and accident risk after 12 h on shift is twice that seen after 8 h (Folkard and Tucker, 2003). Night shift, particularly the end of night shift, is also reported to be a high-risk time (Axelsson et al., 1998; Folkard and Tucker, 2003; Rosa and Bonnet, 1993) and is associated with a range of performance impairments (Folkard, 1997; Jay et al., 2006; Monk et al., 1997; Muller et al., 2008; Rollinson et al., 2003). Finally, the number of consecutive shifts worked is also a risk factor for accidents and incidents (Folkard and Tucker, 2003). Twelve-hour shift rosters, particularly those involving night shifts contain each of these elements – long hours, night work and strings of shifts.

A major advantage of 12-h shifts is that they compress the working week into fewer days, thus providing more rest days away from work. In addition, the rest days are often grouped together to provide blocks of time off. While extended blocks of days off are attractive for employees (Smith et al., 1998), there may be negative repercussions for performance and safety when the number of consecutive shifts is increased. The number and timing of rest days is an important component of the shift pattern, particularly in 12-h rosters (Tucker et al., 1999) and insufficient and/or infrequent recovery days may cause impairment due to cumulative sleep loss.

A 12-h break provides for approximately 6 h of sleep depending on the start time of the break (Roach et al., 2003). Current knowledge suggests that 6 h of sleep per night is a threshold below which performance becomes significantly impaired due to cumulative sleep restriction (Belenky et al., 2003; Van Dongen et al., 2003). Analysis of accident and error data confirm this hypothesis such that sleep loss associated with work hours is indeed predictive of impaired performance (Dorrian et al., 2004a,b, 2008; Lockley et al., 2004). Thus, in any investigation of work hours and waking function, sleep history is an essential component.

Each of the work factors discussed, long shifts, nights, and consecutive shifts, is associated with circadian misalignment, extended wakefulness, inadequate sleep, or a combination thereof. The current study therefore looked at the impact of both work- and sleep-related factors on an objective measure of performance in operators working different 12-h shift patterns. It was expected

* Corresponding author.
E-mail address: sally.ferguson@unisa.edu.au (S.A. Ferguson).

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that both work- and sleep-related factors would be associated with performance changes in this population and that roster type would mediate performance due to different distribution of rest days.

2. Methods

2.1. Participants

The study was conducted in two phases in 2005 and 2007. Initially, a total of 111 participants across four different roster patterns were recruited to the study – 54 in phase 1 and 57 in phase 2. Individual datasets were not included in the analysis if individuals did not complete all aspects of the data collection, if they worked a pattern significantly different to one of the main rosters (sick/annual leave, overtime etc) or if they withdrew from the study. The dataset used in the current analysis consisted of 35 individuals working three different rosters (Table 1). All employees were housed in the township situated approximately 15 min drive from the mine site. Ethics approval for the study was granted by the University of South Australia Human Research Ethics Committee using guidelines established by the National Health and Medical Research Council of Australia.

Three rosters were worked by participants:

4×4 – 4 day shifts, 4 days off, 4 night shifts, 4 days off (16 day cycle)
7×4 – 7 day shifts, 4 days off, 7 night shifts, 4 days off (22 day cycle)
14×7 – 7 day shifts, 7 night shifts, 7 days off (21 day cycle)

Shift start times were 0600 and 1800, and shift length was 12 h for all rosters. On the 14×7 roster, employees had a 24-h changeover period between finishing the final day shift and beginning the first night shift. Employees working the 14×7 roster were all fly-in/fly-out workers meaning that they flew into the area prior to their day shifts and flew out following their last night shift. They were accommodated in mine-owned 'single person's accommodation' in a barracks-style facility. Rooms had a bed, small desk, private bathroom and television. Employees on the 4×4 and 7×4 lived in the township, some with families.

2.2. Protocol

Individuals participated in data collection for one complete cycle of their respective roster (i.e. on both work and non-work days). They were required to collect sleep and wake information every day while work and performance measures were recorded only on work days.

2.2.1. Sleep diary

Participants completed a sleep diary for each sleep period during the data collection period (work and non-work days), including naps. Diaries recorded the start and end time of sleep periods, sleep quality using a 5-point scale and pre-sleep and post-sleep fatigue rating using a 7-point scale (Samn and Perelli, 1982). (NB. Sleep quality and fatigue ratings are not reported here.)

Table 1
Participant demographics taken from self-reported answers on a General Health Questionnaire.

Roster	Age	Body mass index (kg/m^2)	Years shiftwork	Years current position
4×4	38.3 ± 9.0	29.0 ± 4.6	8.1 ± 7.0	3.6 ± 6.1
7×4	46.3 ± 8.4	27.8 ± 3.9	19.9 ± 9.2	6.0 ± 7.6
14×7	43.2 ± 11.7	28.2 ± 4.0	11.8 ± 11.0	4.0 ± 6.5

2.2.2. Work diary

A work diary was used to collect information about actual work hours. Participants recorded the start and end times of work periods and pre- and post-shift fatigue ratings using a 7-point scale (Samn and Perelli, 1982). (NB. Fatigue ratings are not reported here.)

2.2.3. Activity monitor

Participants were required to wear an activity monitor (Actiwatch®, Philips Respironics, Bend, OR) for the entire period of data collection (both work and non-work days). Individuals removed the activity monitor temporarily if it was likely to get wet. The activity monitors recorded activity in 1-min epochs, and sensitivity was set at <40 counts per epoch to identify sleep and wake states. Sleep and work diary information was combined with the activity monitor record to determine sleep duration (total amount of sleep obtained during each sleep period), total time in bed and timing of bedtime and sleep period (Darwent et al., 2008).

2.2.4. Psychomotor vigilance task (PVT)

A 5-min palmPVT was used to objectively assess performance (Lamond et al., 2005; Thorne et al., 2005). Participants were issued with a personal palm pilot and completed a test at the start and end of each work shift. Participants were asked to find a quiet place to complete the test free from distraction, as close to the required time as possible. The mean reciprocal response time (RRT = 1/response time) was calculated for each test conducted for each individual. Consistent with standard methodology (Dorrian et al., 2004a,b), a reciprocal transformation was performed ($\times 1000$) on PVT responses time (RRT).

2.3. Analysis

Linear mixed model analysis was used to test the main effects on RRT of roster (4×4, 7×4 and 14×7), test time (start/day – morning test, start/night – evening test, end/day – evening test, end/night – morning test), sleep in the 24 h prior to shift start (<6 h, 6–7 h, 7–8 h and >8 h) and prior wake at the time of the test. All models specified subject ID as a random effect. An initial model included all predictors, such that the contribution of each predictor could be tested controlling for the others. In this model, prior wake at the time of the test was not significant ($F_{1,409.5} = 0.17$, $p = 0.68$) and was therefore removed from the model. This increased model fit (Akaike's Information Criterion was reduced from 417 to 411). The effect of roster was approaching significance ($F_{2,34.2} = 2.72$, $p = 0.08$), and removing this parameter decreased model fit. Therefore, the final model included roster, test time and sleep in the prior 24 h. Higher RRT equates to faster response times. Analyses were conducted using SPSS v16.0. Denominator degrees of freedom are adjusted by Satterthwaite Correction.

3. Results

3.1. Work-related factors

As illustrated in Fig. 1, the 7×4 roster was associated with lowest RRT scores (indicating highest performance impairment), followed by the 14×7, then the 4×4. Analyses indicated that these differences were not significant ($F_{2,34.1} = 2.69$, $p = 0.08$). There was a main effect of test time ($F_{3,402.6} = 8.25$, $p < .001$) on RRT. Pairwise comparisons indicated that RRT was significantly lower during tests conducted at the end of night shifts compared to any other shift/timing combination indicating poorer performance ($p < 0.01$) (Fig. 2). Mean RRT was not significantly different between tests that