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A field study of sleep and fatigue in a regular rotating 12-h shift system

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ABSTRACT

The aim of this study was to examine a regular rotating 12-h shift system (2D2N4Off) at an Australian Smelter. Sleep behavior, subjective fatigue and neurobehavioral performance were investigated over a 14-day period for 20 employees. Activity monitors, sleep/wake diaries, and 5-min psychomotor vigilance tasks were used. Sleep data showed differences between day and night shifts. While sleep prior to night1 was increased relative to day shifts, a reduced sleep length carried into the period leading to night2. Total wakefulness at the end of shift, and subjective fatigue were increased for night shifts, particularly night1. Decrements in performance data supported these findings. Both *prior wakefulness* and *prior sleep* are important in a 12-h shift system. Employees may "sleep in" after day shifts, rather than taking extra sleep prior to night work. Thus, sleep between day and night shifts is based on *recovery* rather than *preparation*.

1. Introduction

The effects of shiftwork have been extensively researched and reported. They include negative effects on social and domestic activities (Fischer et al., 1993) and long term effects on physical and psychophysiological health (Åkerstedt, 1990; Waterhouse et al., 1993). Also likely to be important is disruption to the sleep–wake cycle (Tepas and Mahan, 1989), leading to reductions in alertness and performance, which not only has immediate implications for occupational health and safety (Folkard, 1990; Åkerstedt, 1991), but is also often repeated many times, resulting in more chronic sleep loss, and therefore cumulative effects, with serious long term implications (Tepas and Mahan, 1989).

A key area of investigation in shiftwork research stems from the need to provide 24-h coverage in many modern industries. There are two main methods of achieving this. Typically, rostering systems comprise either 3 × 8-h shifts or 2 × 12-h shifts in each 24-h period. The 12-h system generates a compressed working week, which has been defined as "any system of fixed working hours more than eight hours in duration which results in a working week of less than five full days" (Tepas, 1985, p. 148). In particular, the medical and nuclear power industries have been at the centre of the investigation of these issues, although results have been complex and often conflicting (Smith et al., 1998; Williamson et al., 1994).

This compression of the working week has been found to be favorable for many employees as it leads to longer periods of time off, and therefore increased opportunity for social and domestic interaction and leisure time (Smith et al., 1998). Twelve-hour shifts have also been noted to lead to a reduction in total commuting time (Gillberg, 1998). Decreases in absence due to sickness, increases in productivity, and increases in satisfaction with work and rostering practices have also been reported (Wedderburn, 1996; Baker et al., 2003). The potential disadvantages of 12-h shift systems have also been examined: predominantly these are the increased potential for fatigue, reduced performance and increased accident risk (Johnston et al., 1989; Rosa, 1995). These disadvantages have been noted to be of particular importance for 12-h night shifts (Smith et al., 1998; Rosa, 1995), and toward the end of a 12-h shift (Rosa and Colligan, 1988; Ugrovics & Wright, 1990; Folkard, 1997), particularly when the job is monotonous or if it involves continuous heavy physical work (Tepas, 1985). Other studies have concluded that the first 12-h shift after a period of rest days is particularly susceptible to fatigue (Johnston et al., 1989). Few studies, however, have systematically investigated the effects of 12-h shifts on sleep and fatigue in the field, and in particular, the implications for effects on performance.

For shiftworkers, anecdotal and research evidence suggests that: (a) sleep is likely to be shortened prior to shifts starting in the early morning; and (b) individual strategies and social/environmental issues may cause sleep to be reduced or even omitted prior to night shifts – particularly where shifts alternate from day to night within a 24-h period (Roach et al., 2003).

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The mining and smelting industry employs workers who are responsible for a variety of work tasks, many of which are safety-critical – and involves working in environments with high temperatures, hazardous chemicals, molten metal and heavy machinery. Shift schedules for smelter employees in Australia typically involve 12-h shifts to achieve 24-h coverage using a regular rotating pattern. These schedules use several different rotations of day shifts (D), night shifts (N) and days off (O) to achieve coverage. Examples include 4×D, 4×O,4×N, 4×O; 7×D, 7×O, 7×N, 7×O; and DDNNOOOO. The focus of the current study was to evaluate sleep, fatigue and performance in smelter workers working a typical (DDNNOOOO), regular-rotating 12-h shift roster in order to determine the potential for disruption to the sleep–wake cycle, fatigue, reduced alertness and impaired performance as a result of extended work periods. This investigation formed part of a larger study to investigate several elements of 12-h shift schedules including the effects of workload and age on fatigue and performance (Baulk et al., 2007; Kandelaars et al., 2006).

2. Methods

2.1. Participants

Participants were 20 male shiftworkers, aged 28–59 years (mean = 40.89; SD = 9.63), with a mean body mass index (BMI) of 28.75 (SD = 3.7). They all worked at an Australian lead smelting plant, in several different types of job. On average, they had been involved with shiftwork for 13.4 (SD = 9.4) years, and consumed 3.84 (SD = 2.73) caffeinated drinks per day. Employees at the plant were informed of the proposed study by email and by poster, before being invited to information sessions to explain its purpose and protocol in full. Individuals interested in participating were asked to complete a general health questionnaire to screen for sleep disorders and other health problems. Thirty individuals volunteered for the study – eight were eliminated from the sample due to health problems and/or medications affecting sleep, or because they were on vacation during the proposed study period. Two volunteers also withdrew from the study on the first day due to personal reasons. The remaining 20 participants all gave informed consent and were not paid for taking part in the study other than their usual salary while at work. The study had approval from the Human Research Ethics Committee at the University of South Australia.

2.2. Work setting

Participants worked a regular rotating 12-h shift schedule consisting of two day shifts (D: 0700–1900 h); two night shifts (N: 1900–0700 h); and 4 days off (i.e.: 2D2N4Off). This 12-h rotating shift system had been in place at the plant for approximately 10 years. The types of work carried out were classified as being ‘control room operations’ or ‘general plant work.’ Control room operations involved tasks such as continuous monitoring, computer work, paperwork and data logging and a limited amount of general plant work when required. General plant work included tasks such as manual handling, furnace tapping, stripping metal sheets, operating machinery, and driving forklifts or bobcats. Many of the working areas at the plant were exposed to high temperatures and/or loud noise. Most areas were also exposed to lead, and all employees were regularly blood-tested to monitor this every 160-h of work (i.e. approximately once per month). All job types at the plant required employees to wear minimum personal protective equipment (PPE), consisting of full overalls, steel-capped boots, a hardhat and goggles. General plant work in high lead environments requires additional PPE such as gloves, visor, hood, and respirator.

2.3. Procedure

The study ran for a 14-day period, during which time all participants continued their regular, rostered work schedule, and went about their normal duties except to complete reaction time tests. All plant supervisors were fully aware of the study and were asked by the plant management to allow participants time for completing tests. All participants reported to the administration building at the beginning of their shift to complete the start-of-shift reaction time test and agree on suitable times for a test *during* the shift (dependent on work activity). Experimenters were contactable by telephone at all times during the study period.

2.4. Measures and data analysis

2.4.1. Subjective sleep duration and quality

Participants were asked to provide detailed information about their sleep for the duration of the study using a sleep diary. For each sleep period (including naps), they recorded date/time of sleep onset, final wake time and the number and length of awakenings during the sleep period.

2.4.2. Objective sleep duration

Objective assessments of subjects’ sleep–wake times were made using activity monitors and Actiware-sleep software (Cambridge Neurotechnology Ltd). Each activity monitor contained a piezo-electric accelerometer with a sensitivity of 0.05 g. The analog sensor sampled movement every 125 ms and the information was stored in 1-min intervals for analysis. Participants were required to wear the activity monitor on their wrist at all times for the duration of the study. Measures extracted from each activity monitor and sleep diary included (1) sleep length; and (2) sleep efficiency. These were also converted to parameters including sleep in the 24 h prior to start of shift; and total wakefulness at the end of shift (i.e. at the end of shift, how long each employee has been awake).

2.4.3. Subjective fatigue levels

Participants rated their level of fatigue before and after each shift using a work diary, which incorporated the 7-point Samn–Perelli Fatigue Scale (Samn and Perelli, 1982): 1 = fully alert, wide awake; 2 = very lively, responsive, but not at peak; 3 = okay, somewhat fresh; 4 = a little tired, less than fresh; 5 = moderately tired, let down; 6 = extremely tired, very difficult to concentrate; 7 = completely exhausted, unable to function effectively. Thus the measures used in data analysis were (a) start of shift fatigue; and (b) end of shift fatigue.

2.4.4. Neurobehavioral performance

A 5-min visual Psychomotor Vigilance Task (PVT192 – Dinges and Powell, 1985) was used to evaluate sustained attention at the beginning, mid-point and end of each shift. This test length was chosen over the standard 10-min test to reduce disruption to the working environment, and volunteers’ normal routines. As the PVT is reported to have a learning curve of 1–3 trials (Dinges et al., 1997), participants were required to complete three practice trials prior to the experimental period. During PVT testing, participants were seated in a room away from their individual work area, and an experimenter was present to supervise tests. The PVT measures reaction time (RT) and outputs several parameters to represent neurobehavioral performance. Parameters used in the analysis of reaction time data were (1) mean reaction time (RT); (2) response speed (1/RT); and (3) the number of LAPSES (i.e. responses > 500 ms).

2.5. Statistical analysis

All data were analyzed to identify significant outcomes using mixed model analyses in SPSS (version 11). Further analyses were completed on data from a single shift rotation (i.e. 2D2N) using repeated measures ANOVA. Post-hoc Tukey tests were used to determine the source of significant differences.

3. Results

Accounting for sick leave and shift changes during the study period, participants completed 418 5-min PVTs, from a possible 429 test opportunities (97.4%) at the start, middle and end of shifts (see Table 1). From a possible 286 workload evaluations, 276 were completed (96.5%). Participants completed 100% of subjective fatigue ratings in their daily sleep and work diaries. As indicated, compliance was very high, and missed tests were usually due to working in remote areas of the plant, or using machinery which made breaks difficult.

3.1. Sleep data

Fig. 1a shows the average amount of sleep obtained in the 24 h prior to work shifts. Less sleep is generally obtained on the second shift of each type (days, nights). In general, participants obtained at least 5 h sleep before each work shift. However, it is important to note that less sleep was obtained prior to the second night shift. This result was strengthened using mixed model analyses to examine the effect of shift type on sleep. This showed a significant effect (df: 3, 108; $F = 6.93$; $P < 0.001$).

Fig. 1b shows the total wake time at the end of shift, across the rotating 12-h shift cycle. This graph clearly shows a trend for wakefulness to be extended as a result of the night shifts, in particular for the first night shift in the cycle where wakefulness was approaching 20 h.

3.2. Subjective fatigue

Subjective fatigue ratings were compared across the shift schedule and the mean ratings are shown in Fig. 2a. A paired samples *t*-test showed that post-shift fatigue levels were significantly higher than pre-shift ratings ($t = -11.056$, df = 67, $P < 0.001$). While fatigue levels reached during day shifts were mild to moderate (between 3, "okay, somewhat fresh", and 5, "moderately tired, let down") the night shifts led to higher levels, particularly toward the end of shift, where the mean subjective fatigue rating is >5 on the Samn–Perelli scale. It is also clear to see that the change in subjective fatigue, as a result of the 12-h work shift, is affected significantly by the shift number (see Fig. 2b). There was a significant effect of shift, as tested by mixed model analysis ($F = 6.756$; $P = 0.001$).

3.3. Neurobehavioral performance

PVT data are shown in Fig. 3, plotted for the Start, Middle and End of shift tests. There was a significant effect of shift number on response speed ($F = 7.966$; $P = 0.001$, see Fig. 3b), with performance being worse during the night shifts. There was also a significant effect of trial number ($F = 16.217$; $P = <0.001$) most notably causing reductions in performance across the first of the two night shifts. Mean LAPSES were also examined across this shift schedule, and are shown in Fig. 3c. There were no significant outcomes, although the effect of shift number was approaching significance using mixed model analysis ($F = 2.228$; $P = 0.072$). In particular, lapses were most prevalent at the end of the second night shift.

Table 1
Mean times (Standard deviation in minutes) of PVT testing at Start, Middle and End of shifts.

	Day	Night
START	0630 h (47 min)	1818 h (49 min)
MIDDLE	1219 h (66 min)	2347 h (25 min)
END	1811 h (38 min)	0611 h (36 min)

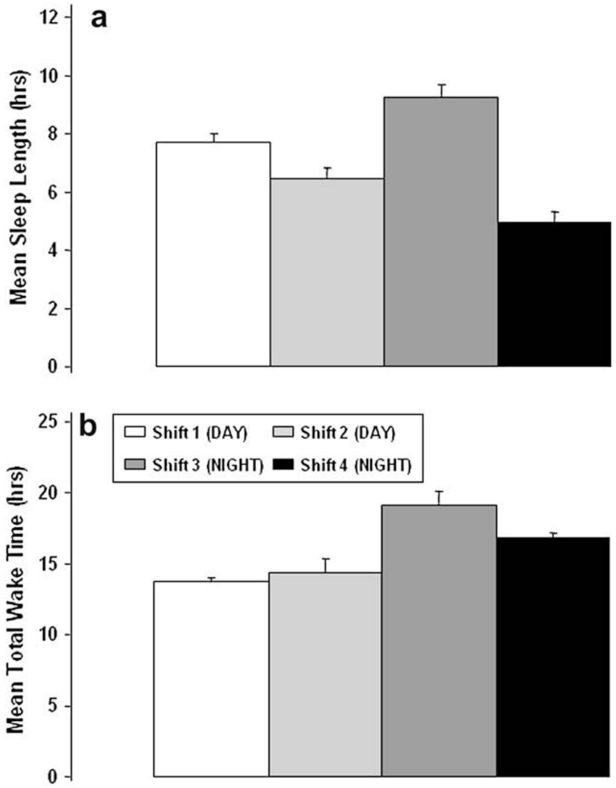

Fig. 1. (a) Mean Sleep Length (±SEM) in Previous 24 h across shift cycle (DDNNOOOO). (b) Mean Total Wake Time (±SEM) at END of shift across shift cycle (DDNN).

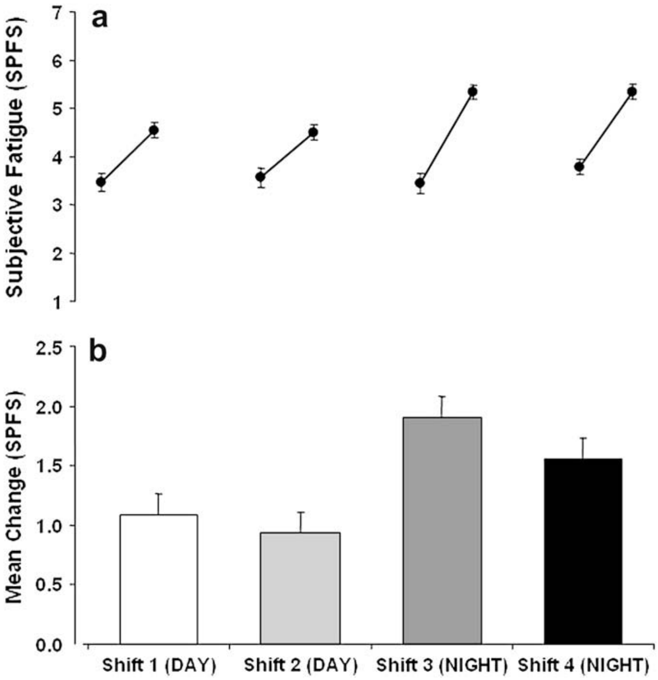

Fig. 2. (a) Mean Subjective Fatigue Ratings (±SEM) at START and END of shift across shift cycle. (b) Mean Change in Subjective Fatigue (±SEM) from START to END of shift across cycle.

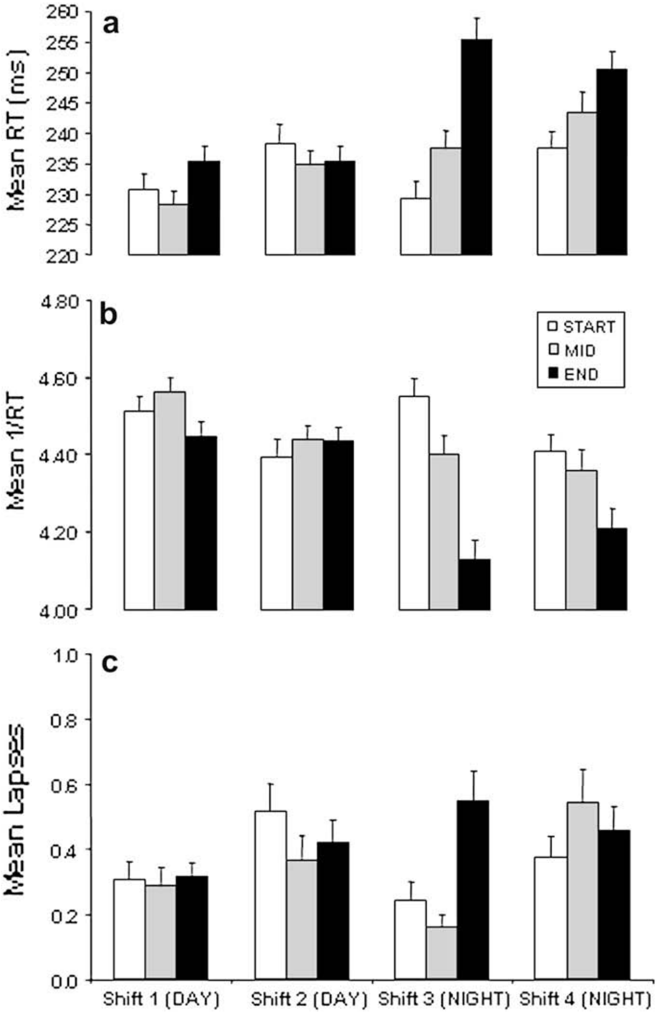

Fig. 3. Mean PVT data (±SEM) at START, MIDDLE and END of shift across shift cycle, for (a) Mean reaction time (RT); (b) Response Speed (1/RT); and (c) LAPSES ($RT > 500$ ms).

4. Discussion

Participants' sleep varied as a function of the shift cycle. In particular, the first night shift showed adequate sleep in the previous 24 h, and sleep actually *increased* relative to the day shifts. However, the 24 h prior to the second night shift demonstrated *reduced* sleep. In addition, the total amount of wakefulness accumulated by the end of shift was increased as a result of both night shifts, although the first night shift was particularly affected. Participants' sleep strategies may account for these differences. A logical strategy might be to take an extra, *preparatory* sleep, or "nap" prior to the night shift at some point during the afternoon or early evening preceding it. Sleep propensity curves indicated that almost 50% of the sample population chose to do this, while other participants used an alternative strategy (only sleeping later following the day shift), leading to extended wakefulness following the first night shift. Thus, between day and night shifts, sleep was generally both *recovery* and *preparatory* in nature, but the time of day limited preparatory sleep.

Subjective fatigue data demonstrated no significant difference in pre-shift ratings across the shift cycle. However, the 12-h shifts led to significantly higher post-shift ratings of fatigue. In addition, the day and night shifts were clearly distinguishable. In particular, the first of the two night shifts caused the most marked increase in subjective fatigue. PVT data showed that the day shifts did not cause significant impairment. In contrast, the night shifts demonstrated a marked decline in performance as measured by response speed across the shift, and this was particularly clear for the first night shift, with the last portion of the shift showing a different trend to the second shift (i.e. a steeper decline in performance). In addition, lapses were clearly evident during portions of the first night shift. While lapses were reduced at the start and mid-point of the shift, these were much higher at the end of shift. This is not surprising, since prior sleep was high for this shift, and therefore participants were able to maintain performance at the beginning. However, performance decreases sharply across the last half of this 12-h shift. On the basis of research demonstrating performance deterioration with time-on-task, it was hypothesized that a steady decline in PVT performance across each shift would occur. While this was clearly the case for the night shifts, there was no such obvious decline present during day shifts. It is important to note that this study used 5-min PVTs, rather than the standard 10-min version. Although the reduced length has been shown to affect results, it has also been noted that the 5-min test is a reasonable alternative in time-constrained experimental scenarios (Loh et al., 2004).

Also important to note is the fact that the amount of time off created by a 12-h system allows time for employees to take on a second job (Smith et al., 1998). This may be a significant factor, and was not measured in the current study. For example, one study concluded that 25% of 12-h shiftworkers were "moonlighting" (Colligan and Tepas, 1986). We are currently investigating methods of collecting this information in future protocols.

Clearly, there is a trend for night shifts to be more fatiguing. This is to be expected given that research has demonstrated the adverse effects of both night- and early-morning shifts (Axelsson et al., 1998). It is also important to note is the fact that the first night shift (and to a lesser extent, the first day shift) is rated higher than the second. There is also evidence from other studies to show that fatigue is higher during the first shift following a group of rest days, and during the first night shift (Sallinen et al., 2003). Looking at fatigue levels seen here, there is potential for some increases in risk if additional shifts or overtime is added. The trend for changes in sleep, subjective fatigue and performance data indicates a difference between the first and second night shifts. This may indicate that total wake time interacts with these measures differently to sleep length. It is important that 12-h shift schedules are appropriately managed with regards to fatigue. In particular, closer attention may be required in terms of continuous work hours or overtime, and for fitness for duty policies. A key issue with 12-h shift systems and the potential for increased fatigue and reduced alertness is the regulation of overtime (Gould, 1989). This should be systematically regulated and tracked in order to avoid further extension of wakefulness wherever possible (or so that additional safeguards can be used if wakefulness is extended beyond acceptable limits). Most regulated systems specify that no longer than 4 h of additional work be added to any 12-h shift, and also that a minimum period of 8–10 h rest break be taken following any period of extended work. It is also important to note that given the extended wakefulness which may be associated with 12-h shifts, there should also be some regulation of travelling/commuting, which may additionally impact upon wakefulness, but more importantly acknowledge the increased accident risk associated with these long commutes. This has been recommended not to exceed a total of 3 h per workday (Gould, 1989). However, operational requirements must also be considered.

This study has demonstrated that managing fatigue is a responsibility which falls to both employers and employees. While hours of work must be scheduled to allow adequate recovery between shifts, employers must also educate on work-related risk, including fatigue. They must use risk assessments and analyses of potential hazards to investigate tasks and conditions which may negatively interact with fatigue. In turn, employees have a responsibility to use their non-work time to get adequate rest and recovery, and to report hazards which have the potential to expose themselves or others to fatigue or other risks.

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