The impact of returning to a daytime schedule on sleep, performance and mood after simulated fixed and rotating split shift schedules

Centofanti S, Short M, Hilditch CJ, Dorrian J, Kohler M, Banks S
The impact of returning to a daytime schedule on sleep, performance and mood after simulated fixed and rotating split shift schedules

Centofanti S, Short M, Hilditch CJ, Dorrian J, Kohler M, Banks S

a Centre for Sleep Research, School of Psychology, Social Work and Social Policy, University of South Australia
b School of Psychology, Flinders University

Students involved at the time of data collection:
Centofanti S, Hilditch CJ – PhD Student, University of South Australia

ABSTRACT

Split shift schedules which minimise consecutive hours awake and maintain adequate total sleep time per 24h may be a suitable alternative to long shifts. However, when returning to a daytime schedule (RTDS), performance and sleep deficits may occur as a result of changing the timing of sleep and wake periods. The first aim of the current study was to check whether fixed and rotating split shift schedules with 20h time in bed (TIB) per 48h minimised cumulative deficits in sleep, performance and mood. The second aim was to investigate whether RTDS following these shift schedules had a negative impact on sleep, performance and mood. Twenty-four participants (10M, 21-36y) completed a 9-day laboratory study with two 10h baseline sleeps (22:00h-08:00h); one of three shift conditions for four 24h periods: one of two 6h on / 6h off schedules, (Fixed A: 5h TIB at 03:00h/15:00h, or Fixed B: 5h TIB at 09:00h/21:00h), or an 8h on / 8h off schedule (Rotating: 6h40 TIB); and RTDS with 10h TIB for 2-nights (22:00h-08:00h). Psychomotor vigilance was stable throughout the shift schedule period. Subjective sleepiness \((p<0.001)\), positive affect \((p<0.01)\) and negative affect \((p<0.001)\) were all significantly worse by the second 48h shift schedule period SS2 compared to Baseline (BL). Amount of Stage R sleep was significantly lower by SS2 compared to BL. Subjective sleepiness and positive affect returned to BL levels upon RTDS. Negative affect was significantly higher than BL upon RTDS \((p<0.001)\). Stage R sleep was not significantly different to BL upon RTDS, however amount of N3 sleep upon RTDS was significantly reduced compared to BL in the Fixed B condition. For all conditions, sleep onset latency, N2 onset latency and N3 onset latency were significantly longer during RTDS compared to baseline \((p<0.05)\). Consistent with previous literature, split shift schedules did not result in cumulative impairments to sleep and performance. However, findings suggest that workers may still experience sleepiness and worsened mood. Switching back to a daytime schedule may also result in delays in falling asleep and also deep sleep.

KEYWORDS: cognitive performance; mood; recovery; shift work; split shifts

*Corresponding author: stephanie.centofanti@unisa.edu.au
1 INTRODUCTION

Due to growing demands for round-the-clock services, working hours outside of the standard working week are becoming increasingly common, with approximately 1.5 million Australians engaging in shift work (1). Most types of shift work involving night work or long work hours lead to excessive sleepiness and reduced alertness (2, 3). These factors contribute to reduced physical and psychological wellbeing, lower productivity, and increased risk for accidents (2-5).

Adverse outcomes are mainly a result of circadian misalignment and sleep loss associated with shift work and extended time-on-shift (6). When shift workers are required to work long, overnight shifts, a discord between the sleep-wake schedule and internal circadian rhythm occurs (7). Sleep quantity and quality is substantially reduced during shift workers’ off-duty period, especially when this occurs during the day, due to an increased circadian drive for wake (8). Sleep restriction can occur as a result, causing cumulative decreases in alertness and performance during periods of wake, particularly at night (9). The culmination of homeostatic sleep pressure and the circadian nadir in the early hours of the morning can lead to increased sleepiness and reduced alertness whilst on-shift (10). This is a concern for safety-critical work that occurs over 24h, such as emergency services and healthcare industries. Furthermore, the body is exposed to chronic stress whilst attempting to adjust to new working hours and changing back to regular sleep-wake hours (11), such that sleep and performance may be impaired in the days following a period of shift work.

A number of industries utilise split shift schedules, including transport, maritime and healthcare industries. A benefit of split shift schedules is more frequent sleep opportunities, which should result in a reduction to number of hours awake, and consequently, reduced sleep pressure. Split shift schedules also allow for more nocturnal sleep opportunities compared to long, overnight shifts such as those in 12h on / 12h off shift schedules. Split shift schedules may have start times that are fixed (i.e. the same start times each day such as in 6h on / 6h off shift schedules), or rotating (i.e. start times that rotate over days such as in 8h on / 8h off shift schedules). Several field studies have investigated performance and sleep during split shift schedules (12-18). The majority of studies have found that shifts with 4h on / 8h off schedules appear to be superior in terms of reducing sleepiness, fatigue and performance decrements compared to 6h on / 6h off and 8h on / 8h off shift schedules (19). However, this shift schedule requires increased staff numbers and results in more shift handovers, and therefore may be unviable in some industries. Overall, studies regarding sleep and performance in split shift schedules utilising two crews of workers (such as 6h on / 6h off and 8h on / 8h off) focus on the maritime industry, consist mostly of male samples and lack objective sleep and performance measures. There is also a paucity of information regarding how sleep and performance recover when switching back to a day schedule following a period of split shifts.

This is important to investigate, as there is some evidence to suggest that a recovery period of sleep following a period of shift work can be detrimental rather than beneficial. Van Dongen, Belenky, and Vila (20) assessed psychomotor vigilance performance following a 34h recovery period, which included a total of 20h time-in-bed (TIB), between two cycles of simulated day or night duty. Performance following recovery stabilised in the day duty condition, but continued to decline in the night duty condition. This could be due to those in the night duty condition accumulating deficits that were not recoverable during the limited recovery period, and/or due to experiencing difficulties adapting back to a day schedule, resulting in a reduced ability to utilise the recovery period.

A recent study by Jackson, Banks, and Belenky (21) found differing results in terms of recovery when comparing long shifts (either in the night or the day time) with split shift schedules. Firstly, night-time sleep and split sleep conditions had significantly more total sleep time (TST) than those in the daytime sleep condition during the experimental period. When switching back to a night-time sleep schedule, the split sleep condition had significantly increased TST compared to the daytime sleep condition. This suggests that participants in the daytime sleep condition had more difficulty switching back to a night-sleep schedule. Split shift schedules may therefore be preferable to daytime sleep schedules in terms of ability to utilise a nocturnal sleep opportunity as recovery. Further, it may be that in split shift schedules, where a portion of the sleep is during the biological night, minimal circadian adaptation (or phase change) is likely to occur while on the schedule, resulting in better sleep when switching back to a night-time sleep schedule. Similar arguments have been made for fast-rotating shifts, which, in avoiding circadian adaptation, may result in better recovery on days off (22).
Figure 1. Protocol schematics with 24h time across the x-axes. Black bars represent sleep opportunities. Grey bars represent wake time, and boxed grey bars represent on-shift periods. Unshaded crosses represent practice neurobehavioural test bouts and shaded crosses represent analysed neurobehavioural test bouts. All conditions undertook two baseline nights with 10h TIB sleep opportunities, four 24h periods on a Fixed A, Fixed B or Rotating shift schedule with 20h TIB per 48h, and two days back on a day schedule with 10h TIB ‘recovery sleep’ opportunities.
However, it should be noted that shift workers may show no circadian adaptation even on a fixed 12h on / 12h off schedule with consolidated daytime sleep opportunities for several days (23). Importantly, simply altering sleep time by as little as one hour can have flow-on effects for performance. On the day following the switch to Daylight Saving Time in which one hour is lost, workers have been found to sleep 40 minutes less than on other days, and sustain more workplace injuries (24). Therefore, understanding whether, in the absence of any expected circadian adaptation, changes in sleep timing may result in impaired recovery is important when evaluating split shift schedules. Unfortunately, the Jackson et al. study (21) described above did not report performance and mood data during recovery days, and therefore the effect of switching back to a day schedule remains unknown.

Since research suggests that split sleep-wake opportunities provide comparable benefits for performance to a consolidated sleep if TST per 24h is maintained (25, 26), split sleep may not cause sleep loss during a split shift roster. That is, in split shift schedules that are designed to maintain 24h TST, deficits may not accumulate during the shift period. Given that changes in the timing of sleep per se can result in impairment, it is still not clear whether, even under these conditions, impairment may be seen during return to daytime schedules following the roster period. The implication for shift workers is that if recovery is not achieved before a subsequent period of shift work begins, an accumulation of deficits can exacerbate safety risks. Therefore, the current study aimed to investigate whether (a) fixed and rotating split shift schedules with 20h time in bed (TIB) per 48h minimised cumulative deficits in sleep, performance and mood; and (b) returning to a daytime schedule following these shift schedules had a negative impact on sleep, performance and mood.

### MATERIALS AND METHODS

#### 2.1 ETHICS STATEMENT

Ethics approval for the study was granted by the University of South Australia Human Research Ethics Committee. Participants provided written informed consent prior to commencement of the laboratory study and were paid an honorarium for their time.

#### 2.2 PARTICIPANTS

Twenty-four healthy adult participants (10M, aged 21-36y, mean body mass index 23.9 ±SD 3.1) participated in the study. Participants were required to be of sound physical and mental health and reported no habitual napping, insomnia, daytime sleepiness, or other sleep disturbances (confirmed by self-report measures). All participants were non-smokers and did not engage in shift work, transmeridian travel, excessive caffeine or alcohol consumption (>2 caffeinated beverages or >2 standard drinks of alcohol per day) for the two months prior to the study. Screening measures included the Composite Scale of Morningness-Eveningness (intermediate types included) (27) and the Pittsburgh Sleep Quality Index (scores <5 included) (28). Urine tests and blood tests were undertaken to screen for illicit substance use and health abnormalities respectively, and current medication use (except for oral contraception) was not allowed. In the week prior to the study, participants were required to have a bedtime before midnight and rise time before 09:00h. They were not allowed to nap, or consume

---

**Table 1. Linear mixed model analyses for sleep variables summed into 48h periods (BL, SS1, SS2, RTDS).**

<table>
<thead>
<tr>
<th>Variable</th>
<th>F-value</th>
<th>df</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>TST (Hours)</td>
<td>3.20</td>
<td>2, 20</td>
<td>0.062</td>
</tr>
<tr>
<td>Condition</td>
<td>37.02</td>
<td>3, 60</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>Condition x 48h Period</td>
<td>2.75</td>
<td>6, 60</td>
<td>0.020*</td>
</tr>
<tr>
<td>WASO (Mins)</td>
<td>5.97</td>
<td>2, 20</td>
<td>0.009*</td>
</tr>
<tr>
<td>Condition</td>
<td>31.27</td>
<td>3, 60</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>Condition x 48h Period</td>
<td>2.49</td>
<td>6, 60</td>
<td>0.032*</td>
</tr>
<tr>
<td>Sleep Efficiency (%)</td>
<td>3.51</td>
<td>2, 20</td>
<td>0.049*</td>
</tr>
<tr>
<td>Condition</td>
<td>38.94</td>
<td>3, 60</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>Condition x 48h Period</td>
<td>2.49</td>
<td>6, 60</td>
<td>0.032*</td>
</tr>
<tr>
<td>N1 (Mins)</td>
<td>0.19</td>
<td>2, 20</td>
<td>0.832</td>
</tr>
<tr>
<td>Condition</td>
<td>0.39</td>
<td>3, 60</td>
<td>0.764</td>
</tr>
<tr>
<td>Condition x 48h Period</td>
<td>1.28</td>
<td>6, 60</td>
<td>0.278</td>
</tr>
<tr>
<td>N2 (Mins)</td>
<td>5.86</td>
<td>2, 20</td>
<td>0.010*</td>
</tr>
<tr>
<td>Condition</td>
<td>34.38</td>
<td>3, 60</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>Condition x 48h Period</td>
<td>2.49</td>
<td>6, 60</td>
<td>0.032*</td>
</tr>
<tr>
<td>N3 (Mins)</td>
<td>0.23</td>
<td>2, 20</td>
<td>0.795</td>
</tr>
<tr>
<td>Condition</td>
<td>5.29</td>
<td>3, 60</td>
<td>0.003*</td>
</tr>
<tr>
<td>Condition x 48h Period</td>
<td>4.01</td>
<td>6, 60</td>
<td>0.002*</td>
</tr>
<tr>
<td>Stage R (Mins)</td>
<td>0.06</td>
<td>2, 20</td>
<td>0.936</td>
</tr>
<tr>
<td>Condition</td>
<td>31.47</td>
<td>3, 60</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>Condition x 48h Period</td>
<td>0.34</td>
<td>6, 60</td>
<td>0.913</td>
</tr>
</tbody>
</table>

*p<0.05
Figure 2. Mean ± SEM per 48-hour period for sleep variables – total sleep time (TST), wake after sleep onset (WASO), sleep efficiency (SE), N1, N2, N3 and rapid eye movement (R). Grey bars display the Fixed A group, white bars display Fixed B and black bars are the Rotating group. Asterisks represent statistically significant differences between conditions, and asterisks with brackets represent statistically significant differences between 48-hour periods to BL and/or RTDS (p<0.05).
alcohol or caffeine. Sleep diaries and actigraphy were used to ensure proper sleep times were adhered to. There were no differences between conditions in total sleep time in the week prior to the study. At the commencement of the study, participants were randomly assigned to one of three conditions: a ‘Rotating’ shift schedule (N=8, 26.6y ± 5.4); a ‘Fixed A’ shift schedule (N=8, 24.5y ± 4.2); or a ‘Fixed B’ shift schedule (N=8, 27.8y ± 4.3) (Figure 1).

The Rotating condition undertook approximately four days (four 24h periods) on a rotating split shift schedule. Wake periods were 9h20 in length, and sleep opportunities were 6h40. Shortened sleep periods were implemented for two reasons. Firstly, to reflect real-world shift work scenarios, where part of each rest period during an 8h on / 8h off split shift schedule would be used for activities other than sleep, and secondly, to allow for comparable TIB per 48h across study days and conditions. The Fixed A condition undertook approximately four days (four 24h periods) on a fixed split shift schedule, with sleep opportunities at 03:00h and 15:00h each day. Wake periods were 7h in length, and sleep opportunities were 5h in length. The Fixed B condition undertook approximately four days (four 24h periods) on a fixed split shift schedule, with sleep opportunities at 09:00h and 21:00h each day (opposite rotation to Fixed A). Wake periods were 7h in length, and sleep opportunities were 5h in length.

The laboratory environment was free of natural light, with artificial lighting set at <50 lux during wake

Figure 3. Mean ± SEM for sleep latencies during baseline and return to daytime schedule (RTDS) 48h periods – sleep onset latency (SOL), N2, N3 and rapid eye movement (R) latencies. Grey bars display the Fixed A group, white bars display Fixed B and black bars are the Rotating group. Asterisks represent statistically significant differences between conditions, and asterisks with brackets represent statistically significant differences between 48-hour periods to BL and/or RTDS (p<0.05).
periods. The laboratory was temperature (22±1°C) and sound controlled. Showers and calorie-controlled meals were provided at set times. Breakfast, lunch and dinner were provided at 09:30h, 13:30h and 19:00h in each condition, with at least 30min before neurobehavioural testing occurred. When not engaged in testing, participants were permitted to read, watch movies or socialise in a communal living area. Use of backlit devices such as laptops was not permitted, and mobile phone use was restricted to 10min per day (no internet use). Mobile phones were made available at 10:00h in the Fixed A condition and 16:00h in the Fixed B condition. In the Rotating condition, phones were available at 10:00h or 20:00h depending on the scheduled wake times. Phone usage occurred at least one hour prior to neurobehavioural testing and at least 4.5h before any sleep periods commenced.

One hour prior to bedtime, participants were prepared for polysomnographic recording of sleep. Approximately every two hours during wake periods, participants completed a computer-based neurobehavioural test bout, which included a 10min psychomotor vigilance task (PVT), the Karolinska Sleepiness Scale (KSS), and the Positive and Negative Affect Scale (PANAS).

### 2.4 MEASURES

#### 2.4.1 SLEEP

Sleep was measured using polysomnography (PSG) during all sleep periods. PSG recordings were made using the Compumedics Grael Sleep System, and Compumedics Profusion PSG 3 Software (Melbourne, Australia). Placement of electrodes was according to the 10/20 system of electrode placement (29). The PSG montage included placements C3/A2, C4/A1, F3/A2, F4/A1, O1/A2, bilateral electrooculogram (EOG), electromyogram (EMG), and electrocardiogram (ECG). Sleep data were analysed and scored by a trained sleep technician who was blinded to the study aims in 30-second epochs in accordance with the criteria of the American Academy of Sleep Medicine (30).

Measures derived from PSG were total sleep time (TST; total amount of sleep within a scheduled sleep episode), sleep onset latency (SOL; third consecutive 30-second epoch of Stage 1 or first epoch of any higher stage), wake after sleep onset (WASO), sleep efficiency (TST divided by actual TIB), sleep stages (N1, N2, N3, and rapid eye movement [Stage R] sleep, expressed in minutes), and stage latencies (first epoch following sleep onset of N2, N3, or Stage R).

#### 2.4.2 NEUROBEHAVIOURAL TEST BOUT

##### 2.4.2.1 PERFORMANCE

A 10min PVT was used to measure sustained attention and response speed. The PVT is a standard test of vigilance used to assess fatigue (31). Participants were asked to attend to a small square on a computer screen and to respond as quickly as possible by pressing a button with their dominant thumb as soon as the stimulus, a number in milliseconds, appears. Interstimulus intervals varied from 2 to 10 seconds. PVT lapses and median response speed were used to measure sustained attention. Lapses were defined as the number of reaction times per 10min task that were greater than 500 milliseconds.

##### 2.4.2.2 SUBJECTIVE SLEEPINESS

Subjective sleepiness was measured using the KSS (32). This scale has been found to significantly correlate with polysomnographic, behavioural and subjective indicators of sleepiness (33). The KSS consists of the question, ‘How do you feel at the moment?’ and nine response options ranging from 1- ‘Extremely alert’ to 9- ‘Very sleepy, great effort to stay awake, fighting sleep’.

##### 2.4.2.3 MOOD

Mood was measured using the PANAS, which is a 20-item measure of subjective mood (34). Participants were asked to rate the extent to which they were experiencing each particular emotion at that moment, with reference to a 5-point scale, from 1- ‘Very slightly or not at all’, to- 5 ‘Very much’. The PANAS has been found to be a reliable and valid measure of affect in non-clinical samples (34, 35). The PANAS provides outcomes for two separate domains- Positive Affect and Negative Affect (min score = 10, max score = 50), which have been shown to be independent to one another (36).

#### 2.5 STATISTICAL ANALYSIS

Analyses were performed using SPSS Statistics Version 21.0 (IBM Corp., Armonk, NY, USA). A difficulty with comparing the three shift schedules was that they vary in regard to timing of sleep opportunities during shift schedule days. A strength of the current study design was that there was a consistent total opportunity for sleep of 20h per 48h period throughout the baseline, shift schedule, and RTDS phases. In order
to compare variables across the three shift schedules during shift schedule days and upon return to a daytime schedule (RTDS) sleep and performance variables were analysed in 48h periods (48h baseline period [BL], 48h shift schedule period 1 [SS1], 48h shift schedule period 2 [SS2], and 48h period on RTDS). Although the shift schedule was designed to minimise cumulative sleep and performance deficits, splitting the shift schedule period into two 48 hour periods allowed for observation of any differences between the first and second halves of the shift schedule period. This analysis provides an overview of the cumulative cost of rotating and split shift schedules rather than specific time of day effects, as the main focus of this paper was to investigate RTDS under conditions where accumulation of sleep and performance deficits during the shift work period was minimised. Time of day effects during shift schedule days in the Fixed A, Fixed B and Rotating shift schedules will be reported elsewhere. N=22 complete performance datasets (N=2 lost due to technical difficulties) and N=23 complete sleep datasets (N=1 lost due to technical difficulties) were analysed. Whole numbers are reported for degrees of freedom, and F values are rounded to two decimal places. Post-hoc pairwise comparisons are described where significant interaction effects were found.

TST, WASO and sleep stages for each sleep period were totalled into 48h study periods, and sleep efficiency was averaged into 48h study periods. Linear mixed model ANOVAs were conducted to test the effects of shift conditions (Fixed A, Fixed B, Rotating) and 48h study period (BL, SS1, SS2, RTDS) on these sleep variables.

Due to a differing number of sleep onset opportunities across the shift schedule days, SOL and sleep stage latency data were examined in BL and RTDS only, as sleep timing was consistent across BL and RTDS days for each condition. Linear mixed model ANOVAs were conducted to test the effects of shift conditions (Fixed A, Fixed B, Rotating) and 48h study period (BL, RTDS)
on sleep stage latencies.

PVT lapses and median response time, KSS, and PANAS variables were averaged into 48h study periods. Linear mixed model ANOVAs were conducted to test the effects of shift conditions (Fixed A, Fixed B, Rotating) and 48h study period (BL, SS1, SS2, RTDS) on these variables. Statistical significance was determined at p<0.05.

3 RESULTS

3.1 SLEEP ACROSS THE WHOLE STUDY PERIOD

For TST, no significant main effect of condition was found (p>0.05; Table 1; Fig 2). There was a significant main effect of 48h period (p<0.001), and a significant condition*48h period interaction (p<0.05), such that the Fixed B condition had significantly higher TST during SS1 compared to Fixed A and Rotating conditions.

For WASO, significant main effects were found for condition (p<0.01) and 48h period (p<0.001). There was a significant condition x 48h period interaction (p<0.05), such that the Fixed B condition also had significantly less WASO than the Fixed A and Rotating conditions during SS1, and compared to the Rotating condition during SS2 (Table 1; Figure 2).

For sleep efficiency and N2 sleep, there were significant effects of condition (p<0.05), 48h period (p<0.001) and their interaction (p<0.05), such that the Fixed B condition had significantly higher sleep efficiency and more N2 sleep during SS1 compared to Fixed A and Rotating conditions. The Rotating condition had significantly lower sleep efficiency than the Fixed A and Fixed B conditions at BL (p<0.05), and significantly less N2 sleep than the Fixed A and Fixed B conditions in SS2 (p<0.05; Table 1; Figure 2).

No significant main effect of condition was found for Stage R sleep. A significant main effect of 48h period was found (p<0.001), such that Stage R sleep was significantly lower in SS1 and SS2 compared to BL and RTDS (Table 1; Figure 2).

During RTDS, the only observed difference was in N3 sleep. No significant main effect of condition was found for N3 sleep. However, there was a significant main effect of 48h period (p<0.01), and a significant condition x 48h period interaction (p<0.01), revealing that the Fixed B condition had significantly less N3 sleep during RTDS than the Fixed A and Rotating conditions compared to during BL, SS1 and SS2 (p<0.01). No significant differences were observed in N1 sleep (Table 1; Figure 2).

3.2 SLEEP ONSET DURING BASELINE AND RECOVERY (EQUIVALENT SLEEP OPPORTUNITIES)

There were no significant main effects of condition for SOL, N2 latency, N3 latency, or Stage R latency. Significant main effects of 48h period were found for SOL (p<0.05), N2 latency (p<0.05), and N3 latency, such that all were significantly longer during RTDS compared to BL. No differences were observed in Stage R latency (Table 2; Figure 3).

3.3 WAKING FUNCTION

For PVT lapses and median response time, there were no significant main effects of condition, 48h period or their interaction (Table 3; Figure 4).

No significant main effect of condition was found for subjective sleepiness. A significant main effect of 48h period was found (p<0.001), such that all conditions had significantly higher subjective sleepiness during SS1 and SS2 compared to BL and RTDS (p<0.001) (Table 3; Figure 4).

A significant main effect of condition was found for positive affect (p<0.01), such that the Rotating condition had significantly lower positive affect than the Fixed A and Fixed B conditions. A main effect of

Table 2. Linear mixed model analyses for sleep onset latencies averaged into 48h periods for time-matched sleep opportunities (BL, RTDS).

<table>
<thead>
<tr>
<th>Sleep Onset Latency</th>
<th>F-value</th>
<th>df</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Condition</td>
<td>1.88</td>
<td>2, 20</td>
<td>0.179</td>
</tr>
<tr>
<td>48h Period</td>
<td>7.45</td>
<td>1, 20</td>
<td>0.013*</td>
</tr>
<tr>
<td>Condition x 48h Period</td>
<td>1.65</td>
<td>2, 20</td>
<td>0.217</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sleep Onset Latency</th>
<th>F-value</th>
<th>df</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Condition</td>
<td>1.85</td>
<td>2, 20</td>
<td>0.184</td>
</tr>
<tr>
<td>48h Period</td>
<td>7.59</td>
<td>1, 20</td>
<td>0.013*</td>
</tr>
<tr>
<td>Condition x 48h Period</td>
<td>2.13</td>
<td>2, 20</td>
<td>0.145</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sleep Onset Latency</th>
<th>F-value</th>
<th>df</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Condition</td>
<td>1.24</td>
<td>2, 20</td>
<td>0.310</td>
</tr>
<tr>
<td>48h Period</td>
<td>5.08</td>
<td>1, 20</td>
<td>0.036*</td>
</tr>
<tr>
<td>Condition x 48h Period</td>
<td>2.87</td>
<td>2, 20</td>
<td>0.080</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sleep Onset Latency</th>
<th>F-value</th>
<th>df</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Condition</td>
<td>0.65</td>
<td>2, 20</td>
<td>0.532</td>
</tr>
<tr>
<td>48h Period</td>
<td>0.72</td>
<td>1, 20</td>
<td>0.407</td>
</tr>
<tr>
<td>Condition x 48h Period</td>
<td>2.38</td>
<td>2, 20</td>
<td>0.118</td>
</tr>
</tbody>
</table>

*p<0.05
48h period was also found ($p<0.001$), indicating that positive affect scores were significantly lower than BL during SS1 and SS2, but not during RTDS (Table 3; Figure 4).

No significant main effect of condition was found for negative affect. A significant main effect of 48h period was found ($p<0.001$), such that negative affect scores were significantly higher than BL during SS1, SS2 and RTDS ($p<0.001$) (Table 3; Figure 4).

4 DISCUSSION

Overall this study found that there were no differences in waking function between conditions during the shift schedule period, with the exception of positive affect, which was lower in the Rotating condition. Whilst PVT performance remained stable during the shift schedule period compared to baseline, deficits in positive affect, subjective sleepiness and negative affect accumulated over the shift schedule period. The key differences observed in sleep during the shift schedule period were that the Fixed B condition had significantly better sleep than the Fixed A and Rotating conditions, and all conditions had significantly less Stage R sleep compared to BL. Upon RTDS, subjective sleepiness and positive affect returned to BL levels during RTDS, but negative affect remained above BL levels. When switching back to a consolidated, nocturnal sleep, the Fixed B condition had less N3 sleep than at BL. For all conditions, SOL, N2 and N3 latencies were longer than at BL upon RTDS.

Deficits in PVT performance did not accumulate over the shift schedule period, and PVT performance was not affected during the RTDS. While analyses of cumulative performance reported in this paper do not include the potential performance impairment at individual time points during the study, these findings are similar to previous studies, which have found that if adequate TST per 24h is maintained during a split shift schedule, cognitive function is comparable to that after consolidated periods of sleep (21, 25, 26). Subjective sleepiness on the other hand was increased during schedule days for all conditions. However, daily mean scores did not exceed five out of nine, which is similar to scores observed in a previous study on split shifts (21). This score reflects the descriptor “neither alert nor sleepy”. Jackson et al. (21) did not report subjective sleepiness after the split shift period, however the current study found that subjective sleepiness returned to BL levels during RTDS.

Although negative affect increased during the shift schedule period and remained higher than BL levels when switching back to a day schedule, overall scores were low throughout the study and did not exceed an average score of 13. This score falls within the range of normative PANAS scores (16 ± 5.9) observed in a large non-clinical sample (37). Positive affect was significantly lower than BL during the shift schedule period for all conditions. Furthermore, positive affect was lower in the Rotating group compared to the Fixed A and Fixed B schedules, but all conditions were within the normal range, and returned to BL levels when back on a day schedule. A consideration when interpreting changes in mood is that social factors differ in a laboratory, which may have contributed to the observed fluctuations in mood (38, 39). For example, social support outside of the laboratory may keep mood more positive whilst on shift (40). Conversely, social stressors in a real-world setting may lead to further decrements to mood (40) as opposed to inside the laboratory.

The Fixed B condition appeared to be better in terms of sleep quantity, with increased sleep time, sleep efficiency and reduced wake after sleep onset during the shift schedule period compared to the Fixed A and
Rotating conditions. These findings differ to a previous study, which found that the two crews on a simulated 6h on / 6h off split shift schedule did not differ in sleep quantity (12). However these disparities may be due to methodological variations, as shift times differed and included a rotation to the alternative schedule during the middle of the simulation. In addition, sleep data were obtained via subjective sleep diaries in the Eriksen study (12). In the current study, the Fixed B condition subsequently had less N3 sleep upon RTDS compared to during BL and the shift schedule period. This is consistent with the reduced sleep disruption throughout the shift schedule, resulting in less accumulation of sleep pressure when switching back to a day schedule (41, 42). In addition, the Fixed B condition had a sleep opportunity that ended 8h prior to the first nocturnal sleep back on a day schedule; therefore less prior wake may have contributed to the reduction in N3 sleep during RTDS. Overall, it appears that participants in the Fixed B schedule slept better during the shift schedule period compared to the other conditions. It is important to note when scheduling workers on a 6h on / 6h off shift schedule that the two rotations of the schedule (i.e. Fixed A versus Fixed B) may not be equal in terms of sleep loss. On the whole, these results support the assumption that split shift schedules with adequate TIB per 24 hours minimise the accumulation of sleep and performance deficits over shift schedule days. However, simply switching back to a consolidated nighttime sleep led to changes in the timing of sleep. All conditions had significantly longer sleep onset latencies, N2 latency, and N3 latency during RTDS. This may be due to a lack of accumulated sleep pressure making it more difficult to sleep when switching back to a consolidated nighttime sleep schedule (41, 42). Although this means that the schedules succeeded in reducing the accumulation of sleep pressure, a longer sleep onset latency during recovery may have implications when sleep opportunities are less than the 10h allowed in the study. Participants obtained approximately 8h sleep per 10h sleep opportunity on RTDS nights. This long sleep opportunity may not be achievable in a real-world setting which may require workers to commute in between periods of split shift work (40), thus resulting in curtailed opportunities for recovery. Delayed sleep onset could also potentially cause sleep-related anxiety or poor mood (43, 44). Therefore it is important for shift workers to be aware of the fact that experiencing difficulties falling asleep in subsequent days may be due to changing the timing of sleep rather than being indicative of a sleep disorder such as insomnia.

The success of obtaining adequate sleep during split shifts in a real-world setting would also be heavily dependent upon factors including an optimal sleep environment and adhering to shift start and finish times (19). Sleep environments in the laboratory are optimal (e.g. lack of noise, light and social interferences) compared to in the real world (45). Sleep duration may be reduced in operations where sleeping occurs in ship cabins, trains or in emergency service situations such as bushfire fighting, compared to in sleeping areas at home or on layover (19). In the event that sleep quantity and quality during split shift periods is hindered, a situation of sleep restriction would occur, especially during daytime sleep opportunities (11, 46).

Indeed, a recent meta-analysis showed that participants on 8h on / 8h off shift schedules had an average of 5.6h sleep per 24h, while individuals on 6h on / 6h off rosters averaged 5.9h sleep per 24h (19). This is in contrast to the current laboratory study, where participants in the 8h on / 8h off Rotating schedule had an average TST of 7.2h per 24h during the shift schedule period, and average TST of 7.6h and 8.1h on the 6h on / 6h off schedules (Fixed A and Fixed B respectively). Previous studies have found that performance deficits begin to accrue with 7h TIB per 24h for seven nights, and fail to recover to BL levels during subsequent days with 8h TIB opportunities per night (47). Therefore, further studies are needed to ascertain the effects of switching back to a day schedule following split shift schedules when sleep is restricted, and the ability to utilise ‘recovery’ sleep periods in these situations.

It is also important to consider that time of day fluctuations were not captured within the current analyses, which aimed to observe the cumulative cost of rotating and split shift schedules rather than specific time of day effects. However, this does not mean the shift schedules are devoid of periods of performance decrements during circadian low points (7). Especially outside of the laboratory when sleep may be restricted, the build-up of cumulative performance decrements across days may be intensified during the early morning hours (48). Another consideration is that split shift schedules result in an increased number of wake-ups, which are associated with sleep inertia (49). Furthermore, the current participants were sleep-satiated, healthy, young adults. Therefore results may differ in actual shift workers, who are likely to have an increased risk of health issues including metabolic disorder, and potentially engage in unhealthy behaviours such as smoking which can affect sleep (50).
some effects were very close to reaching statistical significance, it is possible that increasing the sample size may lead to main effects being detected for condition. For example, the main effect of condition for TST was $p=0.062$. It is possible, based on patterns emerging in the means, that Fixed B may have obtained significantly less TST if the sample size were larger. Further studies with a larger sample size are needed to confirm this pattern.

The present study shows that the trialled fixed and rotating shift schedules did not produce accumulation of sleep and performance deficits. Switching back to a day schedule following these schedules led to increased sleep latencies and did not improve negative mood. However, it is known that time needed to recover depends on the amount of cumulative sleep loss during a duty period (47), and that sleep environments outside of the laboratory may be sub-optimal. Therefore, further studies are needed to determine whether returning to a daytime schedule acts as a recovery opportunity when sleep is restricted throughout and following a period of split shift work.

5 ACKNOWLEDGEMENTS

The authors would like to thank Professor Hans Van Dongen for his mentorship and input into the design of the study, interpretation of data and analyses. We also acknowledge Gary Wittwer for assistance during the screening process, financial support from The Bushfire Cooperative Research Centre, and the staff and students who assisted in running the project.

6 REFERENCES

4. Crowley, SJ, Lee, C, Tseng, CY, Fogg, LF, & Eastman, CI. Complete or partial circadian re-entrainment improves performance, alertness, and mood during night-shift work. Sleep: Journal of Sleep Research & Sleep Medicine, 2004; 27(6), 1077.
12. Eriksen, CA, Gillberg, M, & Vestergren, P. Sleepiness and sleep in a simulated “six hours on/six hours off” sea watch system. Chronobiology International, 2006; 23(6), 1193-1202. doi: 10.1080/07420520601057981


42. Dijk, D-J, & Czeisler, CA. Contribution of the circadian pacemaker and the sleep homeostat to sleep


48. Mollicone, DJ, Van Dongen, H, Rogers, NL, Banks, S, & Dinges, DF. Time of day effects on neurobehavioral performance during chronic sleep restriction. Aviation, Space, and Environmental Medicine, 2010; 81(8), 735-744.
