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Do split sleep/wake schedules reduce or increase sleepiness for continuous operations?

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ABSTRACT

This study compared the impact of split and consolidated sleep/wake schedules on subjective sleepiness during the biological day and biological night. This was achieved using a between-group design involving two forced desynchrony protocols: consolidated sleep/wake and split sleep/wake. Both protocols included 7 × 28-h days with 9.33 h in bed and 18.67 h of wake each day. While the consolidated sleep/wake protocol had 1 × 9.33-h sleep opportunity and 1 × 18.67-h wake period each day, the split sleep/wake protocol had 2 × 4.67-h sleep opportunities and 2 × 9.33-h wake periods each day. For both protocols, subjective sleepiness was measured using the Karolinska Sleepiness Scale every 2.5 h during wake. A total of 29 healthy adult males participated, with 13 in the consolidated sleep/wake group (mean age = 22.5 yrs) and 16 in the split sleep/wake group (mean age = 22.6 yrs).

On average, subjective sleepiness during wake periods of the split condition was significantly higher than that during the first half of wake periods of the consolidated condition, but was similar to the level during the second half. These findings were observed for wake periods that occurred during both the biological day and biological night. Previous data have shown that cognitive impairment at night is lower for split schedules than consolidated schedules, but the current data indicate that feelings of sleepiness are greater for split schedules than consolidated schedules for at least half of the time awake. Thus, it should be explained to people operating split sleep/wake schedules that although they may perform well, they are likely to feel sleepy.

1. Introduction

1.1. Background & previous studies

Severe sleepiness is a common complaint among shift workers. This is primarily due to working and sleeping at irregular hours, designated by work–rest schedules (Akerstedt, 1995, 2003; Rajaratnam et al., 2013). Typically, shift workers have so called 'consolidated' schedules, which contain a single work period and a single rest period each day – e.g., 12 h on/12 h off (Rosa and Bonnet, 1993; Tucker et al., 1996; Baulk et al., 2009) and 8 h on/16 h off (Rosa and Bonnet, 1993; Tucker et al., 1996). As alternatives, split schedules also exist, where compared to consolidated schedules the daily work and rest periods occur twice as often and half the duration – e.g., 6 h on/6 h off (Harma et al., 2002; Eriksen et al., 2006) and 4 h on/8 h off (Condon et al., 1988; Harma et al., 2002). Given that shift work cannot be eliminated, it is important to determine which schedule type yields a lower level of sleepiness at work.

From a theoretical perspective, each schedule type has its own advantage. Assuming that rest periods are primarily used for sleep, the more frequent rest periods of split schedules imply that workers on such schedules do not stay awake for as long as do workers on consolidated schedules before the next sleep opportunity. It is well known that sleepiness accumulates with an increasing level of wakefulness (Dijk et al., 1992; Dijk and Czeisler, 1995). Split schedules may then yield a lower level of sleepiness at work than consolidated schedules. On the other hand, the shorter rest periods of split schedules would mean shorter recovery opportunities for sleepiness before the next work period. It is well known that the recovery of sleepiness is sleep dose dependent (Jewett et al., 1999; Belenky et al., 2003; Van Dongen et al., 2003), such that shorter sleeps would not provide as much recovery as longer sleeps. With longer rest periods, consolidated schedules may then yield a lower

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level of sleepiness at work than split schedules. Thus, it seems difficult to select a better schedule type theoretically. Nor does empirical evidence provide an adequate basis to make a selection.

Field studies have examined sleepiness during consolidated schedules such as 12 h on/12 h off (Rosa and Bonnet, 1993; Tucker et al., 1996; Baulk et al., 2009) and 8 h on/16 h off (Rosa and Bonnet, 1993; Tucker et al., 1996), as well as split schedules such as 4 h on/8 h off (Condon et al., 1988; Harma et al., 2002), 6 h on/6 h off (Harma et al., 2002; Eriksen et al., 2006) and 8 h on/8 h off (Darwent et al., 2008; Jay et al., 2008). However, these studies intend to describe sleepiness during a given schedule type, rather than comparing sleepiness between schedule types. In laboratory settings, only two published studies to date have directly compared split and consolidated schedules on subjective sleepiness. A study by Mollicone and colleagues (2008) compared a consolidated schedule with a daily sleep opportunity of 8.2 h at night with an array of split schedules that contained a night-time sleep, 4.2–6.2 h in duration, and an afternoon nap, 0.4–2.4 h in duration. Schedule type explained too little variance in subjective sleepiness to be considered to have an impact. Thus, split and consolidated schedules seem to yield a similar level of sleepiness. However, in this study sleepiness was mainly assessed during the biological day, such that the difference between the two schedule types during night-time wake periods is undetermined. This is an important point for consideration, given that sleepiness is particularly elevated during the biological night (Dijk et al., 1992; Dijk and Czeisler, 1995).

Different from Mollicone et al., Jackson and colleagues (2014) observed that, having two 5-h sleep opportunities, from 0300 h to 0800 h and from 1500 h to 2000 h, yielded a lower level of sleepiness than having a single 10-h opportunity, but only when this single sleep opportunity occurred during the biological day. In this study, sleepiness was assessed during the biological day in the split condition (i.e., 2×5-h sleep), but it was assessed during the biological night in the consolidated condition (i.e., 10-h sleep). Thus, the result is largely explained by time of day variation in sleepiness, as opposed to schedule type. Once again, in this study differences between the two schedule types during night-time wake periods remain undetermined.

1.2. Current study

Given the abovementioned difficulty in theoretical prediction and the gap in empirical evidence, the current study systematically compared a split sleep/wake schedule with a consolidated schedule on subjective sleepiness during night-time wake periods and during day-time wake periods.

2. Materials & methods

2.1. Ethics

The study was approved by the Human Research Ethics Committees at the University of South Australia and Central Queensland University. Prior to taking part, participants were informed about the general nature of the study and gave written consent. Upon completion, all participants received financial compensation.

2.2. Participants

A total of 29 males participated. They were recruited through flyers around the general community in Adelaide, Australia. Participants' health status was assessed using a general health questionnaire. Based on their responses, participants did not have any medical conditions, psychiatric disorders, or sleep disorders; none of them were taking any prescribed medication or had a high consumption of alcohol or caffeine at the time of the study. These participants were not shift workers and had not undertaken trans-meridian travel in the last three months. One week prior to the experiment, participants were instructed to go to bed between 22:00 h and 00:00 h and to have a ~8-h bed period each night, which was verified using activity monitors (Kosmadopoulos et al., 2014b; Actical, Philips Respironics, Bend, Oregon, USA) in conjunction with self-report sleep diaries.

2.3. Design & procedures

The study employed two forced desynchrony (FD) protocols with a consolidated sleep/wake schedule and a split schedule. Out of the 29 participants recruited, 13 were in the consolidated schedule (mean age 22.5 ± 2.2 yrs, mean body mass index 22.2 ± 2.1 kg/m^2), and 16 were in the split schedule (mean age 22.6 ± 2.9 yrs, mean body mass index 22.0 ± 1.9 kg/m^2). The consolidated protocol was carried out between years 2008 and 2009 at the Centre for Sleep Research, University of South Australia. The split protocol was carried out in the year 2013 at the sleep laboratory of Appleton Institute, Central Queensland University.

The sleep/wake schedules of the two protocols are summarised in Fig. 1. Both protocols began with two training days, during which subjective sleepiness and other neurobehavioural tasks were introduced and practiced. The training phase was followed by a baseline day, where subjective sleepiness was assessed five times at 2-h intervals. The following forced desynchrony phase comprised 7×28-h days. The wake to rest ratio of each day was set at 2:1, such that a total of 18.67 h was allocated to wakefulness and a total of 9.33 h to sleep, which is essentially equivalent to 8 h in bed per 24 h. Sleep and wakefulness alternated in 9.33 h/18.67 h cycles in the consolidated schedule, but in 4.67 h/9.33 h cycles in the split schedule. Thus, for each 28-h day participants in the consolidated schedule had a single 18.67-h wake period and a single 9.33-h sleep period, whereas participants in the split schedule had two 9.33-h wake periods and two 4.67-h sleep periods (Fig. 1A).

For both protocols, subjective sleepiness along with a set of other neurobehavioural tasks were assessed every 2.5 h starting from 1.5 h into scheduled wakefulness. In total, there were seven test sessions per day in the consolidated schedule but six in the split schedule (due to an extra set-up requirement for sleep recording). The two protocols were configured such that all seven sessions spread over a continuous 18.67-h wake period for the consolidated schedule, whereas for the split schedule the six sessions spread across to two 9.33-h wake periods, with three sessions in each period (Fig. 1A). For the ease of comparing the two protocols, test session 7 of the consolidated schedule was excluded from analyses.

All test sessions were conducted individually in each participant's living room. Between sessions, only non-strenuous activities such as watching pre-recorded TV programmes and reading books were permitted. No naps were allowed during wake periods. To ensure compliance, participants were closely monitored by researchers either in person or via a closed circuit television system. Prior to each scheduled sleep period, a polysomnography montage was applied to each participant for sleep monitoring. The polysomnography data are reported in another paper (Roach et al., 2015). To recap briefly, participants in the consolidated schedule obtained an average of 7.6 h of sleep per 9.33 h in bed, which did not significantly differ from the 8.0 h obtained by their counterparts in the split schedule. There was no significant difference between the two protocols for the average amount of REM sleep, although participants in the split schedule obtained slightly more slow wave sleep (~2.8 h/9.33 h in bed) than their counterparts in the consolidated schedule (~2.2 h/9.33 h in bed).

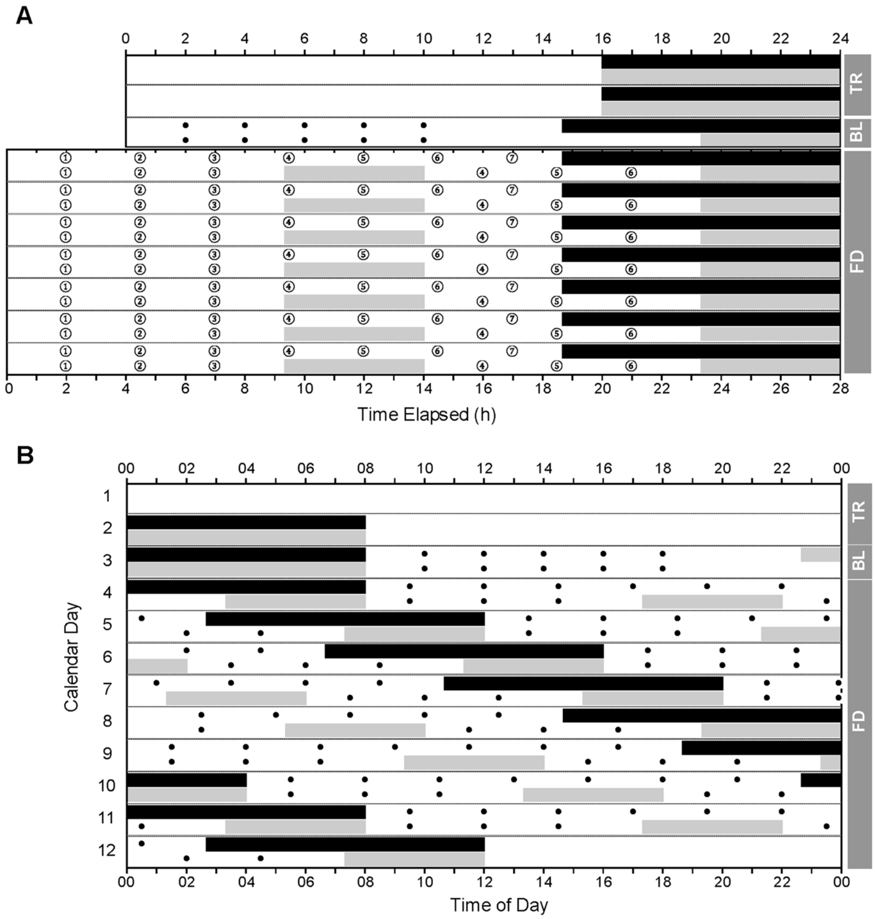

Fig. 1. The split vs. consolidated sleep/wake schedules as a function of time elapsed into each day (Panel A) and as a function of time of day (Panel B). Panel A highlights differences between the two schedule types: each day the split schedule contained two sleep/wake cycles half the duration of the single cycle of the consolidated schedule. Panel B highlights the commonality of the two schedule types: the wake and sleep periods of both schedules coincide with different times of day. Sleep periods are represented using black bars for the consolidated schedule and grey bars for the split schedule. Black dots represent test sessions where subjective sleepiness was assessed, and in Panel A test sessions during the forced desynchrony phase are labelled using a number to reflect their order. TR = training phase; BL = baseline phase; FD = forced desynchrony phase.

2.4. Materials & equipment

Subjective sleepiness was assessed using the Karolinska Sleepiness Scale (Akerstedt and Gillberg, 1990) (KSS). The scale required participants to circle a statement that best describes how sleepy they feel, from nine descriptors, where '1' = 'Extremely alert', '9' = 'Very sleepy, great effort to keep awake, fighting sleep' (see Fig. 2 for all descriptors). The higher the KSS rating, the sleepier the participant felt at the time of completion.

Core body temperature was sampled using rectal thermistors (Cincinnati Sub-Zero Products, Cincinnati, Ohio, USA) at 1-min intervals throughout the study. Activity level was recorded with wrist worn activity monitors (Actical, Philips Respironics, Bend, Oregon, USA) throughout the study. Sleep was recorded using a standard polysomnography montage (Compumedics E-Series EEG/PSG system, Victoria, Australia) during each scheduled sleep period. Polysomnography recordings were then manually scored in 30-s epochs using established criteria (Iber et al., 2007).

2.5. Data analyses

Core body temperature data from FD days 2–7 were used to estimate circadian phase for each participant. The estimation was a 5-step process, which has been described in detail elsewhere (Darwent et al., 2010). In brief, these steps are (i) cleaning of the raw CBT data to account for erroneous or missing values due to downloading of the data, slippage of the thermistor, or malfunction of the equipment; (ii) de-masking for physical activity using a purification by intercepts approach (Waterhouse et al., 2000); (iii) de-masking for sleep-wake differences using a sleep-state correction factor; (iv) fitting of a cosine equation with a fundamental period and a single harmonic to the de-masked CBT data using the method of least squares; and (v) assigning a circadian phase estimate (i.e., 0–360°, with 0° representing the minimum of the fitted core body temperature curve) to each 1 min of the FD portion of the protocols using the resultant cosine equation. The tau value of each participant was estimated based on the composite (i.e., a fundamental plus one harmonic) fitted core body temperature curve.

KSS ratings during the baseline phase (five in total for each participant) were averaged within each participant. The baseline KSS averages from the two schedule types were then compared using an independent *t*-test to determine any existing differences between the participants of the two schedule types.

KSS ratings during the FD phase were assigned one of two schedule types (i.e., consolidated or split), one of six test sessions (i.e., 1–6), one of two circadian phase bins (i.e., biological night or biological day). Biological night was defined by circadian phases equal to or greater than 270° and less than 90°, whereas biological day was defined by circadian phases equal to or greater than 90° and less than 270° (Zhou et al., 2012).

KSS ratings were analysed using a mixed-effects analysis of variance with 'schedule type' (2 levels), 'test session' (6 levels), 'circadian phase' (2 levels) as fixed terms, and 'participant' ($N=29$) as a random term. To control for any potential confounding influence of test days, an additional fixed term, 'test day', was initially included in the above mixed-effects model. However, the initial analysis showed no significant main effect of test day and no significant test day × schedule type interaction. As such, test day was eventually removed from the mixed-effects model. All analyses were conducted using SPSS 17.0. The statistical significance of all fixed effects was determined using *F* tests. The denominator degrees of freedom for *F* statistics were computed using the Satterthwaite approximation method.

Table 1
Mixed-effects analysis of variance of Karolinska Sleepiness ratings.

Term	df	*F*-value	*p*-Value
Schedule[a]	1, 27	2.00	0.17
Session[a]	5, 1167	37.90	<0.0001
Phase[a]	1, 1167	105.33	<0.0001
Schedule × session	5, 1167	20.51	<0.0001
Schedule × phase	1, 1167	<0.01	0.95
Phase × session	5, 1167	1.04	0.40
Schedule × phase × session	5, 1167	1.61	0.16

[a] Schedule = schedule type; session = test session; phase = circadian phase.

3. Results

3.1. Baseline phase

The mean baseline sleepiness level for the consolidated schedule, which was 4.06 ± 1.39 (SD), was not statistically different from that for the split schedule (4.03 ± 1.27; $t(28)=0.07$, $p=0.95$).

3.2. Forced desynchrony phase

Results of the mixed-effects ANOVA are listed in Table 1. Fig. 2 presents mean KSS ratings over six test sessions for the consolidated and split conditions. There was a main effect of circadian phase. Participants of both schedule types on average reported a higher sleepiness level during the biological night than they did during the biological day (Fig. 2B vs. C). There was no main effect of schedule type, indicating that the overall sleepiness levels of the two schedule types were comparable.

There was a significant schedule type × test session interaction (Table 1), which can be interpreted in two ways. First, the impact of test session depends on schedule type. For participants in the consolidated schedule, subjective sleepiness progressively increased over six test sessions. By contrast, for participants in the split schedule, sleepiness initially increased over the first three sessions, but at session 4 it was reverted to a level equivalent to that at session 1, or more specifically to the average baseline sleepiness level, before it started to increase again (Fig. 2A). A second way to interpret the schedule type × test session interaction is that the impact of schedule type depends on test session. Specifically, post hoc unpaired *t*-tests indicate that for the first three sessions, the sleepiness level was greater in the split schedule than in the consolidated schedule, but there were no schedule type differences for the last three sessions (Fig. 2A).

There was no significant schedule type × test session × circadian phase interaction (Table 1). This indicates that the schedule type × test session interaction above did not depend on circadian phase (Fig. 2B vs. C).

4. Discussion

This study employed a consolidated sleep/wake schedule and a split schedule. Both schedules included 7 × 28-h days with 9.33 h in bed and 18.67 h of wake each day. While the consolidated schedule had a single 9.33-h sleep opportunity and a single 18.67-h wake

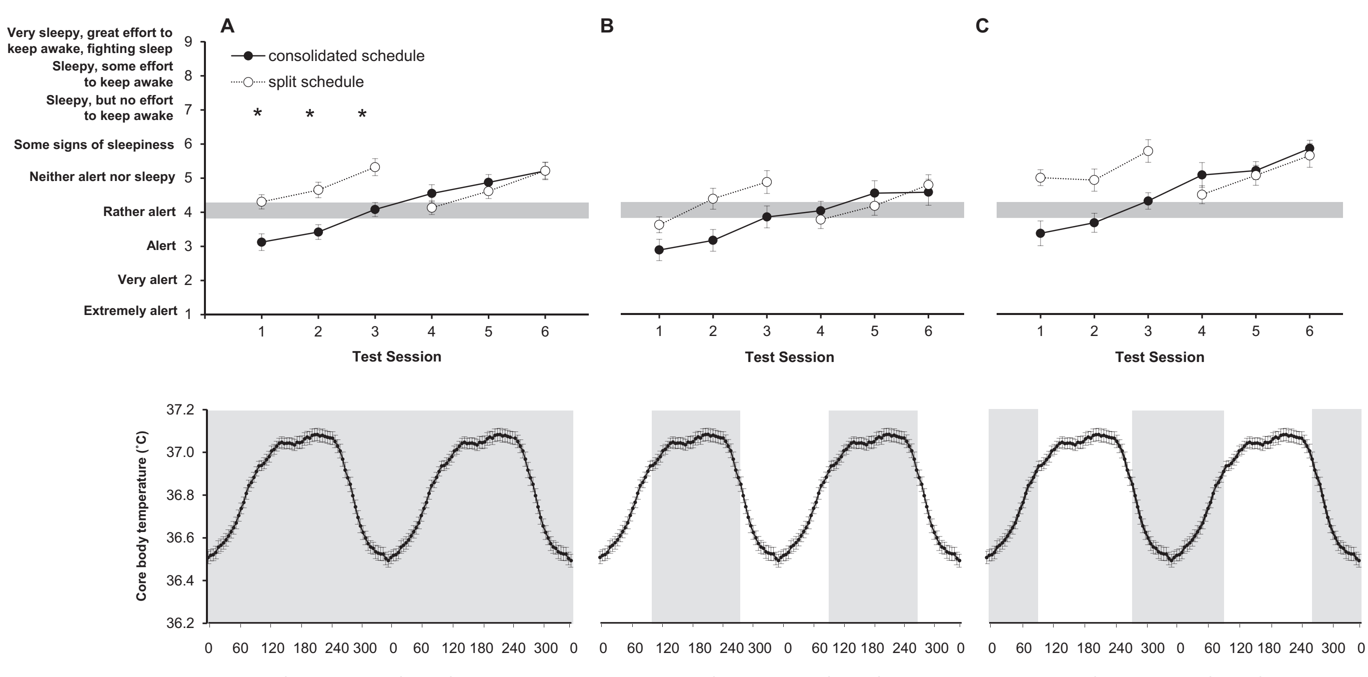

Fig. 2. Comparisons between the split and consolidated sleep/wake schedules for mean (±1 SEM) Karolinska Sleepiness Scale ratings as a function of test session. Panels A, B and C respectively show data averaged across all circadian phases (A), phases corresponding to the biological day (B), and phases corresponding to the biological night (C) for each test session of the two schedule types. The grey band in Panels A–C is the mean baseline KSS rating ±1 SEM. The bottom row presents mean (±1 SEM) core body temperature, the phase marker, as a function of circadian phase. Shaded areas indicate the range of circadian phases for which KSS ratings were included. Asterisks indicate significant differences between the two schedules, based on post hoc analyses ($p<0.05$).

period each day, the split schedule had two 4.67-h sleep opportunities and two 9.33-h wake periods each day. Subjective sleepiness was assessed daily in 6 sessions, which were spread over the single wake period in the consolidated schedule but across the two wake periods in the split schedule. To determine which schedule yields a lower level of sleepiness, the current study compared the two schedules for test sessions that occurred during the night and for sessions that occurred during the biological day.

4.1. Which schedule type is better?

We found a schedule type × test session interaction. In the split condition, sleepiness continuously increased over six sessions, but in the consolidated condition this continuity was interrupted between session 3 and session 4, where sleepiness was reverted to the baseline level (Fig. 2A). The 4.67-h sleep period between sessions 3 and 4 of the split condition must have reset sleepiness. Thus, for a given amount of wakefulness, when it occurs in a single period, sleepiness would accumulate continuously, but by splitting it into two shorter periods with a sleep period in between, sleepiness can be reset by the sleep period. The 4.67-h sleep periods of the split condition did not reset sleepiness to the same extent as the 9.33-h sleep periods of the consolidated condition, though. Subjective sleepiness was consistently higher in the split condition than in the consolidated condition for the first three test sessions, which occurred within the first 6.5 h of scheduled wake for both conditions (Fig. 2A). However, there was no between-condition difference in sleepiness for the last three test sessions (Fig. 2A). As with the first three test sessions, the last three sessions in the split condition occurred within 6.5 h since waking from the 4.67-h sleep period, but for the consolidated condition, the last three sessions occurred between 9 and 14 h since waking from the 9.33-h sleep period. This means then the sleepiness level upon waking from a 4.67-h sleep was already equivalent to the level of being awake for 9 h after a 9.33-h sleep, and it further accumulated over the next five hours to the level of being awake for 14 h after a 9.33-h sleep.

Further, the above result held for test sessions that occurred both during the biological night and during the biological day (Fig. 2B and C). This is evidenced by the absence of a significant circadian phase × schedule type × test session interaction. Therefore, our results suggest that, for a given amount of duty hours, whether they occur during the day or night, workers on a split work–rest schedule would feel sleepier than their counterparts on a consolidated schedule for at least half of the time.

Interestingly, from exactly the same schedules, contrasting results were found for neurobehavioural performance (Kosmadopoulos et al., 2014a). Instead of compromising performance, the split schedule yielded performance at a level similar to the consolidated condition during the day and better performance during the night. The contrasting results are in line with differential sleep dose response curves for neurobehavioural performance and subjective sleepiness. While the former is exponentially saturating, the latter is linear, such that reducing an 8-h sleep to 5 h affects subjective sleepiness more than neurobehavioural performance (Jewett et al., 1999). In light of this, splitting a 9.8-h sleep into 4.67-h sleeps would affect subjective sleepiness more than neurobehavioural performance.

4.2. Alternative explanations

The differences in sleepiness between the two schedule types are unlikely due to any pre-existing differences between the participants of the two schedules or due to any systematic difference between the laboratories where the two schedules were implemented. This is because there is no difference in sleepiness between the two schedules on the baseline day. The extended wake period (i.e., 19 h) in the split schedule during the transition from the baseline to the FD phase may have contributed to the increased sleepiness level (see Fig. 1). The extended wake period may cause sleep deficits which may not be fully recovered over 4.67-h sleep periods. If that is the case, though, one would expect a main effect of schedule type; yet there is no main effect of schedule type in this study.

4.3. Comparison with previous studies

The wake and phase dependent changes in subjective sleepiness during the split schedule in our study are consistent with those documented in field studies that involve split work–rest schedules (Condon et al., 1988; Harma et al., 2002; Eriksen et al., 2006; Jay et al., 2008). However, in these field studies, there are no or limited comparisons with consolidated sleep/wake cycles. Even when adequate comparisons were made in laboratory studies (Mollicone et al., 2008; Jackson et al., 2014), sleepiness was assessed during the biological day. Thus, our study adds to the literature in that it examined the impact of split sleep for wake periods that occur during the biological night.

Based on the data obtained during the biological day, the higher level of sleepiness in the split condition found in our study seems inconsistent with previous studies, where no difference was found between split and consolidated schedules (Mollicone et al., 2008; Jackson et al., 2014). Differences in protocol and analysis method between studies could contribute to the inconsistency. For example, the test sessions of the split and consolidated protocols in the study by Jackson and colleagues (Jackson et al., 2014) are not aligned in terms of time of day or circadian phase, such that their results may not reflect the impact of split sleep per se. In contrast, using the forced desynchrony paradigm, circadian phase was controlled for in our study. In terms of analysis method, Mollicone and colleagues' results are based on the daily average levels of sleepiness, which may mask any schedule type × test session interaction effect. In fact, the impact of split sleep is revealed by a schedule type × test session interaction effect in our study, despite the absence of a main effect of schedule type. In this sense then, our results are not necessarily inconsistent with previous studies.

4.4. Conclusion & future direction

In summary, split sleep increased sleepiness for at least half of the time awake, whether these waking hours occurred during the day or the night. This is in contrast to our previous observation that split sleep improves neurobehavioural performance during the night. Thus, workers on a split schedule should be aware that although they may perform well, they are likely to feel sleepy. It should be noted, though, our finding may only be valid for split schedules with the sleep to wake ratio of our protocol (i.e., 1:2). Given that shift workers do not often achieve this ratio, further research is required to validate our finding for split schedules with reduced sleep to wake ratios.

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