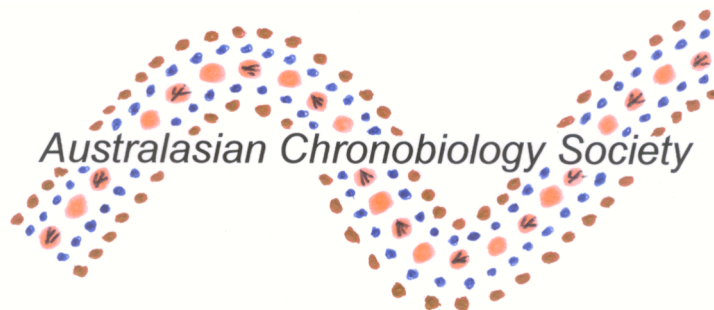


Living in a 24/7 World: The impact of circadian disruption on sleep, work and health

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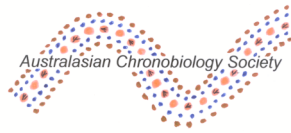
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Chapter 3

The influence of circadian phase and prior wake on positive and negative mood during a sleep-restricted forced desynchrony protocol

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Aims: To determine the effects of prior wake and circadian phase on subjective mood while employing a novel sleep restricted forced desynchrony (FD) protocol. It was hypothesised that positive mood (i.e. Vigour) would be influenced by a circadian and homeostatic process, whereas negative mood (i.e. Confusion, Tension, Anger, Depression, Fatigue) would not.

Methods: 10 healthy males, with a mean (\pm SD) age of 22.3 (\pm 3.5) years and a body mass index of 22.8 (\pm 1.8) kg/m² participated in a 28-h sleep restricted FD protocol. During the FD periods, participants were scheduled to 7h sleep and 21h wake (the equivalent of 6h sleep per solar day). Subjective mood was assessed using the Profile of Mood States (POMS) 1.5h after waking and every 2.5h thereafter. Circadian phase was assessed using the core body temperature rhythm that was sampled using a rectal thermistor (Steri-probe 491B).

Results: Separate linear mixed-model ANOVA were conducted on the total mood disturbance score and individual mood subscales. The positive mood scale of the POMS (Vigour) showed main effects for circadian phase and prior wake. The negative mood scales of Fatigue, Confusion and Tension were also influenced by both processes. No significant effects of circadian phase or prior wake were found for Anger or Depression.

Discussion: Very few studies have reported an influence of circadian phase or prior wake on negative mood states. No FD studies have yielded such results. Finding circadian and prior wake influences on 3 negative mood subscales within this FD study, could therefore be due to the use of the novel sleep restricted protocol, suggesting that negative mood is only influenced under reduced sleep. The findings from this study have practical implications as they give insight into how mood is affected when people receive 6h sleep per night which more closely mirrors that of today's society.

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Introduction

Positive mood (affect) is influenced by a circadian and homeostatic process (i.e. prior sleep/wake).^{3,7} Investigations in to whether negative affect follows this same pattern have yielded equivocal results.^{3,5,6,7} Circadian phase influences on negative mood have been observed

during an ultra-short sleep/wake cycle,⁶ which only partially de-masks the influence of prior wake.² Additionally, homeostatic influences on negative mood have been noted during sleep restriction,⁵ where results are confounded by the influence of circadian phase. In order to look at the influence of the circadian and

homeostatic process separately, a protocol that can remove the masking effect of the opposing process needs to be employed. A forced desynchrony (FD) protocol enables mood to be sampled across all possible combinations of circadian phase and prior wake, thus allowing for the effects of the two processes to be separated through data folding and averaging procedures.

Previous FD studies have employed a sleep/wake ratio of 1:2 (the equivalent of 8h sleep and 16h wake per solar day), giving insight into how mood is affected with the recommended 8h sleep per night. However, many people work varying or extended hours during both the biological day and biological night and consequently no longer receive 8h of sleep per night. Instead, many only obtain about 6h.⁸ The independent influence of circadian phase and prior wake on mood under sleep-restricted conditions is unknown. It is under this premise that a novel sleep restricted FD protocol will be conducted whereby sleep/wake will be scheduled at a 1:3 ratio (the equivalent of 6h sleep and 18h wake per solar day).

The aim of this study is to use this novel approach to determine the influence of the circadian and sleep/wake homeostat on mood as measured by the Profile of Mood States (POMS).⁹ Based on the findings of previous FD studies, which have only found circadian and prior wake effect on positive mood scales, it was hypothesised that positive mood would show circadian and homeostatic influences whereas negative mood would not. This study will provide information on how mood is influenced under conditions where individuals are receiving sleep which more closely parallels that routinely obtained by individuals.

Method

Participants

Twelve male volunteers were recruited; however two withdrew due to personal reasons. The remaining participants

(n=10) had a mean (\pm SD) age of 22.3 (\pm 3.5) years and a body mass index of 22.8 (\pm 1.8) kg/m². Participants were non-smokers, drug and medication free, did not consume high levels of caffeine or alcohol and were of good physical and mental health as determined by a screening interview and a General Health Questionnaire. Participants wore a wrist activity monitor (Actiwatch-64, Philips-Respironics) and kept a sleep diary the week prior to the study to monitor sleep habits. Only those who maintained a nocturnal sleep/wake cycle and obtained 7 to 8h sleep per night were admitted as participants. Each participant provided written informed consent to partake in this study, which was granted ethics approval from the UniSA Human Research Ethics Committee and conforms to the guidelines established by the National Health and Medical Research Council of Australia.

Measures

Participants completed a battery of tests assessing various aspects of their neurobehavioural function of which the POMS was the first measure administered. The POMS is a 65 item assessment of transient mood state in which participants rate each item from 0=not at all to 4=extremely. It is a valid and reliable measure⁹ frequently used in sleep studies^{4,5,6} and provides a Total Mood Disturbance (TMD) score as well as a score on six individual subscales. The TMD score is the sum of the five negative mood subscales: Fatigue-Inertia (FI), Confusion-Bewilderment (CB), Tension-Anxiety (TA), Anger-Hostility (AH) and Depression-Dejection (DD) minus the positive mood subscale: Vigour-Activity (VA).

Core body temperature (CBT) was continuously recorded in 1-minute epochs using a rectal thermistor (Steri-probe 491B) inserted 10cm beyond the anal sphincter muscles. Circadian phase was determined by fitting a regression model for CBT with one fundamental (24h) and

one additional harmonic (12h) for the intrinsic circadian component. From this, an estimate of intrinsic period and clock time for the CBT rhythm was produced. Circadian phase was divided into $6 \times 60^\circ$ bins. The nadir of the fitted temperature rhythm was assigned circadian phase 0° .

Protocol

Participants lived in the time isolation laboratory for 12 consecutive solar (24h) days. During this time they had no access to time cues such as clocks, live television, the Internet or mobile phones. Ambient light was kept at 10-15 lux (dim indoor light) during wake periods and less than 0.03 lux (darkness) during sleep opportunities. Ambient temperature was set at $22 \pm 1^\circ\text{C}$.

The protocol consisted of two adaptation/training days and a baseline day where sleep was scheduled to begin at midnight and end at 8:00am. The FD period began upon waking after the baseline night. During this phase, the length of each 'day' was extended to 28h and the sleep/wake ratio was reduced to 1:3. Participants were scheduled to 7h sleep and 21h wake each 28h period (the equivalent of 6h sleep per solar day) and were scheduled to wake up 4h later each FD period. Test batteries were administered on 8 occasions each waking period, with the first being administered 1.5h after waking and then every 2.5h thereafter. Sleep was assessed using polysomnography (PSG) and scored according to the accepted criteria.¹¹

Data Analyses

Separate linear mixed-model ANOVA were used to determine whether there were main effects of prior wake and circadian phase for TMD and the six individual subscales. Circadian phase and prior wake were entered into the model as fixed factors, with TMD, VA, FI, CB, TA, AH or DD entered as the dependent variable. Sleep efficiency (the percentage of time in bed spent asleep) was included as a covariate to take in to account

variation in sleep length and time awake. Subject ID was entered as a random effect to account for the between-subjects variance. Post hoc comparisons, with Bonferroni corrections, were conducted to compare scores on the mood scales at each circadian phase with scores at circadian phase 0° . Scores at the varying prior wake categories were compared with scores at prior wake 1.5h. Significant differences are denoted in Figure 1 by asterisks.

Results

Linear mixed-model ANOVA revealed a main effect of circadian phase ($F_{(5,95)}=18.0$, $p<.001$) and prior wake ($F_{(7,72)}=11.6$, $p<.001$) for TMD. Participants experienced the greatest level of mood disturbance around the circadian nadir (0°) and the least at the acrophase of the CBT rhythm (180°). Mood disturbance increased with lengthened prior wake.

The main effects (and post hoc tests) of circadian phase and prior wake for the VA, FI, CB and TA subscales are plotted in Figure 1. Analyses of the positive subscale (VA) revealed a significant main effect of circadian phase ($F_{(5,115)}=22.5$, $p<.001$) and prior wake ($F_{(7,71)}=12.4$, $p<.001$). Vigour was highest at 180° and lowest at the circadian nadir. Vigour was inversely proportional to the level of prior wake.

Analyses of the negative subscales revealed significant main effects of circadian phase for FI ($F_{(5,85)}=13.9$, $p<.001$), CB ($F_{(5,83)}=8.4$, $p<.001$) and TA ($F_{(5,77)}=4.8$, $p=.001$). FI and CB were at their highest at the circadian nadir. TA was highest at circadian phase 300° (on the upward arm of the CBT rhythm). FI and CB exhibited a persistent minimum from 120° to 240° , whereas TA was lowest at 180° . A significant effect of prior wake was also found for FI ($F_{(7,60)}=10.1$, $p<.001$), CB ($F_{(7,61)}=7.5$, $p<.001$) and TA ($F_{(7,61)}=2.3$, $p<.05$), wherein negative mood increased with prior wake. No main

effects of circadian phase or prior wake were found for AH and DD.

Discussion

While the results supported the hypothesis that positive mood would follow a circadian rhythm and show an effect of prior wake, the hypothesis that negative mood would not was only partially supported.

Significant main effects of circadian phase and prior wake were found for TMD. Participants showed greatest overall mood disturbance around 5am (circadian phase 0°) and the least amount of disturbance around 5pm (circadian phase 180°). Participants also reported a greater mood disturbance the longer they had been awake. However, while total mood disturbance worsened during these periods, none of the effects were clinically significant.⁹

The presence of significant main effects of circadian phase and prior wake for the positive mood subscale (Vigour) is congruent with the notion that positive affect is influenced by a circadian and homeostatic process.^{3,7}

The negative subscales of Fatigue, Confusion and Tension were also influenced by circadian phase and prior wakefulness. Diurnal variation in negative affect has previously only been observed during an ultra-short sleep/wake cycle.⁶ Although this protocol greatly diminishes homeostatic pressure, it only partially de-masks this influence.² Additionally, an effect of prior wake has been seen during sleep restriction⁵ where results are confounded by the influence of circadian phase. In order to separate these two processes and assess their independent influence on mood, a FD protocol is required. FD studies have found that negative mood domains do not fluctuate across circadian phase or with prior wakefulness.^{3,7} Hence, the findings of this FD study, which show a circadian and homeostatic influence for the

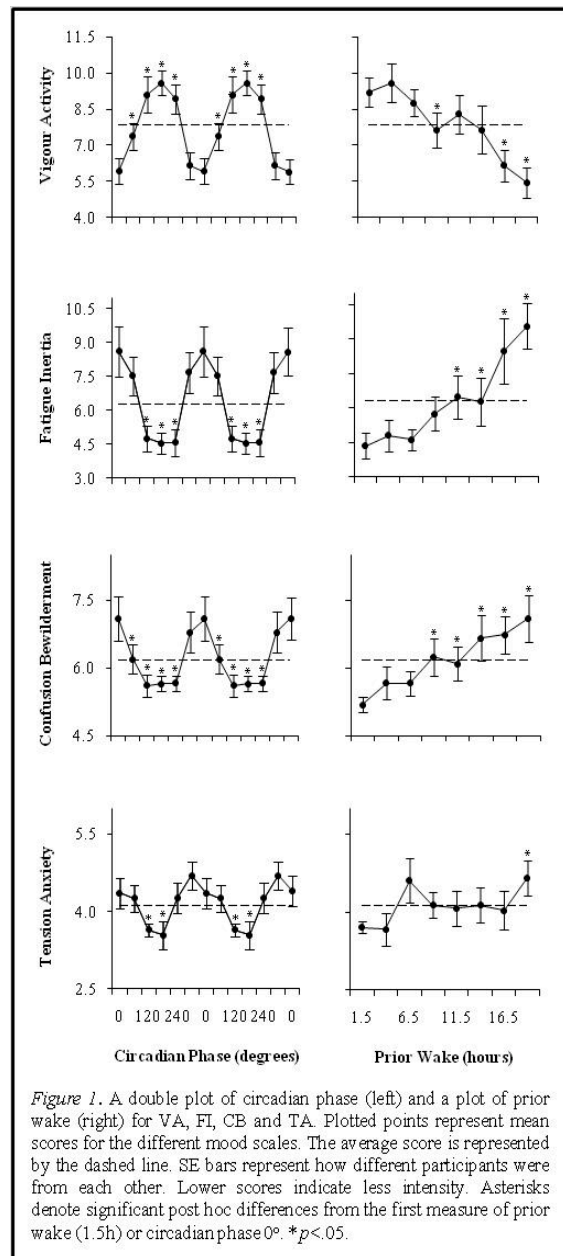


Figure 1. A double plot of circadian phase (left) and a plot of prior wake (right) for VA, FI, CB and TA. Plotted points represent mean scores for the different mood scales. The average score is represented by the dashed line. SE bars represent how different participants were from each other. Lower scores indicate less intensity. Asterisks denote significant post hoc differences from the first measure of prior wake (1.5h) or circadian phase 0°. * $p < .05$.

Fatigue, Confusion and Tension subscales, are novel. Previous FD studies have employed a 1:2 sleep/wake ratio (the equivalent of 8h sleep per night). In this study, participants were scheduled to a 1:3 ratio (the equivalent of 6h sleep per night). Therefore, the novelty of our observations may be attributed to the sleep restriction (or extended wakefulness) that was imposed on participants. That is, prior sleep history could be a mediating factor for the presence of circadian and homeostatic variation in the negative mood domains.

Previous FD studies have used visual analogue scales (VAS) to assess mood. However, most of these VAS measures are uni-polar and only measure one mood domain (i.e. happiness or cheerfulness). The POMS covers six mood subscales and also supplies a global measure of mood disturbance. Therefore, whilst a direct comparison between previous FD studies and the current study cannot be made, this study provides insight on the influence of circadian phase and prior wake on a wider range of mood scales than previously looked at in FD.

The observed results have practical implications for individuals engaged in shiftwork, as well as the companies which employ such working conditions. Mood has been linked with a variety of work related outcomes. For example, negative mood has been associated with increased absenteeism and turnover in the workplace, which can impact on productivity.¹⁰ Positive mood, on the other hand is known to facilitate coping ability, creative problem solving and conflict reduction.¹ Consequently, those engaged in shifts which run during early hours of the morning, or involve extended hours of wakefulness, are more susceptible to diminished ability and performance. As laboratory studies are free from many external influences, which can impact on mood, field studies involving shift-workers should be conducted to determine whether these results are replicated in a less controlled environment.

Acknowledgements

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