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How the likelihood of missing the alarm during an on-call shift affects pre-bed anxiety, sleep and next day cognitive performance

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Highlights:

- Pre-bed anxiety is higher on on-call nights compared with control
- Poorer sleep on on-call nights where perceived likelihood of missing the call alarm was high
- Faster reaction times on days after on-call nights with a low likelihood of missing the alarm

Summary

This study investigated how the likelihood of missing an alarm affects pre-bed anxiety, sleep and next day cognitive performance during on-call shifts. Participants (n=24) completed one adaptation night, one control night and two on-call nights in a time-isolated sleep laboratory. On one of the on-call nights, participants were informed that they would be woken by a loud alarm that they would *definitely* not be able to sleep through (low likelihood of missing the alarm). On the other on-call night, participants were informed that they would be woken by a quiet alarm that they *may* sleep through

(high likelihood of missing the alarm). The two on-call nights were counterbalanced. Pre-bed anxiety was measured using the State Trait Anxiety Inventory x-1, while sleep macro- and micro-architecture was examined via routine polysomnography and power spectral analyses respectively. Following each sleep, cognitive performance was assessed four times (0930, 1200, 1430, 1700) using the 10-min psychomotor vigilance task (PVT). Results indicated that while pre-bed anxiety was similarly increased during both high and low likelihood of missing the on-call alarm conditions compared with control, only in the high likelihood condition was total sleep time shorter and sleep efficiency lower compared with the control condition. However, more wake after sleep onset was found in the low likelihood condition compared with control. PVT data indicate that response times (mean reciprocal and mean fastest 10% of reaction time) were fastest in the low likelihood condition, indicating better performance when compared with both other conditions. However, there were significantly more lapses in the low likelihood condition compared with control. No significant EEG power spectral differences were observed. As such, it appears that there are detrimental effects of both on-call conditions on anxiety, sleep and performance, with sleep poorest when the likelihood of missing the alarm is high. The adverse impacts on sleep and performance outcomes while on-call may be mitigated by the implementation of workplace systems to reduce the likelihood of missing alarms (e.g., having two available options for contacting on-call workers).

Key words: on-call, anxiety, sleep, cognitive performance, qEEG analysis

Introduction

On-call is a working arrangement where employees are away from their workplace, but are available to attend to a call, and possibly resume work at any time if required (Ferguson et al., 2016). Industries that commonly use these working arrangements include emergency services, healthcare and information technology (Nicol et al., 2004). Periods of time spent on-call but where individuals are not working are considered by many organisations and legal policy as "time off" (European Working Time Directive, 2011). However, it appears that being on-call, even when no calls occur, can have implications for workers' anxiety and sleep (Bamberg et al., 2012; Ferguson et al., 2016; Hall et al., 2016). Specifically, it has been demonstrated that during on-call periods, anxiety may be heightened (Cebola, 2014; Nicol et al., 2004; Sprajcer et al., 2017) and increased anxiety may result in poorer sleep outcomes for on-call workers (Nicol et al., 2004; Torsvall et al., 1987). This is concerning given that poor sleep can result in adverse cognitive, behavioural and physical outcomes, which can significantly impact work performance, safety and productivity (Alhola et al., 2007; Belenky et al., 2003; Van Dongen et al., 2003). Further, increases in anxiety may result in poorer health outcomes for on-call workers over the longer term, including detriments to cardiovascular health (Kawachi et al., 1994) and increased respiratory problems (Katon et al., 2004). One factor that may influence how much anxiety on-call workers experience is their perception of how likely it is that they will miss a call.

Anecdotally, on-call workers report feelings of anxiety related to the potential of missing their alarm (or phone call, or page) (Bamberg et al., 2012; Paterson et al., 2016). For example, on-call firefighters reported anxiety surrounding the possibility that their pager may not go off because of a technical issue or similar (Paterson et al., 2016). One firefighter specifically indicated that "once it goes beyond a week (without a call) you really start to think is your pager working?" (Paterson et al., 2016, p. 177). A perceived increase in the likelihood of missing an alarm was also found in airline cabin crew, where self-reports indicated that individuals experienced increased anxiety and apprehension when they believed they may miss their alarm before early morning work (Kecklund et al., 1997). This suggests that a higher likelihood of missing a call is associated with anxiety, which may subsequently lead to poorer sleep.

Though there is limited research in the on-call area, two laboratory-based studies provide insight into the relationship between on-call work, anxiety and poorer sleep and cognitive performance outcomes. Wuyts et al. (2012) compared on-call nights with nights not on-call, and found that when participants were on-call they experienced a longer sleep latency and reduced sleep efficiency. The alarm used to wake on-call participants was described by the researchers as 'difficult to distinguish', which may have

made participants feel as though they would potentially miss the call. The observed sleep decrements in the on-call condition may be explained by higher levels of anxiety associated with potentially missing the call. In a similar study undertaken by Jay et al. (2016), which also compared sleep outcomes both when on-call and not on-call, a very loud (105dB) alarm was sounded to wake participants during their on-call periods. The participants were aware of the volume of this alarm and that the likelihood of missing it was extremely low. No differences were reported in sleep outcomes between the on-call and not on-call conditions, including sleep efficiency, total sleep time or duration of sleep stages. Taken together, these two studies suggest that the anxiety produced by a higher likelihood of missing the alarm while on-call may impact sleep, though given the different designs employed in these studies, it is difficult to be definitive.

If sleep is negatively affected, there may also be adverse effects on cognitive performance. The negative effects of poor sleep quantity or quality on cognitive performance outcomes are well documented, with potential decrements to reaction time (Van Dongen et al., 2003), constructive thinking (Killgore et al., 2008), reasoning abilities (Harrison et al., 2000) and vigilant attention (Lim et al., 2008), all of which potentially have adverse consequences for on-call workers' performance and personal safety (Allahyari et al., 2014; Wallace et al., 2003). Therefore, this study will investigate the effects of the likelihood of missing an alarm on pre-bed state anxiety, sleep and next day performance outcomes.

Methods

Subjects

Twenty-four male participants were recruited for the study. This sample size was calculated *a priori* by a magnitude based statistical power analysis (Hopkins, 2000), utilising G*Power 3.1.9.2 software (Faul et al., 2007). Effect size was calculated utilising a 10% difference in total sleep time seen in on-call medical doctors (Jay et al., 2008), with an $\alpha = 0.05$ and $\beta = 0.80$, resulting in resulting in n = 24 to account for a 5-10% attrition rate. Participants were screened using a general health questionnaire and were all non-smokers who reported good quality sleep in the previous month (PSQI ≤ 5) (Buysse et al., 1989). Participant characteristics are presented in Table 1. Participants habitually consumed no more than two caffeinated beverages/day, and reported no medical concerns or medications (e.g., selective serotonin reuptake inhibitors) known to impact sleep. Participants were excluded if they had travelled across multiple time zones in the previous four weeks, were a current shift worker, or reported napping regularly. No participants had previous experience with on-call work. In addition, participants completed the Depression Anxiety Stress Scale (DASS) and were excluded if they had severe levels of anxiety, stress or depression (Crawford et al., 2003). Similarly, participants with extreme morning and evening chronotypes, as assessed using the Morningness Eveningness Questionnaire (MEQ), were excluded (Horne et al., 1975).

In the week preceding participation, participants were required to maintain regular bed/wake times within an hour of the bed (2300) and wake times (0700) of the protocol. Participants wore an activity monitor (Actical MiniMitter/Respironics, Bend, OR) (de Souza et al., 2003) and completed sleep diaries to corroborate timing and duration of sleep periods. Participants had an average of 7.02 $\pm$ 1.1 h of sleep per night, with a mean bedtime of 2348 $\pm$ 1.3 h and a mean wake time of 0738 $\pm$ 0.9 h, based on activity monitor recordings, corroborated by sleep diaries.

Design

Participants completed the four-night protocol at the Appleton Institute in Adelaide, South Australia, between February 2016 and May 2017 in groups of six (n = 24). This facility is a temperature (21 ± 2°C) and light (maintained at 100 lux for wake) controlled time-isolation laboratory. This study employed a within-subjects, repeated measures design, with one adaptation night, followed by one control night and two on-call nights. The protocol for the study is presented in Figure 1. The adaptation night was included to acclimatise to sleeping in the laboratory, and as such has not been included in analyses.

As significant changes to sleep were expected in the on-call conditions, the control night was always first, followed by the two counterbalanced on-call nights. This was done to prevent any residual sleep debt from the on-call night/s from confounding the control night. For all conditions, bedtime was 2300, and wake was 0700. On both on-call nights, participants were told that they would definitely be called at some point during the sleep period. However, they were not actually 'called' until the end of their sleep period. As the laboratory is time-isolated, the participants were not aware of the time of these 'calls', and as such did not know how much sleep they had obtained.

The on-call conditions were a *low likelihood of missing the alarm* (loud alarm) and *high likelihood of missing the alarm* (quiet alarm), with twelve participants completing the low likelihood condition first, and twelve the high likelihood condition. On the adaptation day, demonstrations of both the loud and quiet alarms were given to participants. The loud alarm was an 81.2 – 94.6 dB alarm (TOA transistor megaphone with siren signal, model: ER-1215S) and participants were informed that they would definitely wake when it was sounded, and that no participant had ever missed this alarm. At 0700 in the low likelihood condition, participants' bedroom doors were opened simultaneously as the alarm was sounded from the adjacent hallway. The alarm that was demonstrated in the high likelihood condition was a recording of white noise played through a small set of speakers. Participants were told that other participants had missed this alarm in the past, but that it was very important for them not to miss it. At 0700 on the high likelihood morning, participants were woken by a knock at their door and the lights coming on, and were informed that they had missed the alarm. In this condition, the alarm was never actually sounded, to ensure that all participants were woken simultaneously. In both conditions, participants were instructed to respond to the alarm by pressing a button next to their bed as soon as they thought they heard the alarm.

Measures

State anxiety

State anxiety was measured using the State Trait Anxiety Inventory form x-1 (Spielberger, 1983). This 20-item questionnaire includes items such as "I feel at ease" and "I feel nervous", where responses range from 1 ("not at all") to 4 ("very much so"). Participants are required to respond in relation to how they feel "right now, that is *at this moment*". Reverse coding is employed as required for positive items. Scores range from 20-80 with higher scores representing higher levels of state anxiety, with clinically significant scores beginning at 39-40 (Julian, 2011).

Sleep

Polysomnographic recordings were taken during each sleep period (Bloch, 1997) and used to examine the impact of experimental conditions sleep macro-architecture derived from traditional sleep scoring. Electrodes were used in a standard configuration, with electroencephalographic (EEG), electromyographic (EMG) and electro-oculographic (EOG) recordings taken for each participant. C3/M2, F4/M1 and O2/M1 channels were used, and a trained sleep technician scored each sleep period in 30-s epochs according to standard criteria (Iber, 2007). Variables generated include total sleep time (TST), sleep onset latency, wake after sleep onset, sleep efficiency ((TST/time in bed)*100), latency to 10 min of sleep, latency to N3, REM (rapid eye movement sleep) latency, minutes and proportion of total sleep time for each sleep stage (N1, N2, N3, REM, NREM (non-REM sleep)), stage shifts, awakenings and arousals in each sleep stage.

Sleep EEG Power

To examine the impact of experimental conditions on sleep micro-architecture, quantitative EEG analysis was performed using a validated algorithm (D'Rozario et al., 2015). Polysomnographic recordings from the Cz channel for each overnight sleep study were used to determine the EEG frequency composition of each sleep stage using Fast Fourier transformations (FFT) to derive the frequency bands (delta (0.5 - 4.5 Hz), theta (4.5 - 8.0 Hz), alpha (8.0 - 12.0 Hz), sigma (12.0 - 15.0 Hz), and beta (15.0 - 32.0 Hz)) (Vakulin et al., 2016). Any epochs with artefacts were automatically excluded from analyses, but were checked for accuracy by a manual assessment of 10% of sleep periods. It was found that the automatic artefact removal was 97% accurate. EEG spectral power was calculated for each 30s period by averaging data from up to 6 artefact-free 5s blocks. The spectral power within the defined frequency bands was computed for NREM sleep (stages 2 and 3) and REM sleep. Further, the ratio between slow and fast frequency ((delta + theta) / (alpha + sigma + beta)) was assessed (EEG slowing ratio), as was the delta/alpha ratio, for NREM and REM sleep stages. The proportion of frequency bands within each sleep stage are indicative of the quality of sleep, with low frequency (e.g., delta) indicative of deeper sleep (Campbell, 2009).

Subjective sleepiness

Subjective sleepiness was measured using the Karolinska Sleepiness Scale (KSS), a validated, one-item questionnaire that requires respondents to rate themselves from 1 ('extremely alert') to 9 ('very sleepy, great effort to keep awake, fighting sleep') (Åkerstedt et al., 1990). The KSS was administered at 0700, 0815, 0930, 1200, 1430 and 1700 each day, prior to the completion of each psychomotor vigilance task.

Performance

Next-day performance was assessed using the 10-min psychomotor vigilance task (PVT) performed on the control day and both on-call days at four time points (0930, 1200, 1430, 1700). This task is a standard measure for cognitive performance, including sustained attention and vigilance, and is sensitive to sleep loss (Dinges et al., 1985). Three training PVTs were performed on the adaptation day to minimise learning effects (Kribbs et al., 1994). Output measures include lapses of more than 500 ms, reciprocal reaction time (RRT), mean fastest 10% of reaction time (RT) and mean slowest 10% of RRT (Jewett et al., 1999).

Statistical analyses

Linear mixed effects ANOVAs were used to compare all outcome variables between conditions. Fixed effects included condition (control, low likelihood, high likelihood) and order. Time of day (0930, 1200, 1430, and 1700) was also included as an additional fixed effect for PVT analysis. Subject was a random effect in the model to account for individual differences. A Satterthwaite correction was applied to denominator degrees of freedom. Data that had non-normal distributions were log transformed for analysis. Significance was at the $p < .05$ level, and all significant effects had Bonferroni post-hoc testing applied.

Results

State anxiety

There was a significant main effect of condition on pre-bed state anxiety, $F_{(2, 48)} = 19.4$, $p < 0.001$. Pairwise comparisons revealed that state anxiety was significantly lower in the control condition (29.4 ± 4.1) compared to both the low likelihood (34.0 ± 4.9), $p < 0.001$ and high likelihood conditions (33.7 ± 6.1), $p < 0.001$. However, order was also included as a fixed effect in the model, and was found to be significant, $F_{(1, 24)} = 7.966$, $p = 0.009$. Results also showed that participants who experienced the low likelihood condition as their first on-call night (30.2 ± 5.3) had lower levels of pre-bed state anxiety than those who were in the high likelihood condition on their first night (34.6 ± 4.8).

Sleep

There was a significant main effect of condition on TST, SE, WASO, and the amount of N1 sleep as a proportion of TST. See Table 2 for these results. No significant differences were found for all other sleep variables, including quantitative EEG outcomes (see Table 3). Participants appeared to take the on-call instructions seriously, as in the high likelihood condition, four participants pressed their button thinking they had heard the alarm, with one pressing the button twice on the same night. On only one occasion did a participant press their button overnight during the low likelihood condition. Additionally, when participants were debriefed, they all indicated that they had pressed their button upon waking.

Subjective sleepiness

There were significant main effects of both condition, $F_{(2, 403)} = 11.583$, $p < .001$, and time of day, $F_{(5, 403)} = 67.743$, $p < .001$, on subjective sleepiness as measured by the Karolinska Sleepiness Scale. Participants were significantly sleepier in the high likelihood of missing the alarm condition (4.10 ± 1.95) than in the control (3.49 ± 1.75), $p < .001$, and the low likelihood of missing the alarm condition (3.77 ± 1.71), $p = .039$. Participants were significantly sleepier at 0700 (5.99 ± 1.82) compared with 0815 (3.35 ±1.39), 0930 (3.17 ± 1.43), 1200 (3.24 ± 1.58), 1430 (3.37 ± 1.42) or 1700 (3.59 ± 1.48), $p < .001$ for all comparisons.

Performance

There were significant differences in cognitive performance on the PVT between conditions (Table 4) as measured by mean reciprocal reaction time (RRT), mean fastest 10% of reaction time (RT) and lapses. No significant differences between conditions were found in the mean slowest 10% of RT.

There was a significant main effect of time of day for mean RRT, $F_{(3, 264)} = 3.668$, $p = 0.013$. Mean RRT was faster at 1700 (4.43 ± .51) compared with 0930 (4.29 ± .54), $p = 0.007$. There was also a significant main effect of time of day on mean fastest 10% of RT, $F_{(3, 264)} = 4.090$, $p = 0.007$. Mean fastest 10% of RT was significantly faster at 1700 (185.31ms ± 18.65) than at 0930 (189.93ms ± 19.29), $p = 0.004$. The main time of day effect for mean slowest 10% of RRT was significant, $F_{(3, 264)} = 3.208$, $p = 0.024$. Mean slowest 10% of RRT was also faster at 1700 (3.19 1/RT*1000 ± 0.61) than at 0930 (3.00 1/RT*1000 ± 0.74), $p = 0.040$. There were no significant time of day effects for lapses.

Discussion

This study aimed to investigate how the likelihood of missing an alarm impacts anxiety, sleep and performance outcomes during simulated on-call periods. Findings indicated that anxiety was higher on both on-call nights compared with control, but that generally, both sleep and next-day performance were poorest when there was a high likelihood of missing the alarm while on-call.

Pre-bed anxiety was significantly lower on the control night compared with both on-call nights, suggesting that participants felt more anxious before bed when they knew they were on-call, regardless of the likelihood of missing the alarm. However, mean scores on the STAI x-1 prior to bed were not indicative of clinically important anxiety (indicated by scores of above 39-40 (Julian, 2011)). In the high likelihood condition, the increase in anxiety was associated with sleep decrements. In the low likelihood condition however, increases in anxiety were not followed by the same degree of sleep decrements, and indeed, response times were faster (0.3 RRT) in this condition compared with control. However, it is also important to note that while there were significant differences in several sleep measures between conditions, these differences were not large.

Total sleep time was significantly shorter (7.9 min) when the likelihood of missing the alarm was high compared with the control condition. Similarly, sleep efficiency was significantly (1.7%) lower in the high likelihood condition compared with control. Conversely, the highest proportion of wake after sleep onset (WASO) was seen in the low likelihood condition, with 6.2 minutes more than the control

condition. The discrepancy between WASO and sleep efficiency may be explained by a non-significant trend towards a longer sleep latency in the high likelihood condition ($p = .127$). A potential explanation is that sleep efficiency scores are calculated based on time in bed and therefore include sleep latency, whereas WASO is calculated from the time the individual first fell asleep. Though participants had slightly more wake overnight in the low likelihood condition, their longer sleep latency, shorter sleep times and poorer sleep efficiency in the high likelihood condition suggest that sleep overall was poorer when the likelihood of missing the alarm was higher. It is possible that sleep on the on-call nights was affected by having two full 8-h sleep opportunities on the preceding adaptation and control nights, resulting in a slightly decreased sleep need. However, this is unlikely, as the changes in on-call sleep differed between conditions, despite being counterbalanced. As such, had they been affected by these 8-h sleep opportunities on the preceding nights, each on-call night would have all been affected the same way. Further, as sleep was monitored prior to attending the sleep laboratory, participants were well rested and not experiencing sleep debt that may have influenced subsequent sleep periods.

Despite the small but statistically significant sleep PSG outcome differences, there were no significant differences observed when sleep micro-architecture was examined using power spectral analysis which is independent of sleep/stage timing and duration. These findings suggest that there was no significant impact of on-call periods on quantitatively measured brain activity. The impacts of experimental conditions on PSG sleep and performance outcomes were very subtle and therefore may not be detected in the EEG due to significant variation in EEG power phenotypes between individuals.

In addition to slightly poorer sleep outcomes in the high likelihood condition, participants also felt sleepier in this condition, based on their responses on the KSS. This suggests that when participants knew they may miss the on-call alarm, they experienced heightened sleepiness, potentially as a result of the slightly poorer sleep the preceding night. However, as scores on the KSS were within one point between all conditions, this effect is small. Additionally, mean daily scores on the KSS were in the range of ‘alert’ to ‘fairly alert’ in all conditions. This suggests that while there are some statistically significant differences between conditions, real world outcomes may be similar.

In addition to feeling sleepier during the day, performance outcomes were poorer in the high likelihood condition. Participants responded faster (mean RRT and mean fastest 10% RT) in the low likelihood condition compared with both the high likelihood condition (0.14 1/RT*1000 and 11.61ms, respectively), and control (0.3 1/RT*1000 and 11.79ms difference). While the increase in arousal caused by the loud alarm may provide an explanation for these findings, this is unlikely given that the alarm occurred 2.5 h prior to the first 10-min PVT each day. Further, participants had 0.58 more lapses in the low likelihood condition compared with the high likelihood condition. However, mean lapses

and response times in all conditions were within normal ranges for performance (Lim et al., 2008). In the real world, differences such as these may not be significant enough for any personal or operational changes to be required (Alhola et al., 2007). However, it is important to consider that while individuals who have experienced these small changes to sleep or performance may be fit for duty, the multi-factorial nature of the world outside of the laboratory may mean that these small decrements add to other factors that affect work performance and/or safety. Further, there may be cumulative effects of multiple and/or consecutive nights on-call.

While this study provides insight into the effects of the likelihood of missing an alarm while on-call, there are some limitations. Specifically, laboratory research is limited in terms of practical applications, as the real world involves additional stressors and environmental differences. As such, further research is required to apply these findings to real world on-call scenarios, including research with current on-call workers as participants. Additionally, the control night was first in the protocol for all participants to ensure these nights were not adulterated by prior restricted sleep in the on-call conditions. While this design was necessary, it is also a limitation. Further, though participants were instructed several times that it was very important that they wake to the on-call alarms, there is the possibility that they did not take this instruction seriously. However, as several participants woke during the high likelihood condition, it appears that they were aware of the importance of waking. Additionally, participants reported anecdotally during their participation that they believed they may miss the quiet alarm. As the current study represents preliminary, controlled research in a new field, it was necessary to control for the differences to sleep that can occur with age and gender. As such, our sample consisted only of young males (20-33 years), which may limit the generalisability of findings. Additionally, as a large proportion of on-call workers fall into older age brackets, it is important for future research to include older participants. Further, future research should include female participants, to ensure findings are generalizable.

Overall the findings of this study indicate that a higher likelihood of missing the alarm (i.e., the alarm being quiet and easy to miss) is associated with somewhat negatively affected sleep and next day performance. Further, heightened anxiety was found in both on-call conditions, regardless of how likely it was that participants would miss the call. As changes to sleep and performance are linked with work performance and increased risk in the workplace, it is important for workplaces to take factors such as the likelihood of missing an alarm into consideration when designing workplace policy. Specifically, ensuring that the alarm system used for waking workers is effective and is known to wake individuals easily may be a simple way that workplaces can mitigate these negative effects of on-call on sleep and performance outcomes.

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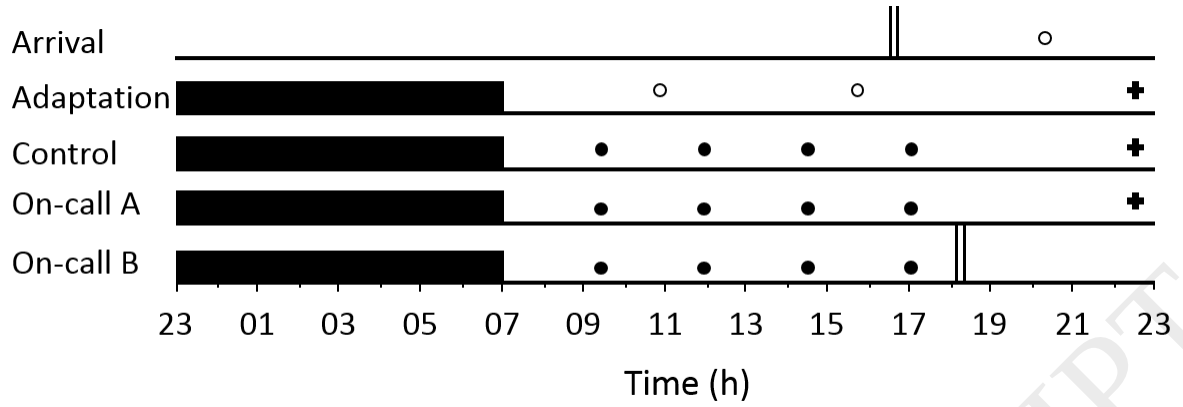

Figure 1. Study Protocol.

‖ Arrival to and departure from the laboratory

○ 10-minute psychomotor vigilance task (PVT) training

● 10-minute PVT

✚ State Trait Anxiety Inventory form x-1

On-call nights A and B counterbalanced for high and low likelihood of missing

Tables

Table 1. Participant characteristics (n=24)

Variable	Range	Mean ± SD
Age (years)	20 - 33	25.0 ± 3.8
Body Mass Index (BMI) ($kg.m^2$)	18.6 - 28.5	23.6 ± 3.0
Pittsburgh Sleep Quality Index (PSQI) score	0 - 5	2.5 ± 1.3
Epworth Sleepiness Scale (ESS) score	0 - 9	3.9 ± 2.4
Habitual bed times (h)	2130 - 0000	2259 ± 0.65
Habitual wake times (h)	0530 - 0930	0738 ± 0.98

Table 2. Sleep outcomes in control, low and high likelihood of missing the alarm conditions (n = 24)

Variable	**Condition**			**$F_{(2, 48)}$**	**p**	**Post-hoc tests**
	Control (C)	Low likelihood (L)	High likelihood (H)			
Total sleep time (TST) (minutes)	447.8 (13.4)	441.9 (17.4)	439.9 (17.2)	4.846	0.012	C > H, p = 0.013
Sleep efficiency (%)	93.3 (2.8)	92.1 (3.6)	91.6 (3.6)	4.841	0.012	C > H, p = 0.013
Sleep onset latency (mins)*	11.2 (7.1)	10.9 (5.9)	15.9 (14.0)	2.157	0.127	-
Wake after sleep onset*	21.0 (12.5)	27.2 (15.3)	24.2 (15.0)	5.166	0.009	C < L, p = 0.007
Latency to REM (minutes)*	74.3 (24.7)	76.0 (39.4)	70.9 (31.6)	0.689	0.507	-
Latency to 10 mins of sleep (mins)*	13.4 (7.2)	12.5 (5.4)	17.4 (13.6)	1.969	0.151	-
Latency to N3 (mins)*	12.3 (4.8)	11.2 (3.4)	10.8 (2.2)	1.056	0.356	-
Minutes of N1*	27.0 (18.5)	29.9 (19.7)	29.6 (15.3)	2.575	0.087	-
N1 % of TST*	6.1 (4.3)	6.9 (4.9)	6.8 (3.7)	3.225	0.049	C < H, p = 0.078
Minutes of N2	179.2 (30.2)	172.1 (29.6)	176.8 (27.5)	1.382	0.261	-
N2 % of TST	40.1 (6.6)	39.0 (6.6)	40.2 (6.4)	0.975	0.385	-
Minutes of N3	126.3 (36.4)	124.0 (35.9)	118.8 (32.2)	1.917	0.158	-
N3 % of TST	28.1 (7.8)	28.0 (7.6)	26.9 (7.0)	1.182	0.315	-

Minutes of REM*	115.3 (18.7)	115.9 (23.6)	114.7 (17.8)	0.014	0.986	-
REM % of TST*	25.7 (4.1)	26.2 (5.2)	26.1 (4.0)	0.099	0.906	-
Minutes of NREM	332.5 (21.5)	326.1 (27.1)	325.2 (22.0)	2.020	0.144	-
NREM % of TST	74.3 (4.1)	73.8 (5.2)	73.9 (4.0)	0.174	0.841	-
Arousals (total sleep period)*	85.0 (37.8)	81.3 (30.5)	78.0 (24.6)	1.313	0.278	-
Arousals (REM)	26.0 (10.7)	26.2 (11.4)	26.3 (11.7)	0.008	0.992	-
Arousals (NREM)*	59.0 (36.1)	55.1 (29.4)	51.8 (21.3)	1.497	0.234	-
Arousals per hour (total sleep period)*	11.4 (5.3)	11.1 (4.4)	10.7 (3.5)	0.694	0.505	-
Arousals per hour (REM)	13.4 (4.4)	13.6 (5.1)	13.9 (6.0)	0.132	0.877	-
Arousals per hour (NREM)	10.7 (6.7)	10.1 (5.3)	9.5 (4.0)	1.007	0.373	-
Awakenings	22.0 (8.8)	23.4 (7.6)	22.7 (6.5)	0.774	0.467	-
Stage shifts	146.3 (34.2)	150.6 (29.5)	147.7 (28.8)	0.458	0.635	-

Abbreviations: REM – Rapid eye movement sleep, NREM – non-rapid eye movement sleep, N1 – stage one sleep, N2 - stage two sleep, N3 – stage three (slow wave) sleep.
Data reported as Mean (SD).
*Data log transformed to normal for analysis

Table 3 Quantitative EEG outcomes in control, low and high likelihood of missing the alarm conditions

qEEG range	**Sleep stage**	**Condition** Mean (SD)			**F**	**df**	**p**
		Control	Low likelihood	High likelihood			
Delta (0.5 – 4.5 Hz)	NREM	681.1 (251.3)	706.6 (309.4)	687.5 (335.2)	0.228	2, 40	0.797
	REM	237.7 (91.9)	233.5 (81.8)	220.0 (87.5)	0.540	2, 43	0.587
Theta (4.5 – 8 Hz)	NREM	41.8 (18.7)	40.8 (17.1)	40.7 (18.1)	1.348	2, 40	0.271
	REM	20.7 (4.9)	20.0 (5.2)	20.1 (5.4)	1.873	2, 40	0.167
Alpha (8 – 12 Hz)	NREM	19.2 (8.8)	18.6 (8.1)	19.9 (10.2)	1.352	2, 39	0.270
	REM	8.6 (3.8)	8.1 (2.8)	8.4 (4.3)	0.936	2, 40	0.401
Sigma (12 – 15 Hz)	NREM	12.2 (5.9)	11.7 (5.3)	12.7 (5.9)	1.089	2, 40	0.346
	REM	2.8 (1.0)	2.9 (1.5)	2.9 (1.4)	0.638	2, 40	0.534
Beta (15 – 32 Hz)	NREM	7.3 (3.0)	8.0 (4.5)	7.3 (3.3)	1.346	2, 42	0.271
	REM	7.6 (4.7)	10.1 (12.9)	8.5 (6.4)	1.070	2, 44	0.352
EEG slowing ratio	NREM	19.45 (5.16)	20.40 (6.65)	18.94 (6.90)	0.117	2, 40	0.890
	REM	14.99 (5.57)	14.34 (5.20)	13.75 (5.02)	0.585	2, 41	0.562
Delta/alpha ratio	NREM	37.36 (10.10)	39.75 (12.75)	36.26 (12.73)	0.467	2, 40	0.631
	REM	29.93 (10.78)	29.87 (8.74)	28.59 (9.77)	0.171	2, 40	0.843

Abbreviations: REM – Rapid eye movement sleep, NREM – non-rapid eye movement sleep, N1 – stage one sleep, N2 - stage two sleep, N3 – stage three (slow wave) sleep

Table 4. Condition effects for performance on the psychomotor vigilance task

Variable	**Condition**			**F**	**df**	**p**	**Post-hoc testing**
	Control (C)	Low likelihood (L)	High likelihood (H)				
Mean RRT (1/RT*1000)	4.21 (.49)	4.51 (.54)	4.37 (.50)	27.529	2, 275	0.000	C < L, p < .001; H < L, p < 0.001
Lapses	0.67 (1.13)	0.83 (1.76)	0.25 (.67)	4.331	2, 238	0.014	H < L, p = 0.016
Mean fastest 10% RT (ms)	191.42 (15.69)	179.63 (18.06)	191.24 (20.72)	70.606	2, 273	0.000	C > L, p < .001; H > L, p < 0.001
Mean slowest 10% RRT	2.97 (.60)	3.04 (.78)	3.20 (.51)	2.789	2, 284	0.063	-

RT – reaction time. RRT = reciprocal reaction time