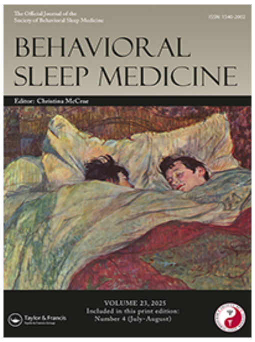

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Sleep in Military Submariners: Exploring its Dynamics in Relation to a Submarine Mission and Interaction with Psychological Factors

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ABSTRACT

Introduction: Operational work contexts promote sleep and circadian disturbances, especially in extreme environments. To identify mitigation factors, this study aimed to explore submariners' sleep changes in relation to a mission and association with different psychological factors.

Methods: Thirty military submariners were evaluated in real-life conditions on three consecutive periods: pre-mission/baseline, submarine mission, post-mission/recovery. Sleep duration, quality, and sleepiness were collected continuously via diary and actigraphy. Personality traits, coping strategies, locus of control, fatigue, anxiety, and depressive symptoms were assessed through questionnaires.

Results: During the mission, there was a significant decrease in sleep duration and quality and increase in sleepiness compared with baseline, recovering post-mission. Submariners slept a median of 55 minutes less than before the mission and 91 minutes less than after the mission. They also rated their sleep quality 0.45 points lower, while reporting 1.85 points higher sleepiness at the beginning of work shifts. Higher work satisfaction and extraversion trait score correlated with better scores on subjective sleep variables during the mission. Higher neuroticism trait and avoidant coping style had a negative impact on sleep-related parameters in all periods, mediated by anxiety symptoms.

Conclusion: Psychological factors are relevant for sleep in extreme occupational settings, especially regarding subjective parameters, and even in highly selected and trained populations, potentially informing intervention opportunities.

Introduction

Operational work contexts, such as military missions and deployments, often lead to sleep disturbances due to challenging physical and environmental conditions, high workload, increased stress, and disruption of circadian rhythms caused by irregular work hours (Bai et al., 2023; Good et al., 2020). Some operational settings face particularly challenging conditions given the extreme nature of the environment (Zivi et al., 2020), including spaceflights, polar environments, subterranean environments and, notably, submarines, in which physical confinement, noise, temperature, sudden pressure changes, social isolation, and low or absent natural light exposure may impact sleep quality and

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quantity. Such professional settings often require exceptional performance due to the critical nature of tasks and the significant safety implications involved (Pilcher & Morris, 2020). Additionally, there is growing interest in the human exploration of these extreme environments.

Extensive research has long demonstrated that disruptions to sleep and circadian rhythm negatively impact both health and performance across different settings (Boivin et al., 2022; Ganesan et al., 2019; Gurubhagavatula et al., 2021; Piechowski et al., 2024). We are thus faced with a conundrum: performance is often most critical in situations where it is most challenged.

In these extreme environments, such as submarines, sleep, and circadian rhythms are affected by environmental characteristics (light, noise, temperature, among others), intrinsic work-related factors (work hours, shift rotation, workload, nature of the task, stress levels, among others) (Caldwell et al., 2019; Linton et al., 2015) and individual factors (genetic, psychological, behavioral, and others) (Casale & Goel, 2021; Tkachenko & Dinges, 2018). Among these, psychological status and personality traits are also recognized as individual determinants of sleep (Philippens et al., 2022). These may play a role in objective sleep but also, and perhaps even more, on subjective sleep perception. First, mood symptoms are known to negatively impact sleep, in fact, this is a bidirectional relationship, considering that insufficient or low sleep quality is also a driver for mood changes (Kalmbach et al., 2017; Mirchandaney et al., 2023; Yasugaki et al., 2023).

Personality traits are a complex product of genetic and environmental factors, life experiences, and other influences. They represent dispositions that tend to remain stable over time (Goldberg, 1993). A relationship between personality traits and sleep quality has been documented in adults (Duggan et al., 2014; Stephan et al., 2018) and with insomnia symptoms in shift workers (Holzinger et al., 2021). However, their putative role in sleep modulation under extreme environments such as submarines is yet to be explored. Moreover, in such potentially adverse and challenging circumstances, individuals are required to engage different coping mechanisms, (either adaptive or maladaptive) with different behavior outcomes.

In addition, having a more internal or external locus of control influences our perception of reality and self-efficacy in responding to said reality (Nowicki et al., 2021). The relationship between these variables (i.e. coping style and locus of control) may negatively impact sleep continuity and quality in the context of adverse circumstances. Indeed, maladaptive coping strategies have been shown to be associated with insomnia symptoms and lower sleep quality in different working populations (Otsuka et al., 2022; Yin et al., 2022). A more complex interaction between sleep and coping strategies, via a mediating effect of depressive symptoms, was also described (Kozusznik et al., 2021), illustrating both the challenge in assessing the influence of psychological factors on sleep, and the importance of considering an integrated evaluation of different interacting factors.

Psychological factors and traits are thus important when considering work-related sleep duration and quality. Furthermore, these are exciting areas for implementing mitigation strategies for sleep and circadian disruption, particularly in submariners, given their equal potential for candidate selection prior to the exposure to adverse sleep and circadian circumstances, and to be measured and worked on through different psychological interventions after candidate selection.

Despite the strict selection process and rigorous continuous training these military personnel undergo, it is important to determine whether psychological factors play a key role in sleep quality, as they have been shown to do in other populations. As such, the aims of this study were: 1) to characterize sleep duration, sleep quality and sleepiness changes in a group of military submariners, in the context of a potential disruption caused by an operational mission, by comparing their profile before the mission, during the mission and following a recovery period after the mission and 2) to explore the relationship of these sleep variables with different psychological and personality factors.

Methods

Participants

Study participants were a group of 30 Portuguese military submariners who underwent an operational submarine mission during the study period. This group represents over 90% of the whole crew of the diesel-electric submarine involved in this mission. Subjects who performed duties in the crew of this submarine during the selected mission were included in the study. Exclusion criteria were a) being previously diagnosed with a sleep disorder or b) taking chronic medication that affects sleep or wakefulness.

The study was approved by the Ethics Committee of the NOVA National Public Health School (CE-ENSP nº12/2022) and all participants provided informed consent prior to data collection.

Procedures

Study period and data collection

Data was collected in real-life conditions during three consecutive periods: pre-mission (P1-baseline), during the mission (P2) and after the mission (P3-recovery).

Pre-mission period consisted of one to two weeks before the mission. There were no operational deployments in the previous months; therefore, this was considered the baseline condition. During this time, subjects performed their duties on the naval base, having in general a "9-to-5" daytime schedule, and off-duty or vacation days. The mission consisted of a three-week operational deployment, during which the participants were continuously aboard the submarine, working on a 6 h "on" (work itself) and 6 h "off" (rest, leisure, other activities) schedule, implying two 6 h working periods every 24 h. These periods could be: 1) from 1AM to 7AM and from 1PM to 7PM, or 2) from 7AM to 1PM and from 7PM to 1AM. Each submariner had the same shift combination throughout the whole mission. A few submariners had specific duties not involving shifts, requiring instead extended work hours or on-call duties.

This type of submarine is highly compact, with this specific vessel measuring 67.9 × 6.3 × 13 meters. However, the crew's habitable area is even smaller, resulting in extremely confined working and living spaces that are in very close proximity to one another. Sleep compartments are immediately adjacent to other areas, like the kitchen, bathroom, and eating/leisure areas, very small and mostly composed of bunk beds, making noise and light isolation quite challenging. On the other hand, there is a complete absence of natural light and artificial lighting is generally of low intensity in all compartments except in the kitchen and bathroom. These light levels are also quite identical throughout the 24 hours.

The post-mission recovery period consisted of three weeks after the mission, with a work schedule similar to baseline (see Supplementary Figure S1 for study flowchart).

Personality traits were characterized using self-report questionnaires upon inclusion, while other psychological variables and fatigue were repeatedly assessed, also through self-report questionnaires, at three timepoints: upon inclusion, at baseline, immediately at the end of the mission, and after the recovery period. Sleep was evaluated via continuous report on a sleep and activities diary and via actigraphy.

Measurements

General characteristics. Questions about individual characteristics, alcohol, tobacco and caffeine use, and potential exclusion criteria. Navy and submarine service length, as well as work satisfaction, the latter rated on a scale from 1 to 10, with 10 representing the highest level of satisfaction, were also assessed.

Fatigue. Fatigue Severity Scale (FSS) was used. It comprises nine items, assessing the level of fatigue perceived by the person in daily life situations rated on a 7-point scale, answered in reference to the last two weeks. Higher total score values indicating higher fatigue levels (Krupp et al., 1989; Laranjeira, 2012).

Anxiety and depressive symptoms. Hospital Anxiety and Depression Scale (HADS) was used, a scale with a total of 14 questions, divided into two subscales that are rated separately, assessing the two dimensions. Higher scores indicate greater levels of depressive or anxiety symptoms. According to its normative values, a score of 0 to 7 is considered normal, whereas a score greater than or equal to 8 is indicative of possible depression or anxiety (Bjelland et al., 2002; Pais-Ribeiro et al., 2007).

Personality traits. Characterized using the Big Five Inventory, one of the most widely used instruments, evaluating an individual's personality traits according to the five major personality types contained in the five-factor model: extraversion, agreeableness, conscientiousness, neuroticism, and openness. It consists of a series of statements to be responded based on the subject's level of agreement or disagreement, each of these evaluating one of the five major personality traits described above. A final score for each trait is obtained, with highest scores representing higher dominance. The short version was used, the Big Five Inventory-10 (BFI-10) (Bártolo-Ribeiro, 2007; Rammstedt & John, 2007).

Coping mechanisms. Coping mechanisms relate to behaviors and attitudes of adjustment facing situations considered stressful or negative, that is, which exceed the individual's internal resources. An effective coping process has adaptive effects, unlike an ineffective coping process. The Brief-COPE questionnaire consists of 28 statements representing beliefs or behaviors for which the respondent selects how much each of the statements applies to himself. There are designated scoring guidelines which allow the evaluation of 14 coping styles, and these can be further grouped in two main coping styles: avoidant coping and approach coping. Avoidant coping involves avoidance of direct confrontation with the stressor, whereas approach coping strategies implicate direct engagement and addressing the stressor and, thus, the first is considered maladaptive and the second more adaptive and providing better long-term outcomes (Carver, 1997; Ribeiro & Rodrigues, 2004; Taylor & Stanton, 2007).

Type of locus of control. The psychological concept of locus of control translates the subject's greater or lesser conviction that they can exercise control over their life and the events that affect them. Hence, it reflects the individual's perception of control over events in their life, namely as these being mainly the result of their actions (internal locus of control), or of external circumstances (external locus of control). Rotter's Locus of Control Scale (RLC) was used to evaluate this psychological parameter, being composed of 29 items. Each item has two statements, and the respondent must choose the one that applies most to himself. The scale has specific scoring guidelines, and the maximum score is 23, higher scores indicating a more external locus of control (Barros, 1989; Rotter, 1996).

Sleep and activities diary. Participants completed a sleep and activities diary throughout the study period, recording sleep schedules, sleep quality, work hours, mealtimes, and caffeine consumption. Regarding sleep variables, the following information was collected for every sleep period: bedtime, time to fall asleep, wake-up time, and subjective sleep quality upon awakening (on a scale from 0 to 3, in which 0 is "*very good*" and 3 is "*very bad*"). For every work period, participants rated the level of alertness at its beginning and at the end using the Karolinska Sleepiness Scale (KSS), a numerical scale relating to subjective drowsiness, rated from 1 – "*very alert*" to 9 – "*very sleepy, great effort to keep awake, fighting sleep*" (Kaida et al., 2006).

Actigraphy. Participants wore an actimeter (ActTrust®, Condor Instruments) on their non-dominant wrist for the entire study period (56 days). This device continuously collected activity and environmental light. All analyses were performed with the ActStudio® software (version 2.2.2). We calculated the sleep duration per period as well as the amplitude of the activity and light. For the activity and light amplitudes, we performed the cosinor analysis for each period (Nelson et al., 1979). Days with more than 4 h of off wrist periods were excluded from the analysis (Loock et al., 2021).

Data analysis

Descriptive statistics and frequency tables were computed to assess sample characteristics. Normality of data distribution was assessed using the Shapiro-Wilk test. Most of the variables included in each analysis did not follow a normal distribution; hence, non-parametric tests were used, and median and quartile 1 and quartile 3 are presented (median [Q1 - Q3]). Variables collected by repeated measurements in each of the three timepoints were compared using Wilcoxon signed-rank test. Relationships between variables were evaluated with Spearman´s rank correlation coefficient. Significant and relevant bivariate associations between sleep-related variables and possible predictors were further evaluated employing generalized linear models, with the sleep variables as dependent. All multivariate models were controlled for age and excluded female subjects, considering there were only three in this sample. Mediation analyses were conducted to further explore possible indirect relationships between potential influencing factors and sleep variables.

All analyses were performed using IBM SPSS version 29 and, for mediation analysis, PROCESS® macro v.4.0 for SPSS was used, performing simple mediation (model 4). Graphs were created using GraphPad Prism 10. Statistical significance was set at 0.05 for all calculations.

Results

Baseline data

Subjects were predominantly male ($n = 27$; 90%), with a median age of 36.6 [32.8–40.0] years. Most had considerable experience working both in active duty (15.5 [12.8–21.3] years) and in submarines (6.0 [2.0–9.0] years), and work satisfaction was reasonably high, with a median of 7.5 [6.0–8.0] points. Table 1 provides a summary of participants' baseline characteristics, including scores for demographics, substance intake habits, and psychological variables. Agreeableness and conscientiousness were the dominant personality traits, with a median score of 9.0 [8.0–10.0] and 8.0 [6.0–9.0], respectively. Conversely, neuroticism was clearly the least dominant, with a median score of 5.0 [4.0–6.0]. Regarding coping strategies, an approach coping style was distinctly favored, with a median score of 1.8 [1.5–2.1]. Locus of control scores revealed a predominantly internal locus of control in this cohort, with a median score of 10.0 [7.0–11.5].

Sleep related variables changes in relation to the mission

Sleep duration (SleepDur) and quality (SleepQual), sleepiness at the beginning and end of each work shift, and caffeine consumption, in the three study periods, are shown in Figure 1 and Table 2.

Table 1. Participants baseline characteristics.

Participants characteristics ($n = 30$)	
Sex (male:female)	27:3
Age in years, Md [Q1-Q3]	36.6 [32.8–40.0]
Active-duty years, Md [Q1-Q3]	15.5 [12.8–21.3]
Submarine years, Md [Q1-Q3]	6.0 [2.0–9.0]
Work satisfaction (scale 1 to 10), Md [Q1-Q3]	7.5 [6.0–8.0]
Caffeine users, n (%)	28 (93.3)
Smokers, n (%)	14 (46.7)
Alcohol consumption at least 1–2 times per week, n (%)	18 (60)
Big Five Inventory-10 (BFI-10) questionnaire scores, Md [Q1-Q3]	
Agreeableness	9.0 [8.0–10.0]
Conscientiousness	8.0 [6.0–9.0]
Extraversion	6.0 [6.0–8.0]
Openness to experience	6.5 [6.0–8.0]
Neuroticism	5.0 [4.0–6.0]
Brief-COPE questionnaire scores, Md [Q1-Q3]	
Approach coping style	1.8 [1.5–2.1]
Avoidant coping style	0.8 [0.8–1.1]
Rotter Locus of Control scale score, Md [Q1-Q3]	10.0 [7.0–11.5]

Md: median; Q1-Q3: interquartile range.

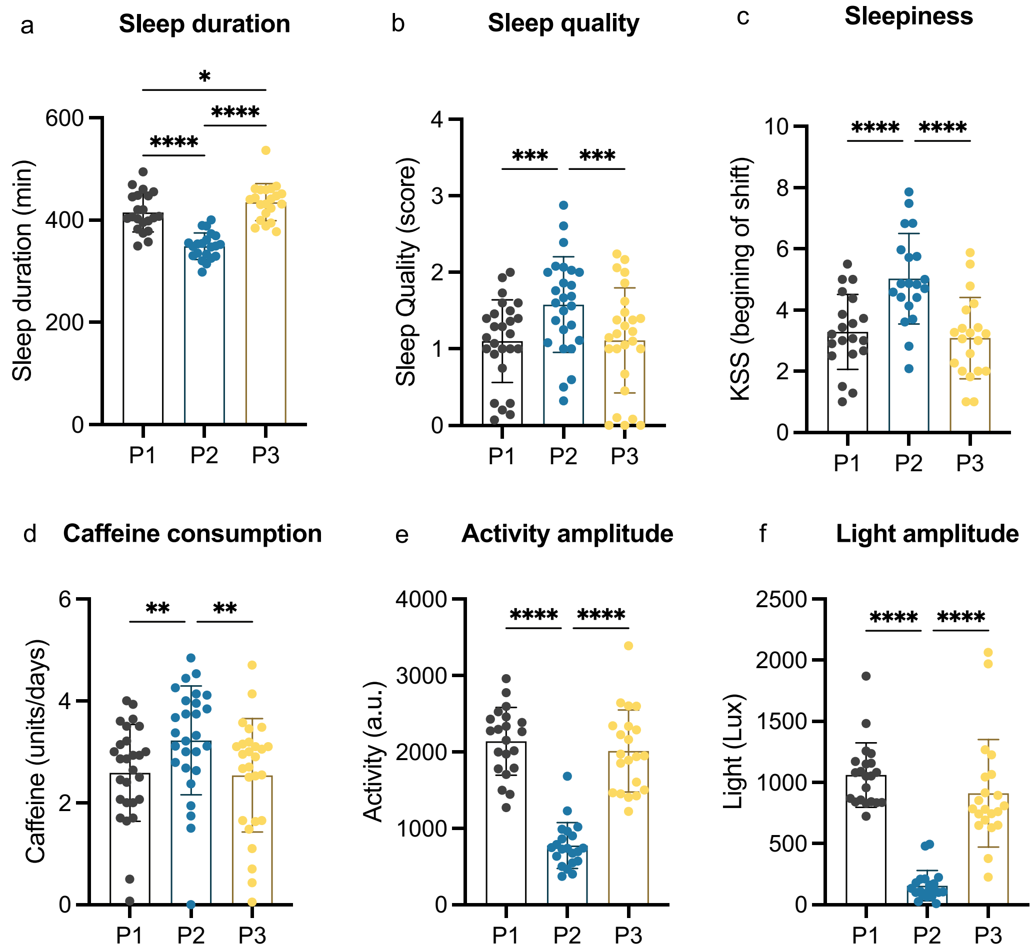

Figure 1. Sleep duration (a) and quality (b), subjective sleepiness at the beginning of work shifts (c), caffeine consumption (d), activity (e) and light (f) amplitudes in the three study periods. Data retrieved from actigraphy or diary and mean values for each period were computed for each subject. Sleep quality score: rating 0=very good to 3=very bad. Sleepiness score: Karolinska sleepiness scale, rating 0=extremely alert to 9=very sleepy; P1: pre-mission/baseline period; P2: mission period; P3: post-mission /recovery period. Wilcoxon signed-rank test: *****p* < .0001; ****p* < .001; ***p* < .01; **p* < .05.

Reported SleepDur corresponds to the total sleep time within a 24-hour period for all the study periods. During the mission, submariners typically had two sleep bouts for each 24-hour period due to the 6 h-on/6 h-off schedule.

Both SleepDur and SleepQual were significantly lower during the mission period when compared to both baseline and recovery ($p < .001$). Median SleepDur during the mission was 55 minutes shorter than pre-mission and 91 minutes shorter than post-mission. Median SleepQual was 0.45 points lower during the mission compared to both pre and post-mission periods. Conversely, SleepQual at baseline and recovery did not differ, while SleepDur was 36 minutes longer on recovery compared to baseline period ($p = .015$). Daily caffeine consumption was higher during the mission, compared to the pre ($p = .005$) and post-mission ($p < .001$) periods. Sleepiness was consistently higher at the end of each shift when compared to its beginning, in all periods (P1 beginning vs P1 end: $Z = -2.658$, $p = .008$; P2 beginning vs P2 end: $Z = -2.153$, $p = .031$; P3 beginning vs P3 end: $Z = -2.937$, $p = .003$). When comparing the three periods, a similar pattern to the other sleep-related variables emerged, with subjective sleepiness, both at the beginning and at the end of the work shifts, being significantly

Table 2. Sleep and psychological variables at the three periods: group scores and comparisons between these periods.

Variable	Baseline	Mission	After recovery	P1 vs P2	P3 vs P2	P1 vs P3
Fatigue	30.5 [25.0–39.5]	33.5 [25.0–37.5]	30.0 [24.8–37.5]	$p = .68$	$p = .11$	$p = .18$
Anxiety symptoms	5.0 [3.8–7.0]	5.0 [3.0–7.0]	4.0 [2.0–6.0]	$p = .45$	$p = .15$	***p* = .02***
Depressive symptoms	3.0 [1.0–7.3]	3.0 [1.0–5.0]	2.0 [0.8–6.0]	$p = .42$	$p = .11$	$p = .12$
Sleep Duration (minutes)	404.0 [382.0–446.0]	349.0 [330.–369.0]	440.0 [406.0–459.0]	***p* <.001***	***p* <.001***	***p* = .002***
Sleep Quality (rating 0 =very good to 3=very bad)	1.15 [0.97–1.43]	1.60 [1.08–2.00]	1.15 [0.67–1.48]	***p* <.001***	***p* <.001***	$p = .99$
Caffeine intake (units)	2.64 [2.00–3.17]	3.27 [2.64–3.99]	2.90 [1.65–3.15]	***p* = .005***	***p* <.001***	$p = .38$
Sleepiness shift beginning	3.00 [2.00–3.76]	4.85 [3.68–6.12]	3.00 [2.00–3.43]	***p* <.001***	***p* <.001***	$p = .808$
Sleepiness shift end	3.85 [2.75–5.04]	5.34 [4.20–6.41]	3.25 [2.92–4.82]	***p* = .004***	***p* = .002***	$p = .251$

Sleep duration was retrieved from actigraphy, while sleep quality, caffeine intake, and sleepiness were retrieved from diary, and median values for each period are reported; Fatigue, anxiety and depressive symptoms during the mission were reported on the last day of the mission; P1: baseline; P2: mission; P3: after recovery; Median [Q1-Q3]; *$p < .05$, Wilcoxon signed-rank test.

higher during the mission period compared to both baseline ($p < .001$ and $p = .004$) and recovery ($p < .001$ and $p = .002$). During the mission, median sleepiness at the beginning of work shifts was 1.85 points higher compared to both pre-mission and post-mission periods. Median sleepiness at the end of work shifts was 1.49 points higher than pre-mission and 2.09 points higher than on post-mission.

For further analyses, only sleepiness at the beginning of each work shift was considered.

Other repeatedly measured variables changes in relation to the mission

As expected, both activity and light intensity amplitude levels were very low during the mission and significantly lower when compared to both baseline and recovery ($p < .001$), as shown in Figure 1e,f and Table 2.

Fatigue, anxiety, and depressive symptoms were measured repeatedly in each of the study sub-periods. Only anxiety symptoms have shown a significant change, being higher in the baseline pre-mission period, when compared to the end of the post-mission recovery period ($p = .023$), however, not during mission period itself (see Table 2).

Relationships between sleep and psychological variables

Spearman's rank order correlations between different psychological variables and between psychological and sleep variables are shown in Table 3.

No correlations were found between environmental light levels and sleep variables, or with psychological variables, including anxiety and depression.

There were also no correlations of psychological variables with SleepDur. However, correlations with SleepQual and sleepiness at the beginning of work shifts were found.

Work satisfaction and anxiety symptoms had the higher proportion of correlations with sleep related variables. Higher work satisfaction correlated with higher SleepQual ($\rho = -0.40$, $p = .031$; $\rho = -0.40$, $p = .040$; $\rho = -0.40$, $p = .040$) and lower sleepiness at the beginning of work shifts ($\rho = -0.56$, $p = .003$; $\rho = -0.40$, $p = .043$; $\rho = -0.44$, $p = .037$) in all three periods. Conversely, higher anxiety symptoms correlated with lower SleepQual ($\rho = 0.58$, $p = .001$) and higher sleepiness ($\rho = 0.49$, $p = .011$) in the pre-mission period, and with lower SleepQual in the post-mission period ($\rho = 0.48$, $p = .011$).

Regarding personality traits, in the mission period higher extraversion scores correlated with both higher SleepQual ($\rho = -0.42$, $p = .030$) and lower sleepiness at the beginning of work shifts ($\rho = -0.40$, $p = .042$). In the recovery period, an approach coping style correlated with higher SleepQual ($\rho = -0.41$, $p = .034$). All the correlations described above can be classified as moderate, with a few exceptions which are at the lower end of a strong correlation. Exploring

Table 3. Spearman´s Rank-Order Correlation Coefficients between baseline characteristics, psychological and sleep variables.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
1 - Age	1																										
2 - Navy Yrs	**0.95**	1																									
3 - Subs Yrs	**0.84**	**0.86**	1																								
4 - Work Sat	0.03	0.07	0.06	1																							
5 - BFI E	−0.04	0.00	−0.05	0.26	1																						
6 - BFI A	−0.01	0.07	0.16	0.26	0.19	1																					
7 - BFI C	−0.08	−0.08	−0.20	0.11	0.06	−0.22	1																				
8 - BFI N	**0.41**	**0.43**	**0.55**	0.14	−0.14	−0.18	0.16	1																			
9 - BFI O	−0.30	−0.21	−0.24	−0.22	−0.09	0.17	0.02	−0.25	1																		
10 - COPE Av	**0.40**	**0.43**	**0.55**	−0.07	0.06	0.09	0.08	**0.55**	−0.30	1																	
11 - Cope App	0.21	0.19	0.25	0.36	0.23	**0.50**	−0.01	−0.05	0.04	0.12	1																
12 - LC	**0.44**	**0.52**	**0.38**	−0.23	−0.03	0.15	0.04	0.13	−0.11	0.34	0.05	1															
13 - Anx P1	0.18	0.17	0.26	−0.33	−0.21	−0.29	−0.19	**0.64**	−0.29	**0.43**	−0.23	0.18	1														
14 - Anx P2	0.21	0.12	0.31	−0.36	−0.09	−0.19	0.00	0.28	−0.26	0.20	−0.03	0.10	**0.39**	1													
15 - Anx P3	0.02	−0.01	0.20	**−0.44**	−0.03	−0.33	−0.03	**0.46**	−0.14	0.30	**−0.42**	0.05	**0.64**	**0.42**	1												
16 - Dep P1	0.28	0.20	0.26	−0.33	−0.29	**−0.48**	0.01	0.30	−0.26	**0.40**	−0.25	0.33	**0.51**	**0.51**	**0.45**	1											
17 - Dep P2	**0.41**	**0.39**	0.36	−0.32	−0.16	**−0.46**	−0.12	0.27	**−0.43**	0.30	−0.32	0.29	**0.51**	**0.54**	0.36	**0.76**	1										
18 - Dep P3	0.13	0.04	0.24	**−0.36**	−0.06	−0.23	−0.18	0.02	−0.22	0.28	−0.15	0.07	0.27	0.33	**0.52**	**0.57**	**0.53**	1									
19 - Sleep Dur P1	−0.03	−0.12	0.02	−0.01	0.35	0.18	0.12	−0.18	−0.23	−0.02	0.25	0.08	−0.02	**0.42**	0.12	0.04	0.04	0.22	1								
20 - Sleep Qual P1	−0.35	−0.29	−0.18	**−0.40**	−0.07	−0.05	−0.22	0.13	−0.04	0.15	−0.26	−0.04	**0.58**	0.08	**0.49**	−0.06	−0.01	0.03	**−0.42**	1							
21 - SIWBe P1	−0.17	−0.21	−0.11	**−0.56**	−0.37	−0.30	−0.28	0.05	−0.00	0.07	−0.19	0.05	**0.49**	**0.49**	0.37	**0.44**	0.33	**0.44**	0.00	**0.53**	1						
22 - Sleep Dur P2	−0.06	−0.07	−0.10	−0.10	−0.06	0.06	0.07	0.16	−0.15	−0.12	−0.01	−0.00	0.36	**0.52**	0.07	0.04	0.15	−0.20	0.01	0.23	0.27	1					
23 - Sleep Qual P2	0.00	0.07	0.08	**−0.40**	**−0.42**	−0.06	−0.22	0.18	0.20	0.04	−0.11	0.34	0.33	0.07	0.07	0.00	0.09	−0.05	−0.26	0.33	0.34	−0.02	1				
24 - SIWBe P2	0.14	0.13	0.26	**−0.40**	**−0.40**	−0.06	−0.30	0.35	0.03	0.14	−0.12	0.19	**0.57**	0.37	0.24	0.30	0.24	0.11	−0.30	0.39	**0.70**	−0.08	**0.68**	1			
25 - Sleep Dur P3	0.25	0.16	0.01	0.26	0.22	0.05	0.15	−0.24	−0.21	−0.19	0.05	0.12	−0.01	0.37	−0.04	0.20	0.22	0.08	**0.73**	−0.36	−0.09	0.16	**−0.47**	−0.12	1		
26 - SleepQual P3	−0.05	−0.02	0.07	**−0.40**	−0.35	−0.19	−0.04	0.38	0.03	0.22	**−0.41**	0.25	**0.66**	0.28	**0.48**	0.22	0.19	0.08	−0.20	**0.63**	**0.49**	0.17	**0.69**	**0.66**	−0.29	1	
27 - SIWBe P3	−0.10	−0.13	−0.19	**−0.44**	−0.41	0.17	−0.01	−0.18	0.05	−0.00	−0.08	0.24	0.09	0.13	−0.03	0.12	−0.09	0.02	−0.13	0.33	**0.52**	0.18	0.23	0.33	0.08	0.31	1

Navy yrs: years of active duty in the Navy; Subs yrs: years of active duty in submarines; Work Sat: work satisfaction; BFI E: Extraversion trait score; BFI A: Agreeableness trait score; BFI C: Conscientiousness trait score; BFI N: Neuroticism trait score; BFI O: Openness to experience trait score; COPE Av: avoidant coping style score; COPE App: Approach coping style score; LC: Locus of control scale score; Anx P1: anxiety symptoms in pre-mission period; Anx P2: anxiety symptoms in mission period; Anx P3: anxiety symptoms in post-mission period; Dep P1: depressive symptoms in pre-mission period; Dep P2: depressive symptoms in mission period; Dep P3: depressive symptoms in post-mission period; SleepDur P1: Sleep Duration in the pre-mission period; SleepQual P1: Sleep Quality in the pre-mission period; SIWBe P1: Sleepiness at the beginning of work shifts in the pre-mission period; SleepDur P2: Sleep Duration in the mission period; SleepQual P2: Sleep Quality in the mission period; SIWBe P2: Sleepiness at the beginning of work shifts in the mission period; SleepDur P3: Sleep Duration in the post-mission period; SleepQual P3: Sleep Quality in the post-mission period; SIWBe P3: Sleepiness at the beginning of work shifts in the post-mission period. Statistical differences were set at $p < .05$ (significant p-values are highlighted with bold characters).

the robustness of these bivariate correlations between sleep and psychological variables further, generalized linear models were performed, with the sleep variables as dependent, when there were several relevant correlations in bivariate analysis (see Supplemental Table S1). All models were controlled for age and excluded female subjects, considering there were only three in this sample. In the pre-mission period, anxiety remained significantly associated with SleepQual, when controlling for work satisfaction ($p < .001$), whereas for sleepiness at the beginning of work periods, depressive symptoms remained associated with higher sleepiness ($p = .016$), but neither work satisfaction nor anxiety symptoms did. In the mission period, when evaluated together, only work satisfaction, but not extraversion trait, remained associated with SleepQual in the mission ($p = .016$). As for sleepiness in the mission period, both work satisfaction and extraversion remained associated with lower sleepiness ($p = .046$, $p = .002$) and, more robustly so, anxiety symptoms in the pre-mission period ($p < .001$). In the post-mission period, none of the variables correlated with SleepQual in bivariate analysis remained associated when evaluated together.

Considering the hypothesis of neuroticism traits and avoidant coping style influencing sleep parameters through anxiety symptoms as a mediator, a mediation analysis was performed using significant correlations between sleep variables and anxiety (Figure 2).

Indeed, there was an indirect effect of neuroticism, mediated by anxiety symptoms, on SleepQual and sleepiness in the pre-mission period, on sleepiness in the mission period, and on SleepQual in the post-mission period. An avoidant coping style also had an indirect effect, mediated by anxiety symptoms, on SleepQual and sleepiness on pre-mission period and on sleepiness during the mission period. These results suggest that higher neuroticism trait and higher avoidant coping style scores have a negative impact on several sleep-related parameters through associating with higher anxiety symptoms.

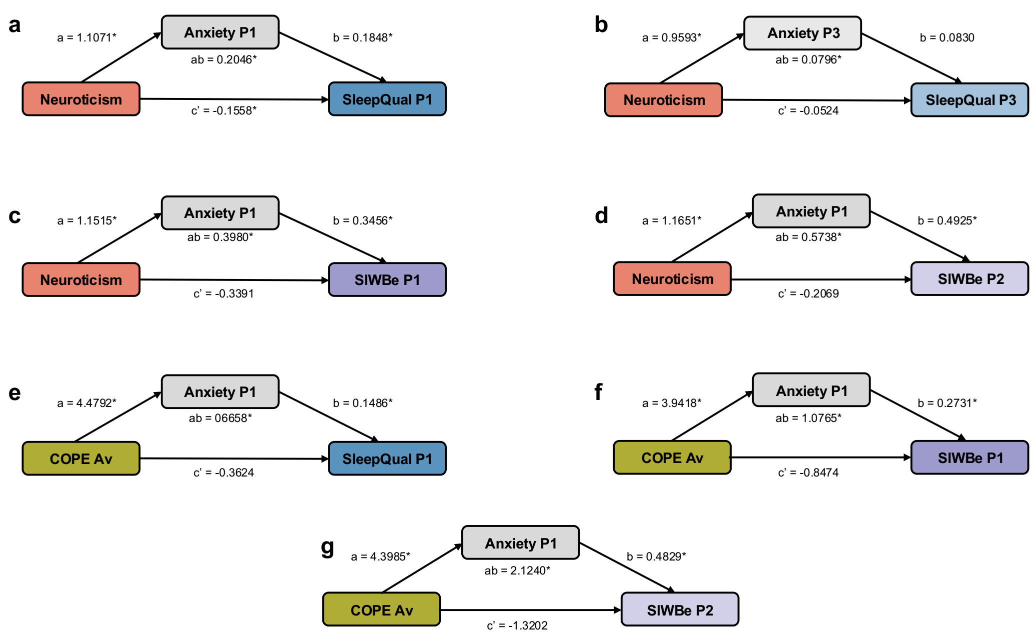

Figure 2. Mediation analysis (model 4) with neuroticism trait score (a, b, c and d) and avoidant coping style (e, f and g) as independent variables, sleep variables as dependent, and anxiety symptoms as mediator variable. SleepQual P1: sleep quality in the pre-mission period; SIWBe P1: sleepiness at the beginning of work shifts in the pre-mission period; SIWBe P2: sleepiness at the beginning of work shifts in the mission period; SleepQual P3: sleep quality in the post-mission period; anxiety P1: anxiety symptoms in pre-mission period; anxiety P3: anxiety symptoms in post-mission period; BFI N: neuroticism trait score; COPE av: avoidant coping style score.

Discussion

In this study, evaluating a group of military submariners before, during and after a submarine mission, overall, a detrimental effect of the mission on objective (SleepDur) and subjective (SleepQual and sleepiness) sleep-related variables was observed. Nonetheless, with a good recovery at 3-weeks post-mission. Previous studies on submariners had already demonstrated lower sleep quality and higher insomnia symptoms (Chabal et al., 2024), as well as low sleep duration and efficiency (Nieuwenhuys et al., 2021) during submarine missions. However, the recovery period after the mission has scarcely been evaluated. Although the mission period is critical, due to the need for excellent performance to achieve goals and ensure safety standards, failing to recover sleep quantity and quality after the mission would mean a further detriment in the following one.

There was no relationship between sleep duration and psychological factors. However, there were a few correlations with subjective sleep variables (sleep quality and sleepiness). Only during the mission, higher extraversion trait scores and greater work satisfaction correlated with better sleep quality and lower sleepiness at the beginning of work shifts. This highlights the importance of these traits for better sleep, particularly in extreme environments. Although limited, there is some evidence that establishes a positive relationship between job satisfaction and sleep quality (Chang & Chang, 2019; Qin et al., 2023) and between extraversion trait and sleep quality (Stephan et al., 2018). Indeed, extraversion is related to lower reactivity to stressors which may lower the likelihood of sleep disruption in a challenging environment (O'Riordan et al., 2023). Additionally, work satisfaction and extraversion may be interdependent, a relationship that has been previously demonstrated (Zhou et al., 2023) and supported by extraversion being related to higher sociability, energy and assertiveness, promoting social interaction and resilience to stress, and possibly resulting in a more positive attitude toward work tasks. In fact, both these factors may impact team environment, dynamics, and cohesion, especially considering the singular relevance of interpersonal interactions in isolated and confined environments such as a submarine (Landon et al., 2019).

Anxiety symptoms were the psychological factor more consistently associated with sleep variables, which is not unexpected given previous research documenting a robust bidirectional relationship between anxiety and sleep disturbances (Peng et al., 2024). However, anxiety symptoms are common in high stress settings, which can certainly be the case of military and other operational contexts. Interestingly, in our study, anxiety symptoms were highest in the pre-mission period, a possible effect of mission anticipatory stress. There was also an interesting finding of a negative impact of an avoidant coping style on sleep quality and sleepiness mediated by anxiety symptoms in the pre-mission period. This may reflect a dysfunctional coping mechanism enhancing mission anticipatory stress, which impacted negatively upon sleep.

Higher scores on neuroticism and avoidant coping strategies also seemed to have a detrimental effect on sleep quality and sleepiness across all periods mediated by anxiety. This was only an indirect effect, possibly due to the small sample size (Agler & De Boeck, 2017), and signals for a complex interaction between these variables that merits further exploration. In any case, it is somewhat in line with population-based research findings, in which the influence of personality traits and sleep measures were rather modest, and, among these, neuroticism had the stronger association, specifically with poorer sleep quality (Duggan et al., 2014; Guerreiro et al., 2024; Hintsanen et al., 2014). Nevertheless, this population is not general by any means: they undergo a double and strict selection process (first for the Navy, and later for the submarine specialization), they have constant rigorous training, and our sample was comprised of quite experienced submariners. This is somewhat supported by the very low representation of dysfunctional psychological traits in this sample. As such, it was not immediately expected that dysfunctional personality and psychological traits would have a negative impact on sleep. However, even in this strictly selected, constantly trained and experienced group of submariners, psychological factors still seemed relevant for sleep quality and sleepiness.

Contrary to expected, despite the significantly decreased amplitude in activity and light levels during the mission, these were not correlated with sleepiness or sleep quality, as previously reported for the general population (Korman et al., 2022). Further factors that may explain these results need to be explored.

The present study may be broadly placed on the vast field of human-related factors in extreme occupational settings. Such settings are of growing interest, as human exploration of remote locations on earth, sea, and space is increasing, for both work and leisure (space and deep-sea tourism are already a reality) (De Araújo et al., 2023). However, intrinsic to these extreme environments is their uniqueness, preventing direct extrapolations between different settings. Indeed, there have been previous studies focusing on sleep in extreme environments and focusing on the interaction between sleep and psychological factors in general and specific populations. However, there are very few studies addressing this interaction in extreme occupational settings and even fewer with more robust measures of sleep. Further, to our knowledge, there are no published studies evaluating the interaction of sleep with psychological factors in a submarine setting.

Other strengths of this study include the homogeneity of the population characteristics, mitigating some potential confounding factors, and having an objective measure for sleep duration and a daily report for subjective sleep-related variables.

This study has several limitations, which warrant acknowledgment and may also inform future research. An obvious limitation in the small sample size, which may account for the absence of more robust and significant associations. One possible example is the somewhat unexpected lack of associations between sleep variables and locus of control; indeed, we expected that a more external locus of control would correlate to worse sleep. However, submariners are a very specific and restricted group of professionals, and the number of subjects included in the present study represents roughly the standard crew in the diesel-electric category of submarines, which is the most represented worldwide. It is also worth noting that this sample is highly homogenous, due to the selection process and niche group culture of these professionals, allowing for the elimination of several confounders. Nevertheless, our study sample was almost exclusively constituted by men. While this is the reality in most operational working populations, the generalizability of these findings for women remains to be determined.

The personality scale was a brief instrument. It is possible that an extended version could better discriminate subjects regarding each trait subscale and, consequently, more robust associations could have been found.

It would have also been relevant to have performance measures to evaluate the impact of sleep detriment on performance and safety outcomes during the mission period. However, defining relevant performance outcomes and metrics in this setting is challenging, and these determinations should have the least possible interference with the work tasks, which is also challenging in an operational setting with high workload such as this one.

Finally, the study submarine mission could be considered somewhat short (3 weeks). A few studies have been conducted in longer submarine missions (Nieuwenhuys et al., 2021; Puyvelde et al., 2022) nevertheless these are still scarce, and it would be relevant to consider missions of different durations.

This study has demonstrated that psychological factors are relevant for sleep in extreme occupational settings, especially regarding subjective parameters, even in highly selected and extensively trained populations such as experienced military submariners, and that these can be both somewhat protective during critical operational periods, as well as detrimental when representing dysfunctional traits. Given the potential for psychological interventions, these findings may inform opportunities for countermeasures implementation and future studies evaluating their outcome.

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No potential conflict of interest was reported by the author(s).

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