Effects of military submarine activities on sleep quality: a systematic review

Efectos de las actividades en submarinos militares sobre la calidad del sueño: una revisión sistemática

Abstract: This study aims to analyze the effects of military submarine activities on sleep quality. A systematic review based on a search carried out on the PubMed, Cochrane, Web of Science, LILACS, SCOPUS, and Embase databases in October 2023 (updated in July 2025) following the PRISMA 2020 guidelines. The descriptors "submariners" and "sleep" (found on MeSH and DeCS) and their synonyms were used. Studies that sampled submariners were included, the results of which indicated sleep quality, medical and laboratory tests, and self-reported questionnaires. In total, 198 articles were retrieved from the databases, of these, six studies were included in this review. Several sleep assessment instruments were found, such as questionnaires, laboratory analyses of salivary melatonin and cortisol, and wrist actigraphy data. Submarine activities affect sailors' total sleep time and self-reported sleep quality. The operational shift work on submarines negatively affects sailors' quality of sleep.

Keywords: Submariner, Sleep, Inadequate Sleep, Military Personal.

Resumen: Este estudio tiene como objetivo analizar los efectos de las actividades en submarinos militares sobre la calidad del sueño. Se realizó una revisión sistemática basada en una búsqueda en las bases de datos PubMed, Cochrane, Web of Science, LILACS, SCOPUS y Embase en octubre de 2023 (actualizada en julio de 2025) siguiendo las directrices PRISMA 2020. Se utilizaron los descriptores "submariners" y "sleep" (encontrados en MeSH y DeCS) y sus sinónimos. Se incluyeron estudios que muestrearon a submarinistas, cuyos resultados indicaban calidad del sueño, pruebas médicas y de laboratorio, y cuestionarios de autoinforme. En total, se recuperaron 198 artículos de las bases de datos; de estos, seis estudios se incluyeron en esta revisión. Se encontraron varios instrumentos de evaluación del sueño, como cuestionarios, análisis de laboratorio de melatonina y cortisol salivales, y datos de actigrafía de muñeca. Las actividades en el submarino afectan al tiempo total de sueño de los marineros y a la calidad del sueño autoinformada. El trabajo por turnos operativo en los submarinos afecta negativamente a la calidad del sueño de los marineros.

Palabras claves: submarinista, sueño, sueño inadecuado, personal militar.

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1 INTRODUCTION

The environmental and operational challenges submariners face in maintaining good sleep are numerous, including noise inside the vessel (Chabal *et al*., 2023), deprivation of natural light and the 24-hour day-night circadian rhythm (Van Puyvelde *et al*., 2022), frequent interruptions (Chabal *et al*., 2023), and shift work (Duplessis *et al*., 2007). However, the successful employment of submarine actions depends on teams that, most of the time, work under physiological and cognitive fatigue (Chabal *et al*., 2018), making sleep quality one of the important points in the success and safety of missions, increasing performance, and reducing accidents (Mysliwiec *et al*., 2013b).

Sleep is considered an essential recovery mechanism for restoring energy, upkeeping the immune system, and replenishing psychophysiological resources (Nieuwenhuys *et al*., 2021). Additionally, long-term sleep problems can increase physiological and psychological issues (Good *et al*., 2020) including: cardiovascular disease (Ulmer et al., 2016), post-traumatic stress disorder, and changes in mood (Good *et al*., 2020; Mysliwiec*et al*., 2013b).

The main American sleep study foundations and academies recommend sleeping a minimum of seven hours per night for adults over 18 years of age (Hirshkowitz *et al*., 2015; Watson *et al*., 2015). However, a large North American epidemiological study with data from more than 110,000 individuals found that more than 37% of Americans slept less than the recommended continuous hours of rest per night (Krueger; Friedman, 2009). The same study also pointed out that some variables are associated with long or short sleep, such as demographic, family structure, socioeconomic, behavioral, and health status variables. In this panorama, studies carried out with military samples from different segments (Army, Air Force, and Navy) indicate a total sleep time below the recommended level for several reasons, mainly due to the peculiarities of their work activities (Ferreira *et al*., 2023; Margel; White; Pillar, 2003; Mysliwiec*et al*., 2013a; Van Puyvelde *et al*., 2022).

A systematic literature review is important to provide input regarding gaps for future experimental studies and to offer a foundation in the history of the subject. Therefore, this systematic review aims to analyze the effects of military submarine activities on sleep quality in those under extreme working conditions.

2 METHODOLOGY

This study was registered on the International Prospective Registry of Systematic Reviews — PROSPERO (CRD42023445442) — and written according to the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines (Liberati *et al*., 2009).

2.1 Search strategy

A search was carried out in October 2023and updated in July 2025 on PubMed, Cochrane, Web of Science, LILACS, SCOPUS, and Embase. The descriptors "submariners"

and "sleep" (found on MeSH and DeCS) and their synonyms were used with no delimitation of period or language. The search phrases were obtained using the Boolean operators AND (between descriptors) and OR (between synonyms). Moreover, the reference lists in the retrieved research were explored to find additional relevant studies.

2.2 Eligibility Criteria

The studies in this review met the criteria described in Table 1.

Table 1 – Inclusion criteria

P	Participants	Submariners
E	Exhibition	Activity in a submarine environment
C	Comparison	Group with no exposure to the underwater environment or pre- and post-exposure comparisons
O	Outcome	Sleep quality indicators, medical and laboratory tests, self-reported questionnaires, etc.
S	Study design	Observational

Source: Authors (2024).

2.3 Study selection

The studies were assessed for eligibility by two independent reviewers using the Rayyan Qatar Computing Research Institute online review software, available at https://rayyan.qcri.org. Duplicates were removed before the title and abstract of the articles were screened. The full texts of the remaining studies were retrieved and assessed for eligibility. Any disagreements regarding the inclusion of a study were solved bya consensus meeting or decided by a third reviewer.

2.4 Data extraction

The following data were extracted from the selected studies: author, year of publication, country, sample, sex, age, study design, objective, segment, sleep quality assessment instrument, and results. The data from the selected studies was independently extracted by two reviewers, and disagreements were resolved by a consensus meeting or decided by a third reviewer.

## 2.5 Assessment of the methodological quality of studies

The National Institutes of Health Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies was used to assess the risk of bias of the included studies (Available at: https://www.nhlbi.nih.gov/health-topics/study-quality-assessment-tools). The reviewers independently answered each question as "Yes," "No," "Unable to determine," "Not applicable," or "Not informed" based on the critical review of each study. Questions answered

with "'Yes" received a score of 1, while other answers, a score of 0. The total score of each study was used to classify the risk of bias as low (10-14) moderate (5-9), or high (0-4). Disagreements were resolved by a consensus meeting or decided by a third evaluator.

3 RESULTS

This study found198 articles and removed 48 duplicates. After screening, 144 failed to meet the inclusion criteria and were excluded from the sample. Figure 1 summarizes the search results and reasons for exclusion. This systematic review included six studies. Table 1 and 2 show the characteristics of these studies and their results. Table 3, shows their methodological quality score and risk of bias.

Figure 1 – Flowchart of the studies in this systematic review on the effects of military submarine activities on sleep quality
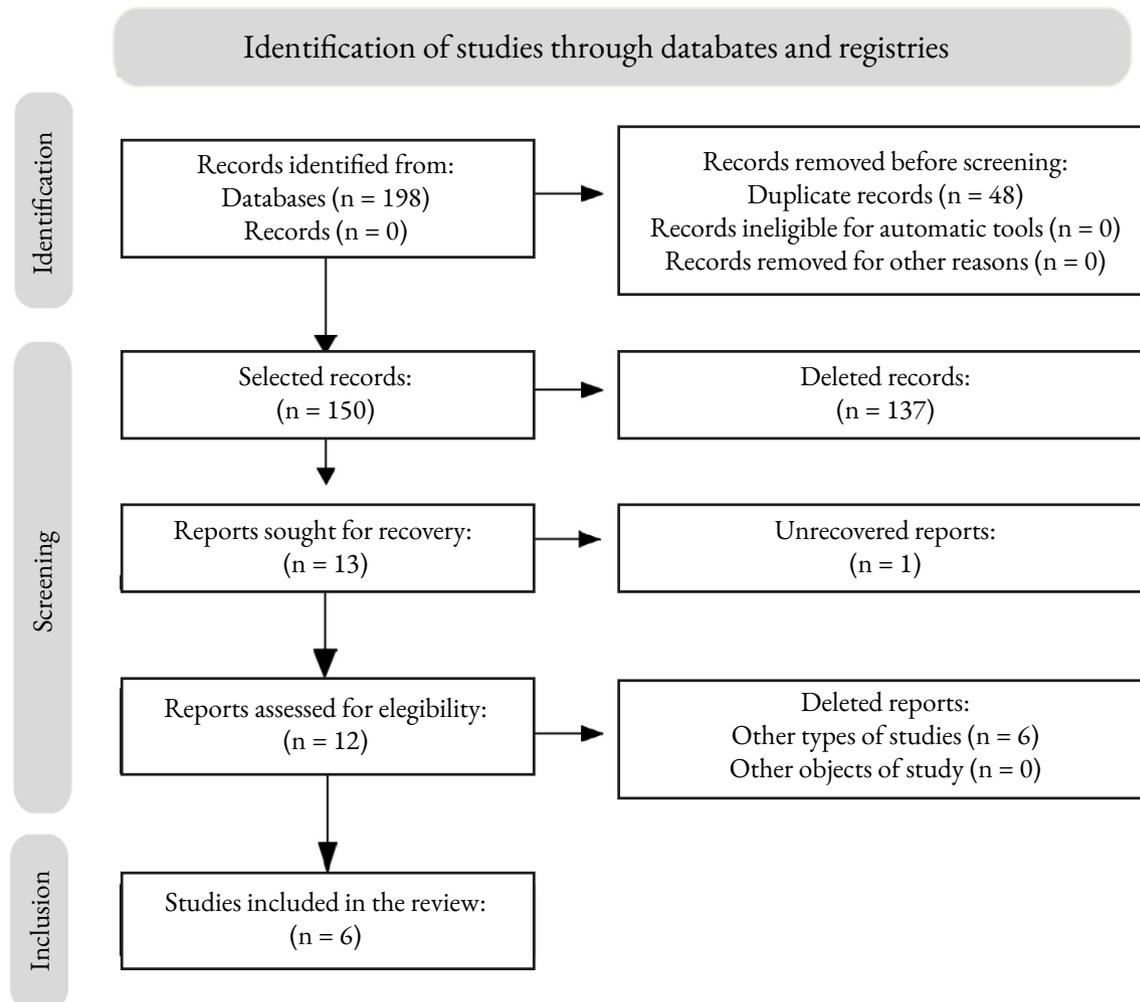
Source: Authors (2024).

Table 1 – General characteristics of the selected studies

Author	Year	Country	N	Sex	Mean age ± SD (years)	Study design	Goal	Follow-up (mission days)
Kelly *et al.* (1999)	1999	USA	20	♂	23.00±3.00	Cohort	Investigate the circadian rhythms of salivary melatonin.	42
Margel, White, and Pillar (2003)	2003	Israel	8	♂	23.00±3.00	Cohort	Monitor sleep by observing respiratory disturbances.	11
Martin-Krumm *et al.* (2021)	2021	France	29	♂	29.80±6.45	Cohort	Evaluate the impact of physical activity on thymic regulation and health.	50
Nieuwenhuys *et al.* (2021)	2021	Netherlands	14	♂	27.36±3.57	Cohort	Examine daily fluctuations in sleep, cognitive performance, and recovery status.	67
Van Puyvelde *et al.* (2022)	2022	Netherlands	8	♂	27.36±3.57	Cohort	Analyze the occurrence of physiological and behavioral adjustment for hormonal secretion and sleep.	67
Chabal *et al.* (2023)	2023	USA	58	♂	27.8	Cohort	Relate the use of caffeine by submariners working within the operational environment with sleepiness.	30

N= number of participants; ♂= male; SD= standard deviation; Source: Authors (2024).

Table 2 – Assessment segment, sleep quality assessment instrument, and results of the selected studies

Author	Segment	Sleep quality assessment instrument	Results
Kelly *et al.* (1999)	Saliva was collected at the beginning, middle, and the end of six weeks of patrol. Questionnaires were answered daily.	Salivary melatonin; NHRC sleep questionnaire; MEQ; and daily sleep records.	Melatonin (24.35 ± 0.18 h) close to the estimated human circadian pacemaker period in this environment. Questionnaire data showed no relationship with melatonin.
Margel, White e Pillar (2003)	Measurements: 1- moored submarine; 2- start of the mission; and 3- end of the mission.	Wrist actigraphy (TST and ES); Epworth Sleepiness Scale (ESE).	TST (285 ± 46.8 min); ES (77 ± 11%); ESE (7.8 ± 3.4).
Martin-Krumm *et al.* (2021)	Sample: practitioners of physical activity on the vessel (AF) and non-practitioners (n-AF) pre- and post-mission.	Leeds Sleep Evaluation Questionnaire (LEEDS).	Sleep duration decreased in the post-AF group when compared withthe pre-AF group, unlike the n-AF group (p = 0.09).

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Table 2 – Continuation

Author	Segment	Sleep quality assessment instrument	Results
Nieuwenhuys *et al*. (2021)	Sleep data were continuously collected for the entire 67 days of the mission, referring to 61 complete 24-hour cycles.	Pittsburgh Sleep Quality (PSQI); HSDQ; Wrist actigraphy (TST, SOL, WASO, and ES).	PSQI (4.8 ± 1.29); HSDQ (1.48 ± 0.22); TST (345.60 ± 87.83 min); SOL (13.30 ± 15.03 min); WASO (26.62 ± 15.25 min); and ES (82.52 ± 9.91%).
Van Puyvelde *et al*. (2022)	Sample analysis: group 1, "daytime sleep group" (operational block 1: 00:00–06:00 h, 2: 12:00–18:00 h) and group 2, "nighttime sleep group" (operational block 1:06:00–12:00 h, 2:18:00–24:00 h).	Salivary cortisol and melatonin; wrist actigraphy (TST, SOL, WASO, and ES).	Cortisol spikes > after sleep blocks with longer sleep periods; i.e., (5.14 ± 1.41 versus 2.13 ± 2.00 in group 1 and 4.95 ± 2.71 versus 1.28 ± 0.76 in group 2, $[F_{(1, 7)} = 9.379, P = 0.018]$. Melatonin showed a preserved endogenous rhythm that peaks in the morning and decreases during the day. Interaction effect between group and block for TST $[F_{(1, 190067.34)} = 126.258, P < 0.001]$, SOL $[F_{(1, 343)} = 1188.94, P < 0.001]$, ES $[F_{(1, 7.068)} = 18.867, P = 0.003]$, and WASO-min $[F_{(1, 6.969)} = 20.318, P = 0.003]$.
Chabal *et al*. (2023)	Comparison of the same soldiers on land and at sea, with eight-hour work shifts.	Wrist actigraphy; AND IF; PSQI; MEQ; and Insomnia Severity Index.	Positive relationships between caffeine consumption and sleep efficiency $(F = 6.11, p = 0.02)$, and negative relationships between consumption and wakefulness after sleep onset $(F = 9.36, p = 0.004)$ and sleep fragmentation $(F = 24.73, p < 0.0001)$. Greater caffeine consumption was also negatively related to self-reported sleep duration at sea $(F = 4.73, p = 0.03)$

NHRC= Naval Health Research Center; MEQ= Morningness-Eveningness Questionnaire; TST= total sleep time; ES= sleep efficiency; HSDQ= Holland Sleep Disorder Questionnaire; SOL= sleep latency; WASO= time awake after the onset of sleep; Source: Authors (2024).

The methodological quality scores of the studies in this systematic review ranged from 8 to 10 out of 14 possible points (Table 3). This review classified five studies as having a moderate risk of bias and one as having a low risk of bias. All studies in this review included their guiding question or objective (item 1) and specified the study population (item 2). Furthermore, all studies indicated a sufficient period in which they could reasonably expect an association between exposure and outcome (item 7), varying levels of exposure to the outcome (item 8), and valid and reliable outcome measures (item 11). However, most studies failed to justify their sample sizes (item 5) and none scored on items 12 and 14.

Table 3 – Quality assessment tool for observational cohort and cross-sectional studies

References	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Total	Risk of bias
Kelly *et al.* (1999)	Y	Y	NI	Y	N	Y	Y	Y	N	Y	Y	NI	NI	N	8	Moderate
Margel, White e Pillar (2003)	Y	Y	Y	N	N	Y	Y	Y	Y	Y	Y	NI	Y	NI	10	Low
Martin-Krumm *et al.* (2021)	Y	Y	NI	Y	N	Y	Y	Y	Y	Y	Y	NI	NI	NI	9	Moderate
Nieuwenhuys *et al.* (2021)	Y	Y	N	Y	Y	N	Y	Y	Y	Y	Y	NI	NI	NI	9	Moderate
Van Puyvelde *et al.* (2022)	Y	Y	NI	Y	N	Y	Y	Y	Y	Y	Y	NI	NI	NI	9	Moderate
Chabal *et al.* (2023)	Y	Y	Y	Y	N	Y	Y	Y	Y	N	Y	NI	N	NI	9	Moderate

Item 1: Was the research question or objective in this article clearly described?; Item 2: Was the study population specified and defined?; Item 3: Was the participation rate of eligible people at least 50%?; Item 4: Were all participants selected or recruited from the same or similar populations [including the same period]?; Were the inclusion and exclusion criteria for being in the study pre-specified and applied uniformly to all participants?; Item 5: Was a sample size justification, power description, or variance and effect estimates provided?; Item 6: For the analyses in this article, were the exposures of interest measured before the outcomes were measured?; Item 7: Was the deadline a sufficient one so one could reasonably expect to see an association between exposure and outcome if one existed?; Item 8: For exposures that may vary in amount or level, did the study examine different levels of exposure about the outcome (e.g., categories of exposure or exposure measured as a continuous variable)?; Item 9: Were exposure measures (independent variables) clearly defined, valid, reliable, and implemented consistently across all study participants?; Item 10: Were exposures assessed more than once over time?; Item 11: Were outcome measures (dependent variables) clearly defined, valid, reliable, and implemented in a manner consistent across all study participants?; Item 12: Were outcome assessors blind to participants' exposure?; Item 13: Was the loss to follow-up after baseline 20% or less?; Item 14: Have the main potential confounding variables been measured and statistically adjusted for their impact on the relationship between exposures and outcomes?; Y: yes; N: No; NA: Not applicable; NI: Not informed. Source: Authors (2024).

4 DISCUSSION

This systematic review aimed to analyze the effects of military submarine activities on sleep quality by including six articles.

The articles used several assessment instruments and methodological designs. Most studies included subjective measures of sleep experience in their self-report instruments, such as the Naval Health Research Center sleep questionnaire, the Epworth Sleepiness Scale, the Pittsburgh Sleep Quality (PSQI), the Morningness-Eveningness Questionnaire-, and the Insomnia Severity Index used by Americans (Bastien; Vallières; Morin, 2001; Johns, 1991); the Leeds Sleep Evaluation Questionnaire used by the French(Tarrasch; Laudon; Zisapel, 2003); and the Pittsburgh Sleep Quality Index, Holland Sleep Disorder Questionnaire, and a sleep diary used by the Dutch (Buysse *et al.*, 1979; Kerkhof *et al.*, 2013); Finally, the Israelis used the Epworth Sleepiness Scale (Johns, 1991). Moreover, laboratory analyses of salivary melatonin and cortisol were used in American and Dutch studies, and actigraphy data pulse measurements

were used to evaluate total sleep time, sleep latency, wakefulness, and sleep efficiency in the Israeli, Dutch, and American studies.

In general, the total sleep time of all articles that obtained this response using wrist actigraphy remained below that recommended for individuals aged over 18 years (Watson *et al.*, 2015): a minimum value of 4.75 hours (Margel; White; Pillar, 2003) and a maximum one of 6.62 hours (Van Puyvelde *et al.*, 2022). Likewise, the analysis of sleep quality in articles that used the PSQI indicated a 'poor' rating (Buysse *et al.*, 1979). However, the drowsiness results using the Epworth Sleepiness Scale (Johns, 1991) indicated "medium drowsiness."

In studies that evaluated shift work, Van Puyvelde *et al.* (2022) showed differences in total sleep time and efficiency for a biphasic sleep pattern. Both groups had longer (about from four to five hours) and short sleep periods (about 1.5 hours) during rest. Melatonin secretion showed a preserved endogenous rhythm and no direct causality effect in the analyses. Cortisol secretion showed adaptation to the shift work routine, indicating an adjustment to a rigorous work schedule, corroborating the study by Pattyn *et al.* (2017). This resembles Kelly *et al.* (1999), which investigated the circadian rhythms of salivary melatonin in crew members living an 18-hour work cycle (six of work and 12 of rest) who lived with crew members exposed to 24-hour stimuli, which may mediate synchronization such as clocks and social contacts. The endogenous melatonin rhythm showed an average period of 24.35 ± 0.18h. Data indicate that social contacts and knowledge of clock time are insufficient for entrainment to a 24-hour period in personnel who live an 18-hour rest cycle on board a submarine. The analysis in Chabal *et al.* (2023) was different. It showed no division of results into shifts, but the consumption of caffeine by submariners on board should be considered in the development of potential countermeasures for drowsiness in shift work conditions. It is important to highlight the in the environments and work/rest cycles of submarines across countries, making comparisons of study results difficult.

A strong point of this systematic review is the large number of bases of electronic data from which it retrieved its included articles. However, given the heterogeneous nature of the literature, this study performed no meta-analysis. Finally, despite its systematic and comprehensive search, this review included few studies, indicating the need for new research to support improvements in the quality of sleep of submariners.

5 CONCLUSION

Submarine activities affect sailors' total sleep time and self-reported sleep quality. Furthermore, the operational shift work on submarines negatively affects their quality of sleep. However, melatonin secretion showed a preserved endogenous rhythm, as did cortisol secretion (which adapted to such work routine).

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APPENDIX

Search phrases used in databases:

Databases	Search phrases
PubMed	(Submariners[Title/Abstract] OR Submarine[Title/Abstract]) AND (Sleep[Title/Abstract] OR "Sleep deprivation "OR "Sleep Hygiene"[Title/Abstract] OR "Sleeping Habits"[Title/Abstract] OR "Sleep Habits"[Title/Abstract] OR "Sleep Habit"[Title/Abstract] OR "Sleeping Habit"[Title/Abstract] OR "Sleep deprivation"[Title/Abstract] OR "REM sleep deprivation"[Title/Abstract] OR "Sleep Insufficiency"[Title/Abstract] OR "Sleep Insufficiencies"[Title/Abstract] OR "Insufficient Sleep"[Title/Abstract] OR "Inadequate Sleep"[Title/Abstract] OR "Sleep Fragmentation"[Title/Abstract] OR "Insufficient Sleep Syndrome"[Title/Abstract] OR "Insufficient Sleep Syndromes"[Title/Abstract] OR "Sleep Debt"[Title/Abstract] OR "Good Sleep Habits"[Title/Abstract] OR "Good Sleep Habit"[Title/Abstract])
Cochrane	Trials matching Sleep OR "Sleep deprivation "OR "Sleep Hygiene" OR "Sleeping Habits" OR "Sleep Habits" OR "Sleep Habit" OR "Sleeping Habit" OR "Sleep deprivation" OR "REM sleep deprivation" OR "Sleep Insufficiency" OR "Sleep Insufficiencies" OR "Insufficient Sleep" OR "Inadequate Sleep" OR "Sleep Fragmentation" OR "Insufficient Sleep Syndrome" OR "Insufficient Sleep Syndromes" OR "Sleep Debt" OR "Good Sleep Habits" OR "Good Sleep Habit" in Title Abstract Keyword AND submariner or Submariners in Title Abstract Keyword
Web of Science	submarines or Submariners (Tópico) and Sleep OR "Sleep deprivation "OR "Sleep Hygiene" OR "Sleeping Habits" OR "Sleep Habits" OR "Sleep Habit" OR "Sleeping Habit" OR "Sleep deprivation" OR "REM sleep deprivation" OR "Sleep Insufficiency" OR "Sleep Insufficiencies" OR "Insufficient Sleep" OR "Inadequate Sleep" OR "Sleep Fragmentation" OR "Insufficient Sleep Syndrome" OR "Insufficient Sleep Syndromes" OR "Sleep Debt" OR "Good Sleep Habits" OR "Good Sleep Habit"
SCOPUS	(TITLE-ABS-KEY (submariner OR submariners) AND TITLE-ABS-KEY (sleep OR "Sleep deprivation" OR "Sleep Hygiene" OR "Sleeping Habits" OR "Sleep Habits" OR "Sleep Habit" OR "Sleeping Habit" OR "Sleep deprivation" OR "REM sleep deprivation" OR "Sleep Insufficiency" OR "Sleep Insufficiencies" OR "Insufficient Sleep" OR "Inadequate Sleep" OR "Sleep Fragmentation" OR "Insufficient Sleep Syndrome" OR "Insufficient Sleep Syndromes" OR "Sleep Debt" OR "Good Sleep Habits" OR "Good Sleep Habit"))
LILACS	(Sleep OR "Sleep deprivation "OR "Sleep Hygiene" OR "Sleeping Habits" OR "Sleep Habits" OR "Sleep Habit" OR "Sleeping Habit" OR "Sleep deprivation" OR "REM sleep deprivation" OR "Sleep Insufficiency" OR "Sleep Insufficiencies" OR "Insufficient Sleep" OR "Inadequate Sleep" OR "Sleep Fragmentation" OR "Insufficient Sleep Syndrome" OR "Insufficient Sleep Syndromes" OR "Sleep Debt" OR "Good Sleep Habits" OR "Good Sleep Habit") AND (submariner or Submariners)
Embase	(submariner:ti,ab,kw OR submariners:ti,ab,kw) AND (sleep:ti,ab,kw OR 'sleep hygiene':ti,ab,kw OR 'sleeping habits':ti,ab,kw OR 'sleep habits':ti,ab,kw OR 'sleep habit':ti,ab,kw OR 'sleeping habit':ti,ab,kw OR 'sleep deprivation':ti,ab,kw OR 'rem sleep deprivation':ti,ab,kw OR 'sleep insufficiency':ti,ab,kw OR 'sleep insufficiencies':ti,ab,kw OR 'insufficient sleep':ti,ab,kw OR 'inadequate sleep':ti,ab,kw OR 'sleep fragmentation':ti,ab,kw OR 'insufficient sleep syndrome':ti,ab,kw OR 'insufficient sleep syndromes':ti,ab,kw OR 'sleep debt':ti,ab,kw OR 'good sleep habits':ti,ab,kw OR 'good sleep habit':ti,ab,kw)