RBFEx
ISSN Online: 2675-1372

Revista Brasileira de Fisiologia do Exercício

Systematic review

Effects of confinement on the physical conditioning and health of submariners: a systematic review

Efeitos do confinamento sobre o condicionamento físico e saúde de militares submarinistas: uma revisão sistemática

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ABSTRACT

Introduction: Submariners tend to be exposed to a metabolically unfavorable environment and occupational confinement factors that can affect their health, such as a sedentary lifestyle and high levels of stress. **Objetive:** This systematic review aimed to analyze the effects of confinement on the physical conditioning and health of submariners. **Methods:** A literature search (January 2022) was performed using Pubmed, Cochrane, Web of Science, SPORTDiscus e Embase. The protocol was registered in the International prospective register of systematic reviews (CRD42021225362). Studies were included that sampled submariners on mission, whose outcome was indicators of health or physical performance. **Results:** From a total of 2,334 articles, 5 studies were included in the review. The following were analyzed: cardiorespiratory fitness, body composition; the food frequency; the frequency of physical activity; the lipid profile, bone function markers and specific neuromotor tests; both in the comparison of onboard and non-embarked military personnel, as well as for only embarked personnel, or military personnel who worked on small or large submarines compared to military personnel who worked on aircraft carriers. Submariners show a negative change in the analysis of body composition, aerobic performance, biochemical analysis of lipids, bone function markers and endocrine regulators. **Conclusion:** Prolonged time aboard a submarine can compromise the health of the military.

Keywords: military personnel, submariner, physical training.

RESUMO

Introdução: Os submarinistas tendem a ser expostos a um ambiente metabolicamente desfavorável e fatores ocupacionais de confinamento que podem afetar sua saúde, como o estilo de vida sedentário e altos níveis de estresse. **Objetivo:** Esta revisão sistemática teve como objetivo analisar os efeitos do confinamento sobre o condicionamento físico e saúde de militares submarinistas. **Métodos:** Uma pesquisa bibliográfica (janeiro de 2022) foi realizada usando Pubmed, Cochrane, Web of Science, SPORTDiscus e Embase. O protocolo foi registrado no Registro Internacional Prospectivo de Revisões Sistemáticas (CRD42021225362). Foram incluídos estudos que tinham como amostra submarinistas em missão, cujo desfecho era indicadores de saúde ou de desempenho físico. **Resultados:** De um total de 2.334 artigos, 5 estudos foram incluídos na revisão. Foram analisadas: a aptidão cardiorrespiratória, a composição corporal; a frequência alimentar; a frequência de atividade física; o perfil lipídico, os marcadores de função óssea e testes neuro motores específicos; tanto na comparação de militares embarcados com não embarcados; quanto para somente embarcados, ou militares que trabalhavam em submarinos de pequeno ou grande porte comparados com militares que trabalhavam em porta-aviões. Militares submarinistas apresentam alteração negativa na análise da composição corporal, desempenho aeróbio, análise bioquímica de lipídeos, marcadores de função óssea e reguladores endócrinos. **Conclusão:** O tempo prolongado a bordo de um submarino pode comprometer a saúde dos militares.

Palavras-chave: militares; submarinista; treinamento físico.

Received: April 27, 2022; Accepted: August 30, 2022.

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Introduction

The population of submariners is epidemiologically unique, whose initial health status is considered good, as they undergo a specialized selection process and specific professional training [1]. However, submariners tend to be exposed to a metabolically unfavorable environment and occupational confinement factors that can affect health, such as a sedentary lifestyle [2], sleep deprivation [3], shift work [3,4], and high levels of stress [4].

Underwater activities involve prolonged periods of submersion with limited opportunity for physical exercise and a compromised supply of fresh food. The environmental conditions inside the vessel can contribute to cardiometabolic health problems, mainly impacted by the decrease in the practice of physical activity [2,5]. Long periods at sea can reduce aerobic conditioning in submariners [6]. It can impair the performance related to the specific underwater task, especially concerning restricted oxygen consumption during missions [7]. In addition, there is a change in the Body Mass Index (BMI) [6], indicating an increase in body fat levels after a mission [8], which can compromise the health of the military, as well as work in a restricted workspace.

Bennett, Schlichting, and Bondi [9] reviewed previous research that tried to measure physical deconditioning in submariners. A progressive increase in heart rate was observed after exercise, as a sign of cardiovascular compensation to maintain cardiac output. Knight et al. [10] reported a decrease of approximately 13% in maximal oxygen consumption (VO2max) measured by pre-and post-shipment levels. This implies that the health of these individuals may be compromised by the potential sedentary lifestyle. On the other hand, in adult men, a 1 MET increase in VO2max was associated with a 12% decrease in risk for all-cause mortality and cardiovascular diseases [11]. In this sense, the higher the VO2max, the better the individual's health status.

In this way, submariners need to adapt to working conditions and perform regular physical exercises in a confined environment. However, little is known about the physical conditioning and health of submariners [12]. Therefore, the objective of the present systematic review was to analyze the effects of confinement on the physical conditioning and health of submariners.

Methods

The present systematic review was written following the guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) [13]. The study protocol was registered in the International Prospective Registry of Systematic Reviews (CRD42021225362).

Search strategy

A search was performed in January 2022, in Pubmed, Cochrane, Web of Science, SPORTDiscus, and Embase databases. The following descriptors were used: "submariner" and "physical training" or "physical conditioning", or "exercise tests", together with their synonyms. The search phrases were obtained using the Boolean operators AND (between descriptors) and OR (between synonyms). In addition, the reference lists were explored to find additional relevant studies. There was no period and language delimitation for the search.

Eligibility criteria

The studies included in the review met the criteria described in Chart I.

Chart I - Inclusion criteria

P	**Participants**	Submariners
E	**Exposure**	Underwater mission
C	**Comparision**	The group not exposed to the underwater environment or pre and post-exposure comparison
O	**Outcome**	Health or physical performance indicators, blood and imaging tests, specific performance, etc.
S	**Study design**	Observational

Selection of studies and data extraction

Eligibility assessments of studies were performed independently by two reviewers. Studies were downloaded to Mendeley Desktop (version 1.19.8) and duplicates were removed before being sorted by title and abstract. The full texts of the remaining studies were retrieved and assessed for eligibility. Any disagreements regarding the inclusion of a particular study were resolved through a consensus meeting or decided by a third reviewer.

The following data were extracted from the included studies: author, year of publication, participant characteristics, sample size, study design, exposure, control, evaluation, follow-up, and results. Data extraction from selected studies was independently processed by two reviewers and disagreements were resolved through a consensus meeting or a decision by a third reviewer.

Assessment of the methodological quality of the studies

The National Institutes of Health (NIH) Quality Assessment Tool for observational cohort and cross-sectional studies (Available at: https://www.nhlbi.nih.gov/health-topics/study-quality-assessment-tools) was used to assess the risk of bias in included studies. Reviewers answered each question as "Yes", "No", "Unable to determine", "Not applicable" or "Not reported", based on the critical review of each study. Questions answered with ""Yes" received a score of 1, while questions answered with "No", "Unable to determine", or "Not reported" received a score of 0. The total score

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from each study was used to classify the risk of bias as low (10-14), moderate (5-9), or high (0-4). The methodological quality assessment was performed by two experienced evaluators independently. Any disagreements were resolved through a consensus meeting or a decision by a third evaluator.

Results

Selection of studies

A total of 2,334 articles were identified and 121 duplicate titles were removed. After screening citations, 2,193 did not meet the inclusion criteria and were excluded. A summary of search results and reasons for exclusion are shown in Figure 1. Five studies were included in this systematic review and are summarized in Table I.

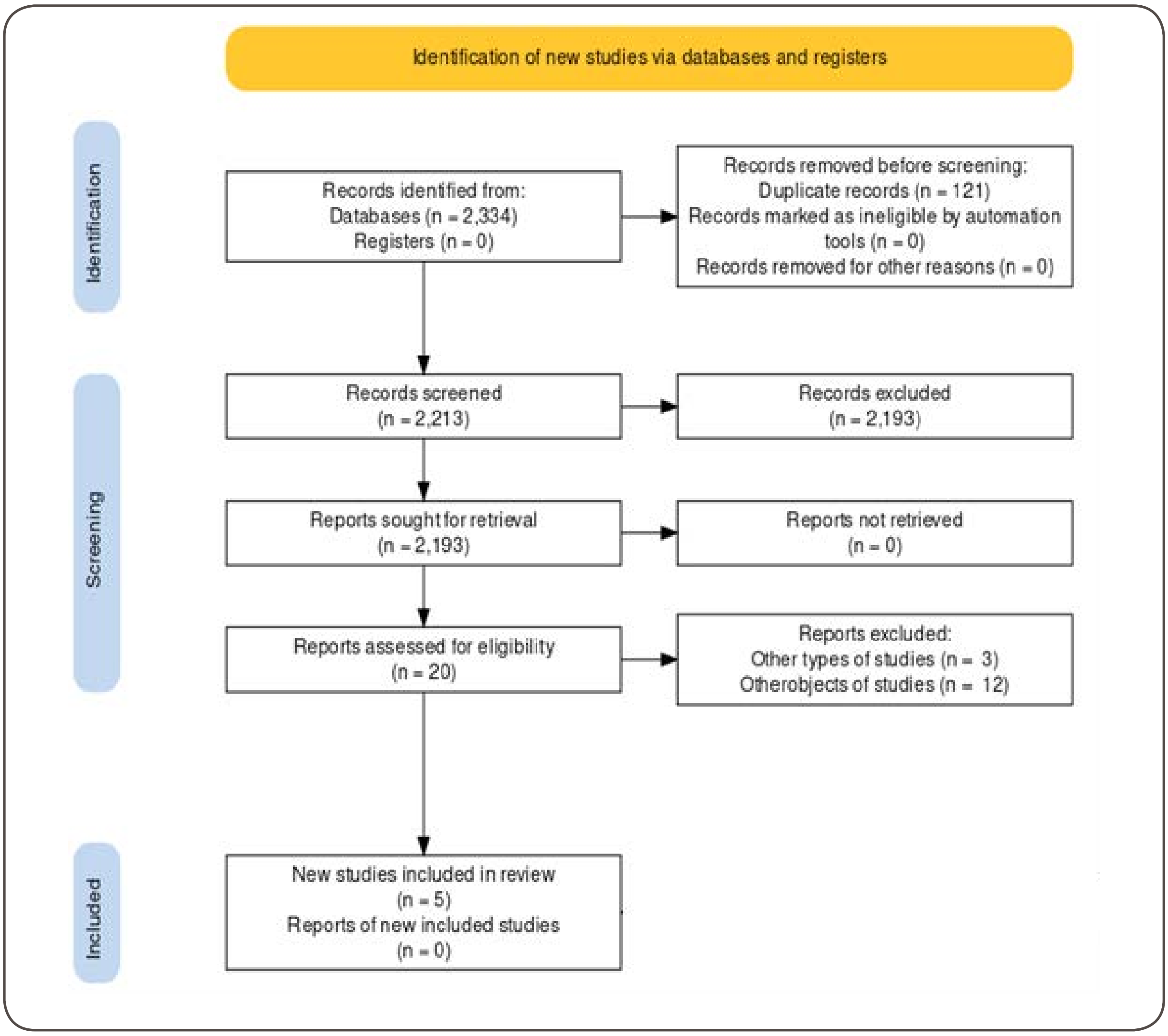

Figure 1 - Flow diagram of the studies included in this systematic review about the effects of confinement on the physical conditioning and health of submariners

Table I - Characteristics of the studies included in the systematic review

Author and year	Participant profile	Study design	Exposure	Control	Evaluation	Follow-up	Result 1	Result 2
Fothergill e Yess, 2010 [7]	n = 19 SEALS (highlighted = 29.26 ± 4.2 years; not highlighted = 29.76 ± 5.8 years), height (highlighted = 1.806 ± 0.047 m; not highlighted = 1.7826 ± 0.082 m) and body mass (highlighted = 83.76 ± 6.3 kg; not highlighted = 84.76 ± 11.5 kg)	Observational (cohort)	10 participants stayed on the submarine "USS Kamehameha SSN 64" (highlighted)	9 remained on the submarine "Ford Island" for control (not highlighted)	12 min Cooper test (pre and post-mission assessment)	33 days	Cardiorespiratory fitness: Percentage variation in distance covered between pre- and post-implantation tests - not highlighted showed a non-significant increase of 2 ± 4.7% in distance covered, while highlighted ones showed a decrease of 7 ± 3.7% in traveled distance after implantation ($p < 0.01$)	Heart Rate: Decreased performance of standouts was not associated with any changes in mean HR and max HR, however, HR recovery time was 47 ± 39.1% longer after implantation [$p < 0.05$]. Additionally, recovery HR decreased by 17 ± 16.7% for those deployed after implantation.
Gasier *et al.*, 2016 [5]	n = 53 US Navy submariners (20-39 years old)	Observational (cross-sectional)	Nuclear submarine mission	None	Body composition; Food frequency; Physical activity frequency questionnaire; Lipid profile and other blood markers. Pre and post-mission	3 months	Body composition/diet: A significant mean reduction in body mass (5%) and fat mass (11%) occurred in the obese group as a result of reduced energy intake (~2000 kJ) during the mission	Biochemistry: Modest improvements in serum lipids were observed, as well as a mean reduction in interferon gamma-induced protein 10 and protein 1 and monocyte chemotactic
Gregg *et al.*, 2012 [6]	n = 37,473 Small submarines (n= 6,192); large submarines (n = 4,198); aircraft carrier (n = 27,083)	Observational (cross-sectional)	Small or large submarines	Aircraft carrier military	BMI and Navy Fitness Readiness Test score (push-ups, sit-ups, and 1.5-mile run test)	None	Body composition: Submariners with higher BMI compared to aircraft carrier military; Higher prevalence of obesity	Neuromotor assessment: Score in the physical test of soldiers of small submarine inferior to the military of aircraft carriers; Sit-ups, Push-ups, and Running: Worst Performing Small Submarine Soldiers
Luria *et al.*, 2010 [14]	n = 32 (22.8 ± 3.8 years), healthy male submariners	Observational (cross-sectional)	Mission on the Dolphin-class non-nuclear submarine	None	BMI; thigh and calf circumference; 2000m run; Bone function markers; Endocrine regulators; Bone assessment with ultrasound	30 days	Body composition: BMI increased from 23.05 ± 0.5 to 23.4 ± 0.5 ($p = 0.002$) Cardiorespiratory fitness: Running time from 507.3 ± 11.6 to 529.2 ± 8.8s ($p = 0.005$)	Bone function markers: Albumin levels from 4.56 ± 0.25 to 4.84 ± 0.30 g/dL ($p=0.0005$); there was a significant increase in circulating calcium. PTH and 25(OH)D levels decreased significantly. Significant decreases were observed in TRAP5b and CTx levels, markers of bone resorption, as well as in PINP
Kang e Song [2018] [1]	n = 513 submariners and 4577 non-submariners	Observational (case-control)	Submariners were defined as individuals who had completed the submarine training course and were working on a submarine at the time of testing	Non-submariners	Post, alcoholism, smoking, physical activity, BMI, lipid profile, metabolic syndrome.	None	APhysical activity: Compared with non-divers, submariners had higher risks of MetS [odds ratio (OR) 1.31 (CI) 1.02, 1.68	Metabolic syndrome: low HDL (OR 1.73, 95% CI 1.36, 2.20), and impaired fasting glucose (OR 1.46, 95% CI 1.21, 1.76). When stratifying subjects according to physical activity, an increased risk of high blood pressure associated with underwater service was evident only in the subgroup with moderate or vigorous physical activity (P for interaction = 0.006).

SEALS = US Navy Combat Divers; HR =heart rate; BMI = Body Mass Index; US = Ultrasonography; PTH = Parathyroid hormone; 25 (OH) D = 25-hydroxy-vitamin D; TRAP 5b = Acid Phosphotase 5; CTx = C-terminal telopeptide fragment; PINP = N-terminal collagen type I propeptide; HDL = High Density Lipoprotein Cholesterol

The methodological quality of studies

The scores of the studies included in the present systematic review ranged from 7 (moderate risk of bias) to 5 (high risk of bias) out of 14 possible points (Table II). Three studies were classified as having a moderate risk of bias [5,7,14], while two studies were classified as having a high risk of bias [1,6]. All studies in this review included the research question or objective (item 1), clearly specified the study population (item 2), and all subjects were selected or recruited from the same or Yesilar populations (item 4). All studies presented valid and reliable outcome measures (item 11). However, most studies did not justify the sample sizes (item 5) and did not show a control [measurement and adjustment] over confounding variables (item 14).

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

References	Item 1	Item 2	Item 3	Item 4	Item 5	Item 6	Item 7	Item 8	Item 9	Item 10	Item 11	Item 12	Item 13	Item 14	Scores
Fothergill e Yess (2010) [7]	Yes	Yes	NA	Yes	No	NA	Yes	No	Yes	No	Yes	NA	NA	No	6/14
Gasier *et al.* (2016) [5]	Yes	Yes	NA	Yes	Yes	No	Yes	No	Yes	No	Yes	NA	NA	No	7/14
Gregg *et al.* (2012) [6]	Yes	Yes	NA	Yes	No	No	No	NA	NA	NA	Yes	NA	NA	Yes	5/14
Kang e Song (2018) [1]	Yes	Yes	NA	Yes	No	No	No	NA	NA	NA	Yes	NA	NA	Yes	5/14
Luria *et al.* (2010) [14]	Yes	Yes	NA	Yes	No	NA	Yes	No	Yes	No	Yes	NA	NA	No	6/14

Item 1 = Was the research question or objective in this paper clearly stated?; Item 2 = Was the study population specified and defined?; Item 3 = Was the participation rate of eligible persons at least 50%?; Item 4 = Were all the subjects selected or recruited from the same or similar populations (including the same period)? Were inclusion and exclusion criteria for being in the study prespecified 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 paper, were the exposure(s) of interest measured before the outcome(s) were measured?; Item 7 = Was the timeframe sufficient so that one could reasonably expect to see an association between exposure and outcome if it existed?; Item 8 = For exposures that can vary in amount or level, did the study examine different levels of the exposure as related to the outcome (e.g., categories of exposure or exposure measured as a continuous variable)?; Item 9 = Were the exposure measures (independent variables) clearly defined, valid, reliable, and implemented consistently across all study participants?; Item 10 = Was the exposure(s) assessed more than once over time?; Item 11 = Were the outcome measures (dependent variables) clearly defined, valid, reliable, and implemented consistently across all study participants?; Item 12 = Were the outcome assessors blinded to the exposure status of participants?; Item 13 = Was loss to follow-up after baseline 20% or less?; Item 14 = Were key potential confounding variables measured and adjusted statistically for their impact on the relationship between exposure(s) and outcome(s)?; NA = Not applicable; NR = Not reported

Discussion

The main results of this systematic review were: that military submariners showed a negative change in the analysis of body composition, aerobic performance, biochemical analysis of lipids, bone function markers, and endocrine regulators. In addition, the studies investigated factors such as food frequency; the frequency of physical activity; and specific neuromotor tests. There was a comparison of onboard and non-embarked military personnel, as well as the results only for embarked personnel, or military personnel who worked on small or large submarines compared to military personnel who worked on aircraft carriers.

The analysis of body composition was considered in most of the studies included. Fifty-three soldiers decreased their total body mass (5%) and fat mass (11%) after a three-month mission in an American nuclear submarine [5]. The authors justify this fact with the decrease in caloric intake. On the other hand, an increase in BMI was observed after a three-month mission of 52 military personnel in a non-nuclear American submarine [14]. In a cross-sectional study [6], the authors reported a higher BMI for submariners when compared to aircraft carrier military, corroborating the Korean study comparing submariners with non-submariners [1]. It is important to point out that high BMI is associated with many health problems such as diabetes and heart disease, and has been observed as a risk factor for musculoskeletal injuries, such as low back pain and lower limb injuries [15], in addition to being a labor complicating factor for environments with restricted spaces such as the interior of a submarine [16].

During a submarine mission, physical activity is severely reduced for most individuals because of the strictly reduced space and working hours [17]. Among the effects resulting from physical deconditioning can be mentioned the rapid decrease in VO2max [15]. Fothergill and Sims [7] applied the Cooper test before and after a 33-day mission and in a non-detached control group, they found a decrease in the distance covered, indicating a decrease in cardiorespiratory fitness, corroborating the results of the study by Gregg et al. [6], only for the 2000m test. The same study analyzed the heart rate (HR) variation during the test in both groups. The decrease in the performance of the standouts was not associated with any changes in mean HR and maximum HR, however, the HR recovery time was longer. In addition, recovery HR decreased for those highlighted after exposure.

A study brought a neuromotor assessment of the military, using the Navy Fitness Readiness Test as a way to assess the physical readiness of submariners [6]. As a result, the score in the physical test of small submarine soldiers was lower than that of aircraft carrier soldiers, indicating worse results for the abdominal and arm flexion tests.

Regarding the lipid profile and other blood markers, in biochemical analysis, after three months of mission in a nuclear submarine [5], modest improvements in serum lipids were observed, as well as an average reduction in protein 10 induced by

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interferon-gamma, in the protein 1 and monocyte chemotactic. This fact can also be explained by the fact that energy intake is reduced. A study that analyzed the Metabolic Syndrome in this population [1] showed lower High-Density Lipoprotein (HDL) Cholesterol and increased Fasting Glucose, compared to non-submariners.

Prolonged submersion led to a significant decrease in bone strength, accompanied by a decrease in bone metabolism, in a study after a 30-day mission aboard a non-nuclear submarine [14]. There was an increase in the levels of albumin and circulating calcium. Parathyroid hormone and 25-hydroxyvitamin D levels decreased significantly. Significant decreases were also observed in the levels of Acid Phosphatase 5 and C-terminal Telopeptide Fragment, markers of bone resorption, as well as in type I collagen N-terminal Propeptide.

The present study carried out an extensive search in the main databases related to health and related areas, using a large number of descriptors and synonyms in the search equations. However, the study is not free from limitations. Among them, we can highlight the lack of articles dealing with specific physical training for this submariner population. In addition, there were a small number of studies eligible for the review that had a moderate or low risk of bias.

Conclusion

Military submariners present changes in the analysis of body composition, biochemical analysis of lipids, bone function markers, and endocrine regulators. In addition, prolonged time aboard a submarine can compromise aerobic performance, which can affect the health of the military. It is suggested to carry out new studies, with a controlled and randomized design, with better methodological quality, especially taking precautions related to the control of confounding variables and justification for the sample sizes.

Conflicts of interest
There are no conflicts of interest.

Financing source
There is no funding.

Authors' contribution
Research conception and design: Miranda MEK, Bunn PS, Rodrigues AI, Vale RGS; **Data collection:** Miranda MEK, Bunn PS, Rodrigues AI; **Data analysis and interpretation:** Miranda MEK, Bunn PS, Rodrigues AI; **Manuscript writing:** Miranda MEK, Bunn PS, Rodrigues AI, Vale RGS; **Critical review of the manuscript for important intellectual content:** Miranda MEK, Bunn PS, Rodrigues AI, and Vale RGS.

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