Mini-Review/Systematic Review

Risk factors and preventive strategies for musculoskeletal injuries associated with load carriage in military personnel: a systematic review with meta-analysis

Carolina Alves Mizuno[1], Bruno Ferreira Viana[1,2], Priscila dos Santos Bunn[1,2]

[1]*Universidade da Força Aérea, Programa de Pós-Graduação em Desempenho Humano Operacional, Rio de Janeiro, RJ, Brazil;* [2]*Centro de Educação Física Almirante Adalberto Nunes, Laboratório de Pesquisa em Ciências do Exercício e Performance, Rio de Janeiro, RJ, Brazil.*

Associate Editor: Paulo Henrique Guerra, Universidade Estadual Paulista "Júlio de Mesquita Filho", Instituto de Biociências, Departamento de Educação Física, Rio Claro, SP, Brazil. E-mail: paulo.guerra@unesp.br.

Abstract - Introduction: Musculoskeletal injuries pose significant challenges to military personnel involved in load carriage activities, affecting both operational readiness and individual well-being. However, there is a notable lack of comprehensive understanding regarding the risk factors and effective prevention measures for such injuries. Thus, this study aimed to investigate the risk factors and prevention strategies for musculoskeletal injuries associated with load carriage. **Methods:** A systematic review was conducted in 2020 and updated in 2022, encompassing eight databases using keywords such as "load carrying", "injuries," and "military", alongside their synonyms. Extracted data included sample characteristics, load carriage specifics, intervention protocols, and musculoskeletal injury incidence. A meta-analysis using StatsDirect software was performed to estimate relative risk (RR). **Results:** Out of 7,673 articles initially screened, 13 met the eligibility criteria. Primary risk factors examined included sex, age, body mass, distance traveled while carrying loads, and load weight. The meta-analysis revealed females had a relative risk of 1.56 (95% CI = 1.11 to 2.20) for musculoskeletal injuries during load carriage compared to males. Prevention strategies such as the use of antiperspirants, socks, and ballistic vests were evaluated. **Conclusions:** Findings from this systematic review suggest that factors such as female sex, smoking, greater walking distances with loads, and longer load carriage durations, and increased duration of load carriage may elevate the incidence of injuries. However, limited studies on prevention strategies precluded definitive conclusions. Further research is warranted in this area.

Keywords: military personnel, injuries, load carriage, risk factors.

Introduction

Soldiers must be prepared to execute the missions assigned to them by their superiors at any time (day or night) and anywhere (domestic or even foreign)[1,2,3]. Due to the challenging and often hostile conditions of operational environments, soldiers are frequently required to undertake long marches on foot while carrying substantial external loads[2,3]. With ongoing transformations in operational contexts and continuous advancements in military operations, there has been a progressive increase in the loads carried by military personnel[2,3,4].

The external load carried by the military comprises basic equipment for conducting operational activities (weapons, ammunition, GPS, night vision goggles, ballistic vests, helmets and nutrition supplies)[5,6]. The literature reports that total load mass can range from 8[6] to 52 kilograms[7]. Load carriage reduces soldiers' mobility, reaction time, and operational efficiency[3,8,9]. In addition to hindering the execution of tactical tasks, load carriage imposes significant physiological and biomechanical strain on soldier[3]. Such strain leads to increased fatigue and raises the risk of musculoskeletal injuries by up to 8%[3].

Musculoskeletal injuries resulting from load carriage can negatively affect not only the individual soldier but also the Military Organization (MO)[3,10,11]. An injured soldier can reduce the MO's readiness and the combat effectiveness of the unit[3,10,12,13], thereby influencing the success of the mission[3,11,13,14]. Data from Knapik et al. (1992), in which soldiers marched 20 kilometers while carrying loads, indicated that 24% of them experienced musculoskeletal injuries, with 4% unable to complete the mission due to injury severity[5], leading to additional costs for the force, including medical evacuation expenses[13,15]. Moreover, treatment and rehabilitation costs, as well as human and financial resources invested in the mission, further increase the burden on the organization[3,6,11].

There are numerous consequences of musculoskeletal injuries associated with load carriage, affecting both the military personnel and the Armed Forces. Several studies have investigated the main risk factors associated with this issue, including increasing age[6,7,16], female sex[2,3,6,15,17], higher body mass index[7,16,18], smoking[7,16,18,19], alcohol consumption[7,18], carrying loads exceeding 25% of body mass[6,19], greater distances traveled under load[2,3,5,7,13,15,19], and a prolonged load carriage duration (more than four hours)[13,15,16,19]. The interaction of multiple risk factors may further contribute to the incidence of musculoskeletal injuries among military personnel[12].

Approaches to minimize the risk of musculoskeletal injuries related to load carriage may include (1) identifying and mitigating modifiable risk factors and (2) adapting military equipment such as backpacks, vests, socks, and boots[7,20,21,22]. Some studies suggest that optimizing military gear can help reduce the incidence of musculoskeletal injuries by decreasing biomechanical or physiological strain[7,20,21,22].

Given the wide range of risk factors for musculoskeletal injuries associated with load carriage reported in the scientific literature, as well as the diversity of intervention studies seeking preventive strategies and the lack of consensus among experts, the present systematic review with meta-analysis is justified. Therefore, this review aimed to identify and synthesize scientific evidence regarding the risk factors and prevention strategies for musculoskeletal injuries associated with load carriage in military p,ersonnel.

Methods

Study design

This systematic review was written in accordance with the recommendations of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020)[23]. To ensure consistency, transparency, and integrity, a study protocol was developed and registered in the International Prospective Register of Systematic Reviews (PROSPERO) under the number CRD42020197586.

Search strategy

Searches were conducted in August 2020 and updated in October 2022 in the CINAHL, Cochrane, EMBASE, LILACS, MEDLINE, SCOPUS, SPORTDiscus, and Web of Science databases. No filters were applied for language or publication year. The descriptors “load carrying,” “injuries,” and “military,” as well as their respective synonyms, were used, including terms from the controlled vocabulary Medical Subject Headings (MeSH) and additional terms identified through a review of other studies. Search equations were constructed using the Boolean operators “AND” (to combine descriptor terms) and “OR” (to combine synonyms and plural forms). In addition to database searches, reference lists of relevant studies were also screened to identify additional eligible articles.

Eligibility criteria

For observational studies, the PECOS strategy (Population, Exposure, Comparison, Outcome, and Study design) was used to define inclusion criteria: Population = military personnel exposed to marching with load carriage; Exposure = risk factors (e.g., female sex, smoking, load carriage longer than 4 h); Comparison = absence of the investigated risk factor (e.g., male sex, non-smoker, load carriage shorter than 4 h); Outcome = incidence of injuries; Study design = observational.

For experimental studies, the PICOS strategy (Population, Intervention, Comparison, Outcome, and Study design) was applied: Population = military personnel performing marching with load carriage; Intervention = injury prevention strategies (e.g., adapted vests, shoes, or socks); Comparison = control group (not exposed to adapted equipment or using standard gear); Outcome = injury incidence; Study design = experimental.

Selection of the studies

Study selection was carried out independently by two reviewers familiar with the subject. Studies retrieved from the databases were imported into EndNote Web (Clarivate Analytics). for reference management, and duplicates were removed. After de-duplication, all records were exported in RIS format to the Rayyan platform (QCRI), where an additional duplicate check was performed.

The two reviewers then independently screened titles and abstracts, followed by full-text assessment of potentially eligible studies. To identify additional relevant papers, the reviewers also examined the reference lists of included studies.

Excluded studies and reasons for exclusion were recorded. Each study was classified as “included,” “excluded,” or “uncertain.” Disagreements were resolved through consensus meetings without requiring a third reviewer. When necessary, study authors were contacted for clarification or to obtain missing information.

Extracted data

Data extraction was conducted independently by two evaluators. Any discrepancies between the extracted data were resolved through a consensus meeting, without the need for a third evaluator. Data from each included study were extracted and organized in tabular format using Microsoft Excel.

Generally, the extracted information included study characteristics (author and year), sample characteristics (participant profile and sample size), and characteristics of the load carriage activity (type of load, loading activity, and load mass).

For observational studies, in addition to general information, data on risk factors associated with injuries (relative risk and 95% confidence intervals) and outcomes (injury definitions, results for exposed groups, and results for unexposed groups) were extracted. For experimental studies, information on prevention strategies aimed at minimizing musculoskeletal injuries associated with load carriage was extracted, along with outcomes reported in the included studies (injury definition and incidence in groups subjected or not subjected to preventive interventions).

Assessment of the risk of bias of studies

To evaluate the risk of bias of the selected observational studies, the two evaluators independently applied the National Institutes of Health (NIH) Quality Assessment tool for observational cohort and cross-sectional studies (available at https://nhlbi.nih.gov/health-topics/study-quality-assessment-tools). This tool consistis of fourteen questions that cover three fields of possible bias: selection bias, comparison bias and outcome bias. Each question was answered as "Yes", "No", "Cannot determine", "Not applicable" or "Not reported". Responses of "Yes" were given a score of 1, while questions answered "No", "Cannot to determine", or "Not reported" received a score of 0. The total score classified the risk of bias as low (10-14), moderate (5-9), or high (0-4). Any disagreements were resolved through consensus without the need for a third reviewer.

For experimental studies, the Cochrane risk of bias tool [RoB2.0] (available at website). was used independently by the two evaluators. Five domains were assessed for each outcome: bias in the randomization process, deviations from intended interventions, bias due to missing data, bias in outcome measurement, and bias in reporting outcomes. Each domain was judged as low risk, some concerns, or high risk based on signaling questions. Discrepancies between evaluators were resolved through consensus meetings, without requiring a third reviewer.

Statistical analysis

A statistical analysis, including a meta-analysis, was carried out on the results of observational studies that compared the incidence of musculoskeletal injuries associated with load carriage between femal and male military personnel. "Sex" was the risk factor used for the meta-analysis due to data availability[24].

The following parameters were used for the analysis: 1) Dichotomous Variable; 2) Mantel-Haenszel statistical method: used to weight the measures of associations between the studies included in the review; and 3) heterogeneity was assessed using the value provided by the Higgins or I^2 inconsistency test, automatically calculated by the StatsDirect software application (version 3). I^2 values up to 50% were classified as low heterogeneity, 50-75% as moderate, and above 75% as high[25]. A random-effects analysis model for analyzing the effect estimate was used because of the existence of varying risk factors among the studies included in the review. A random-effects model (DerSimonian and Laird) was used due to methodological heterogeneity across studies. Adjusted effect measures (odds ratios, prevalence ratios, or risk ratios) were extracted when available; otherwise, crude measures were used. Statistical heterogeneity was assessed using Cochran's Q test and I^2 statistic. Sensitivity analysis was conducted by sequentially removing each study to reassess I^2 and the pooled effect estimate. Relative risk (RR) represents the ratio of injury probability in the exposed versus non-exposed groups. An RR of 1 indicates no difference; RR < 1 indicates a protective factor; RR > 1 indicates a risk factor[26].

The quantitative assessments of publication bias were conducted using Begg's test and the Begg-Mazumdar rank correlation test (Kendall's Tau with continuity correction). Meta-analysis and forest plot construction were performed using the Review Manager software (version 5.4.1). The StatsDirect software (version 3) was used to evaluate the risk of publication bias. All analyses were performed with 95% confidence intervals (CIs). The significance level adopted was $p \leq 0.05$[27].

Certainty of evidence in the meta-analysis

The certainty of evidence in the meta-analysis was independently assessed using the Grading of Recommendations Assessment, Development, and Evaluation (GRADE) approach[28] by two evaluators. Evidence was classified as high, moderate, low, or very low through the GRADEpro website[28]. Evidence from randomized controlled trials initially starts at high certainty, whereas observational studies start at low certainty due to potential confounding factors. Five domains can decrease the certainty of evidence[28]: risk of bias (when study results do not accurately represent the truth due to limitations in study design or conduct); imprecision (associated with small sample sizes, few events in comparator groups, or wide confidence intervals); inconsistency (assessed by inspecting the similarity of point estimates, the overlap of confidence intervals, and statistical measures of heterogeneity); indirectness (occurs when the studied interventions differ from the actual intervention of interest, or when the studied population differs from the target population); and publication bias (the selective publication of studies based on their results). Conversely, three domains can increase the certainty of evidence: large effect size (when a very large magnitude of effect provides strong evidence of a cause-effect relationship); dose-response gradient (when greater exposure leads to a greater effect);

and residual confounding (when unmeasured or unidentified confounding factors influence study outcomes in a way that increases confidence in the observed effect). For each domain that met the criterion, certainty was increased by one level; if the criterion was not met, certainty was decreased by one level. Any disagreements regarding the certainty of evidence were resolved by consensus, without the need for a third evaluator.

Results

Overview

A total of 9,738 studies were identified in searches carried out across eight databases (7,673 records in August 2020 and 2,065 records in October 2022). Through a manual search conducted independently by two evaluators, and with the assistance of the EndNote reference manager and the Rayyan platform, a total of 1,543 duplicate titles were removed. After eliminating duplicates, the two evaluators independently and carefully screened the titles and abstracts of the remaining 8,195 studies.

The full texts of 90 potentially eligible studies were then independently reviewed by the two evaluators for inclusion in the present review, according to the predefined criteria. During the full-text screening process, the authors conducted a secondary search among the reference lists of these 90 studies. Thirty additional titles were identified as potentially eligible, and their full texts were also reviewed by the evaluators. In total, the full texts of 120 studies were assessed independently and in pairs (Figure 1).

Thirteen studies met the eligibility criteria and were included in the systematic review. Of these, 10 studies investigated risk factors associated with musculoskeletal injuries (MSI) resulting from load carriage, while 3 studies examined potential preventive strategies for such injuries. A summary of the search results and the reasons for study exclusion are presented in Table 1, along with the characteristics of the studies included in the systematic review.

The included studies were published between 1992 and 2018 and were written in English. They examined military personnel from six different countries (Australia, Korea, the United States, Finland, Israel, and Switzerland) who experienced musculoskeletal injuries during load carriage activities performed while marching.

A total of 10 studies focused on evaluating risk factors contributing to MSI in military personnel. The examined risk factors included sex, age, body mass, distance marched under load, and load weight. Notably, five studies specifically investigated sex as a risk factor, enabling a more detailed statistical analysis, including meta-analysis, of the impact of sex on MSI during load carriage activities. Further details on the statistical analysis of the sex risk factor are provided in the subsection "Analysis of Observational Studies."

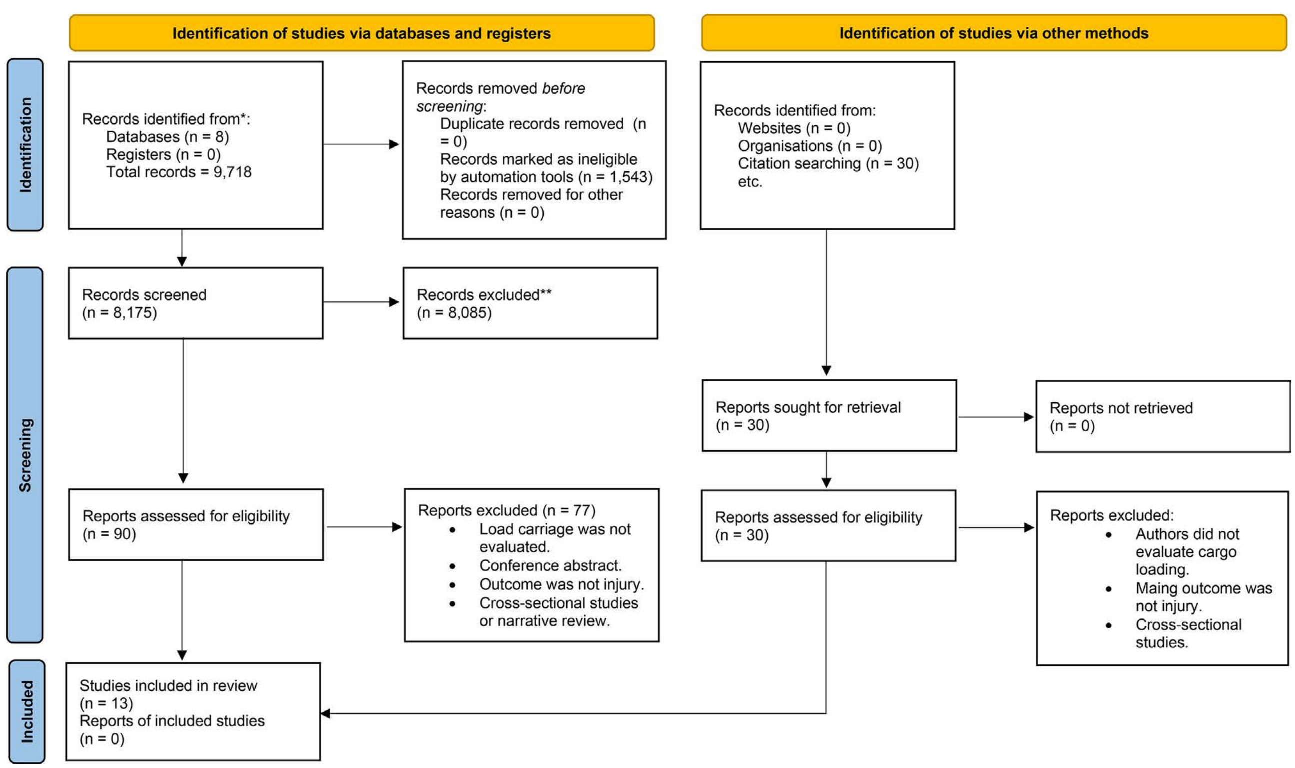

Figure 1 - Flow diagram of studies included in the systematic review about risk factors and prevention strategies for musculoskeletal injuries associated with load carriage[23].

Table 1 - Sample, task and external load characteristics of observational studies

Study/author (year)	Age (years old)	Height (cm)	Body mass (kg)	BMI (kg/m^2)	(n)	Activity	External load
Knapik et al. (1992)	21± 3	177.9 ± 6.4	76.1 ± 9.8	NR	335 (M)	20 km tactical march	Backpack weight: 35 kg Uniform weight: 5 kg Weight other equipment: 5.8 ± 2.0 kg
Reynolds et al. (1999)	21.4 ± 3.9	175.6 ± 7.0	75.5 ± 9.2	24.5 ± 2.6	218 (M)	161 km tactical march (5 days) (32 km/day)	Backpack weight: 47 ± 5 kg
Mäkela et al. (2006)	20 ± 2	178.6 ± 0.05	73 ± 0.8	22.8 ± 0.3	152,142 total: 149,814 (M) 2,328 (W)	Tactical march (± 7 h per day)	Backpack weight: ±30 kg, backpack with and without support frame
Roy et al. (2012)	26.6 ± 6.0	172.7 ± 13	81.4 ± 17.4	NR	593 total: 536 (M) 57 (W)	Tactical march of 61.77 ± 123.93 m (14 weeks)	Backpack and rifle weight: 21.3 ± 13.6 kg Heaviest load: 37.6 ± 20.8 kg,
Kim & Kim (2015)	20.6 ± 1.5	NR	NR	23.9 ± 4.1	209 total	30 km tactical march	Backpack weight: 20 ± 5 kg
Roy et al. (2015)	27.3 ± 7 (W) 26.5 ± 5.8 (M)	158.1 ± 12.7 (W) 174.3 ± 11.9(M)	64.2 ± 9.2 (W) 83.2 ± 12.7 (M)	27.6± 5.1(M) 26 ± 4.6 (W)	593 total: 536 (M) 57 (W)	Tactical march (12 months) 7.06 ± 4.63 km (W) 6.79 ± 4.52 km (M)	22.25 ± 13.43 kg (M) 10.32 ± 9.82 kg (W)
Orr and Pope (2015)	NR	NR	NR	NR	112 total: 111 (M) 11 (W)	Tactical march (2 years)	Combat equipment and vest
Roy et al. (2016)	25 ± 6	160 ± 7.6	66.3 ± 14.2	25 ± 4.1	160 (W)	Tactical activities (9 months)	Uniform/vest weight: ± 17 kg Backpack weight: ± 21.77 kg
Orr and Pope (2016)	NR	NR	NR	NR	24,876 total: 22,435 (M); 2,441 (W)	Tactical activities (2 years)	Load weight: 45 kg
Schuh et al. (2017)	25	NR	NR	25.6	831 total: 822 (M); 8 (W)	Tactical march with an average of 23.8 km (6 months)	Average load weight: 20 kg

To provide a clearer understanding of the risk factors examined in the included studies, data were systematically extracted and are presented in tabular form. Table 1 summarizes the characteristics of the observational studies (author and year), sample characteristics (participant profile and sample size), and details related to load carriage (type of activity, nature of the load, and load mass). Table 2 outlines the risk factors assessed in the observational studies along with the outcomes reported by the respective authors.

Three studies investigated prevention strategies aimed at reducing the incidence of MSI among military

Table 2 - Characteristics of risk factors and outcomes found in observational studies.

Author (year)	Risk factors	Relative risk Chi-square	Injury definition
Knapik et al. (1992)	Walking with external load	NR	Blisters, Sprains, Low back pain, and Joint pain
Reynolds et al. (1999)	Age	RR = 0.88; $p < 0.01$	Blisters, sprains, backache, joint pain, fractures, and neuropathy
	Smoking	RR = 1.58;$p < 0.01$	
	Alcohol	$p = 0.20$	
	Body mass	$p = 0.02$	
	Walking with external load	NR	
Mäkela et al. (2006)	Sex	$p = 0.6$	Brachial plexus injury; Compressive neuropathy

(*continued*)

Table 2 - continued

Author (year)	Risk factors	Relative risk Chi-square	Injury definition
Konitzer et al. (2008)	Smoking	Neck pain: RR = 0.12; p < 0.05	Neck pain, low back pain and lower limb pain
	Wearing a vest for more than 4 h	Backache: RR = 0.14; p < 0.05	
	Age	Pain in upper limbs: RR = 0.15; p < 0.05	
Roy et al. (2012)	Average load in relation to body mass	chi = 16.23; p < 0.001	Lower back pain, knee pain, and on the shoulder; sprains, and neuropathies
	Largest load carried	chi = 11.46; p < 0.02	
	Greater load carried in relation to body mass	chi = 7.90; p < 0.0048	
	Age	chi = 12.77; p < 0.03	
	Sex	chi = 6.37; p < 0.01	
Kim & Kim (2015)	Nonuniform backpack loading	NR	Brachial plexus injury and upper limb paresthesia
	Strap problems	NR	
	History of paresthesia or paresis	NR	
	History of shoulder pain or dislocation	NR	
	History of neck pain	NR	
	History of low back pain	NR	
	Alcohol	NR	
	Smoking	NR	
Roy et al. (2015)	Sex	NR	Backache, knee injury, foot and ankle injury
	Walking with external load	RR = 3.00 (95% CI = 1.52-5.93)	
	Charge charging time	NR	
Orr and Pope (2015)	Sex	NR	Backache, neck pain, sprain, ankle injury, knee injury, and shoulder injury
	Walking with external load	NR	
Orr and Pope (2016)	Sex	RR = 1.02 (95%CI: 0.74-1.41)	Neck pain; shoulder injury; backache; knee injury; foot injury; ankle injury
	Walking with external load	NR	
Roy et al. (2016)	Ballistic vest usage time (h/day)	1 to 4: RR = 1.62 more than 4 h: RR = 1.84	Muscle injury, tendon injury, bone injury; joint damage; and neuropathy
	Backpack usage time (h/day)	RR = 1.85 95% CI: 1.23-2.80	
	External load with % BMI	RR = 2.00 95% CI: 1.31-3.06	
	Greater external load carried in relation to %BMI	RR = 5.83 95% CI: 1.51-22.50	
Orr and Pope (2016)	Sex	RR = 1.02; 95% CI: 0.74-1.41	Neck pain; shoulder injury; backache; knee injury; foot injury; ankle injury
	Walking with external load	NR	
Schuh et al. (2017)	Age	RR = 2.89 95% CI: 1.17-7.16 p = 0.02	Back injury, knee injury, injury ankles, sprains
	Walking with external load	RR = 1.81 95% CI: 1.38-2.37	
	Long distance walking (>53 km)	RR = 1.92 95% CI: 1.17-2.41	
	Load >25% of body mass	RR = 2.09 95% CI:1.08-4.05 p = 0.03	
	Smoking	RR = 3.39 95% CI: 1.43-10.80 p < 0.01	

personnel engaged in load carriage. However, during the evaluation of these studies and their corresponding intervention factors, no quantitative data suitable for detailed statistical analysis were found. The authors examined various preventive measures, including the use of antiperspirants, wool-blend socks, and modified ballistic vests. Notably, no randomized controlled trial (RCT) investigating physical exercise as a primary prevention strategy for load carriage-related MSI during marching has been conducted to date.

Table 3 presents the characteristics of the experimental studies (author and year), sample characteristics (participant profile and sample size), and load carriage details (activity type, load type, and load mass). The studies evaluating prevention strategies did not demonstrate statistically significant effects, and the information extracted from these studies is summarized in Table 4.

Assessment of the risk of bias of observational studies

The bias scores of the studies included in this systematic review ranged from 3 points (indicating a high risk of bias) to 9 points (indicating a moderate risk of bias) according to the NIH assessment tool (Table 5). Three studies were classified as having a high risk of bias: Orr and Pope (2015)[3], Orr and Pope (2016)[2], and Schuh et al. (2017)[19]. The remaining studies received scores between 5 and 9 points, indicating a moderate risk of bias.

With regard to the specific NIH tool criteria, all studies adequately addressed their research question or objective (item 1). Except for Orr and Pope (2015)[3], all studies clearly defined the study population (item 2). Conversely, most studies did not provide a justification for their sample sizes (item 5) and did not employ blinding for outcome assessors (item 12).

Assessment of the risk of bias of experimental studies

The methodological quality of the included experimental studies was evaluated using the Cochrane Risk of Bias Tool (ROB 2.0), as shown in Figure 2. Notably, all three studies demonstrated a “high risk” of bias regarding deviations from the intended interventions (domain D2) and the measurement of reported outcomes (domain D4). Additionally, the randomization process in Studies 1 and 2 was assessed as having a “low risk” of bias. The overall risk of bias for all three studies was considered “high.” The main methodological weaknesses identified included the absence of intergroup comparisons, the lack of blinding for participants and evaluators, and limitations in the methods used for outcome measurement.

Statistical analysis of the observational studies

According to an in-depth examination of the studies included in this systematic review, five articles analyzed “sex” as a risk factor. This allowed for a statistical analysis of the exposure variable “sex” and its association with the incidence of musculoskeletal injuries among male and female soldiers engaged in tactical load carriage activities. Using StatsDirect software, data from these five studies were pooled and subjected to meta-analysis, as illustrated in Figure 3. The meta-analysis revealed a moderate to high level of heterogeneity (I^2 = 73%). Sensitivity analysis indicated that excluding Roy et al. (2012) resulted in the

Table 3 - Sample and external load characteristics of the experimental studies.

Study author (year)	Age (years)	Height (cm)	Body mass (kg)	Sample size	Task performed (task duration)	External load
Reynolds et al. (1995)	22 ± 2.9	177.5 ± 5.5	78.5 ± 8.3	23 (M)	Walking with load on a treadmill for 200 min	Tactical equipment weight: 20.9 ± 0.8 kg
Bogerd et al. (2012)	20.8 ± 2.0	178 ± 7	76.3 ± 9.8	37 total	6.5 km walk for 60 to 70 min	Tactical equipment weight: 22 kg
Palmanovich et al. (2016)	NR	NR	NR	240 (W)	Tactical training for 4 months	Standard ballistic vest weight: 1350 g Adapted ballistic vest weight: 1950 g

Note: M = men; W = women; NR - data not reported; cm- centimeters; kg- kilogram.

Table 4 - Interventions and outcomes of experimental studies.

Study author (year)	Prevention strategies	Group control	Group intervention	Outcomes		
				Definition of Injury	Intervention Group Results	Control group results
Reynolds et al. (1995)	Using antiperspirants with moisturizer	23 (placebo)	23 antiperspirants with moisturizer	Blisters and dermatitis	39% (9 soldiers)	52% (12 soldiers)
Bogerd et al. (2012)	Use of socks with wool, polyamide and polypropylene (BLEND)	37 polypropylene and elastane socks	37 BLEND socks	Bubbles	BLEND (Greater hydration; Lower incidence of blisters)	Polypropylene (less comfort; greater thermal sensation
Palmanovich et al. (2016)	Use of adapted ballistic vest for women	101 standard vests	139 adapted vests	Stress fracture	20% (27 soldiers)	12.9% (13 soldiers)
				Backache	86% (119 soldiers)	81% (81 soldiers)

Note: NR - data not reported; RR- Relative Risk; CI- confidence interval; GI- Intervention Group; GC- Control Group.

Table 5 - National Institutes of Health (NIH) Quality Assessment tool for observational cohort and cross-sectional studies

Study (author/year)	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	Score
Knapik et al. (1992)	Yes	Yes	CD	Yes	No	NR	Yes	No	Yes	Yes	Yes	No	No	No	7 points
Reynolds et al. (1999)	Yes	Yes	CD	NR	No	No	Yes	No	Yes	Yes	Yes	No	NR	Yes	7 points
Mäkela et al. (2006)	Yes	Yes	CD	No	No	Yes	Yes	No	Yes	CD	Yes	No	NR	No	6 points
Roy et al. (2012)	Yes	Yes	CD	Yes	No	No	Yes	Yes	No	NR	No	No	CD	Yes	6 points
Kim & Kim (2015)	Yes	Yes	Yes	Yes	No	No	Yes	No	No	CD	No	No	CD	No	5 points
Roy et al. (2015)	Yes	Yes	CD	Yes	No	NR	Yes	Yes	Yes	No	No	No	NR	Yes	6 points
Orr and Pope (2015)	Yes	No	CD	Yes	No	No	CD	Yes	No	NR	No	No	CD	No	3 points
Roy et al. (2016)	Yes	Yes	CD	Yes	No	Yes	Yes	Yes	Yes	No	No	NR	Yes	Yes	9 points
Orr and Pope (2016)	Yes	Yes	Yes	No	No	No	Yes	No	No	CD	No	No	CD	No	4 points
Schuh et al. (2017)	Yes	Yes	CD	No	No	NR	Yes	No	No	CD	No	No	CD	Yes	3 points

Item 1 = Was the research question or objective in this article clearly described?; Item 2 = Was the study population clearly 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 time period]?; Were the 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 analyzes in this article, were the exposure(s) of interest measured before the outcome(s) were measured?; Item 7 = Was the time frame sufficient to reasonably expect to see an association between exposure and outcome, if one existed?; Item 8 = For exposures that may vary in quantity or level, did the study examine different levels of exposure in relation to the outcome (e.g., exposure categories 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 the exposure(s) evaluated 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 outcome assessors blind to participants' exposure status?; Item 13 = Was the loss to follow-up after baseline 20% or less?; Item 14 = Were the main potential confounding variables measured and statistically adjusted for their impact on the relationship between exposure (s) and outcome(s)?; NA = Not applicable; NR = Not informed. Risk of bias classification: low risk of bias (10-14), moderate risk of bias (5-9), and high risk of bias (0-4). CD = cannot determine.

Figure 2 - Cochrane Risk of Bias assessment tool - RoB2.0. D1 = randomization process. D2 = deviations from intended interventions. D3 = missing outcome data. D4 = measurement of the outcome. D5 = selection of the reported result.

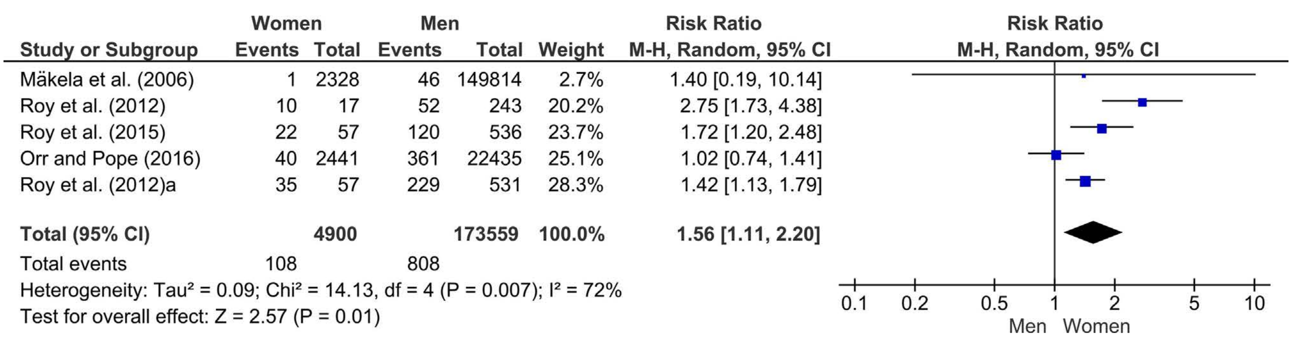

Figure 3 - Forest plot of the meta-analysis of studies that compared the incidence of injuries between men and women exposed to load carriage march. A random effects analysis of the meta-analysis was performed, and the relative risk and 95% confidence intervals were calculated. The size of each square is indicative of the relative weight of the study in the meta-analysis. Pooled relative risk = 1.56 (95% CI = 1.11 to 2.20); I^2 (inconsistency) = 71.7%.

greatest reduction in heterogeneity (I^2 decreased to 52%), suggesting that specific methodological features of this study may have substantially contributed to the variability in effect sizes. Furthermore, publication bias was assessed using a funnel plot and quantified with Begg's and Begg−Mazumdar rank correlation tests (Kendall's Tau = 0.40; p = 0.48), indicating no evidence of publication bias (Figure 4).

Certainty of the evidence

To evaluate the overall evidence related to the risk factor "sex," this study placed emphasis on the outcomes

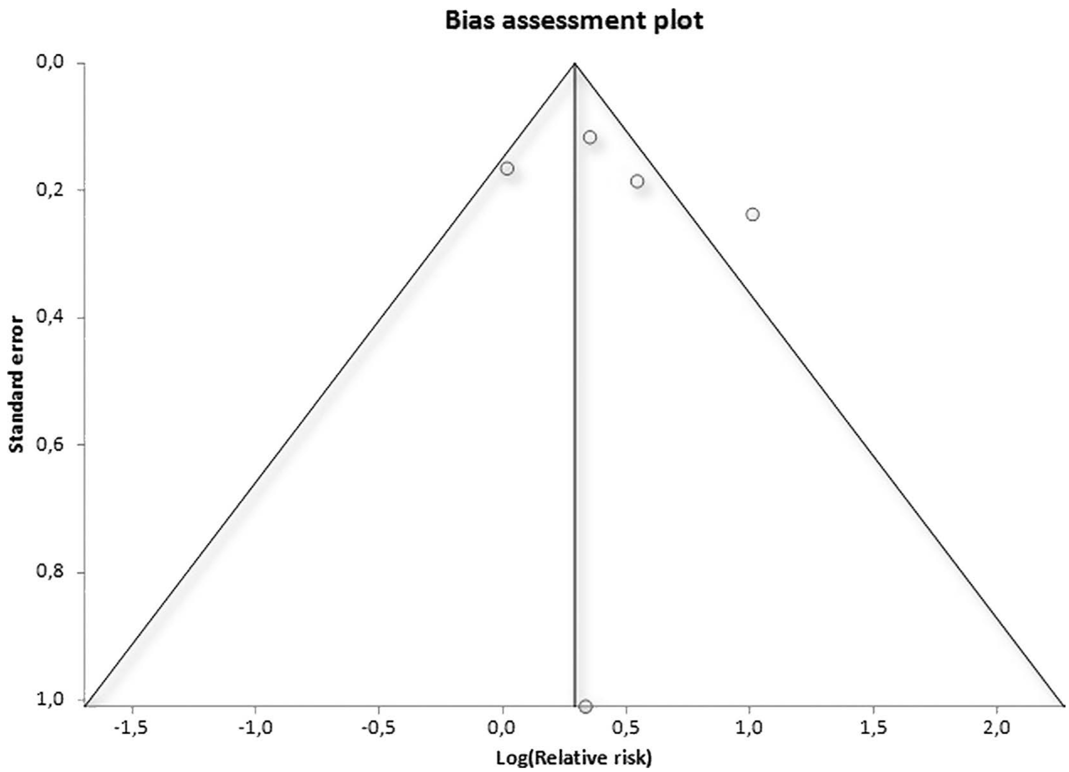

Figure 4 - Funnel plot for the publication risk of bias according to Begg's test. Begg-Mazumdar: Kendall's 0.4; p = 0.48.

derived from the studies included in the meta-analysis. Following the GRADE methodology, the initial quality rating for all five studies was classified as low due to their observational design. After examining key domains-including risk of bias (very serious), inconsistency (serious), indirectness (not serious), imprecision (not serious), and the confidence interval range (1.11-2.20) - the identified limitations led to a one-level downgrade in the certainty of the evidence (Table 6).

Discussion

An important motivation for the present study is that musculoskeletal injuries (MSI) can negatively affect both individual performance and unit readiness, and in some cases, may even compromise mission success. Therefore, a deeper understanding of the causal factors underlying these injuries, as well as the development of effective prevention strategies to reduce their incidence, is crucial for the continual enhancement of military operational performance.

The present systematic review aimed to synthesize the available evidence on risk factors and preventive strategies related to musculoskeletal injuries associated with load carriage in military personnel. A total of 13 studies were included, and a meta-analysis was performed, encompassing 10 observational studies that examined potential risk factors for MSI and 3 clinical trials that investigated preventive interventions. As indicated in the included studies, MSI are prevalent among military personnel engaged in load carriage, with incidence rates ranging from 20.6%[3] to 53.1%[16].

Two major risk factors are associated with tasks commonly performed by military personnel: “marching with an external load” and “load carriage.” With the advancement of weapons and protective equipment, service members are increasingly required to carry heavier loads over long distances and across diverse terrains[2,3]. Regarding the risk factor “marching with an external load,” Roy et al. (2015) reported that when marching with an external load occurs over distances of 6.44 km or more, military personnel are three times more likely to sustain injuries (RR = 3; 95% CI 1.52-5.93)[15]. Another relevant finding was reported by Knapik et al. (1992) and Schuh et al. (2017), indicating that approximately 23% of musculoskeletal injuries were associated with load-carriage march[5,19]. Consistent with these findings, the factor “marching with an external load” shows a direct relationship between the distance covered and the injury incidence.

Regarding the risk factor “load carriage” among military personnel, the results of the included studies revealed that the loads transported included uniforms, weapons, and backpacks, with average load weights ranging from 20 kg[19] to 52 kg[7]. Kim et al. (2015) reported that Korean military personnel, who carried lighter loads

Table 6 - Certainty of evidence of the meta-analysis to compare the risk of injuries between men and women.

N. of studies	Certainty assessment						N. of participants		Effect		Quality of evidence	Importance
	Design of studies	Risk of bias	Inconsistency	Indirectness of the evidence	Imp.	Others considerations	Women	Men	Relative (95% CI)	Absolute (95% CI)		
5	Observational study	Very serious	Serious [a]	Not serious	Non serious	All potential confounding factors would reduce the demonstrated effect	108/4900 (2.2%)	808/173559 (0.5%)	RR 1.56 (1.11 to 2.20)	3 more per 1,000 (from 1 plus to 6 plus)	very low	Important

Table notes = Imp. = imprecision; CI: Confidence interval; a. I^2 = 71%. RR: Relative Risk.

than Finnish personnel, experience a lower incidence of upper limb injuries compared to their Finnish counterparts[18]. Roy et al. contributed three of the ten studies included in this systematic review, all addressing the “load carriage” risk factor. In a 2012 study, Roy et al. reported that the risk of musculoskeletal injuries increased for female military personnel carrying loads exceeding 16.1% of their body mass and for male personnel carrying loads greater than 26.4% of their body mass[6]. In a 2015 study, Roy et al. further reported that women carrying loads for more than 4 h and 45 min and men carrying loads for more than 6 h and 59 min were at a higher risk of injury[15].

The findings reported by Roy et al. in 2012 and 2015 are reinforced in their 2016 study, which indicated that military personnel carrying loads exceeding 10% of their body mass were twice as likely to sustain injuries compared to those carrying lighter loads[13]. Additionally, Roy et al. reported an 84% increase in injuries among service members who engaged in load carriage for more than 4 h[13]. Taken together, these data suggest that both the magnitude of the load and the duration of load carriage are directly associated with an increased risk of musculoskeletal injuries.

Considering the biopsychosocial factors affecting military personnel, the present study identified statistical significance for the risk factor “female sex” (RR = 1.56; 95% CI = 1.11-2.20). In other words, female military personnel performing tasks involving load carriage are 56% more likely to sustain musculoskeletal injuries than their male counterparts performing the same tasks. Sex is an intrinsic characteristic of military personnel and directly contributes to the increased incidence of injuries, as demonstrated in the meta-analysis conducted in this study[2,4,6,11,15]. A likely explanation for the elevated injury risk among female personnel relates to their physical constitution (e.g., height, muscle mass, and BMI) and physical conditioning (e.g., load-bearing and load-carrying capacity)[13,15].

With the removal of barriers limiting women's participation in military and combat roles, there is increased potential for female personnel to be exposed to tasks involving load carriage[2]. Therefore, it is timely to assess the risk of injury for women performing load carriage tasks and to compare it with the risk faced by men performing the same activities, with the aim of determining whether the risk factor “sex” may adversely affect individual performance, unit operability, or even mission success.

Tasks involving load carriage also elicit different musculoskeletal responses depending on the age of the soldier, as reported in four of the ten studies included in this review. The impact of age on injury risk varies across studies. Reynolds et al. (1999) reported that military personnel under 20 years of age experienced a higher incidence of injuries compared to older personnel (RR = 0.88;

$p < 0.01$)[7]. Conversely, Schuh et al. (2017) found that military personnel over 35 years of age were at greater risk of load carriage-related injuries than younger personnel (RR = 2.89; $p < 0.02$)[19]. However, due to the limited number of studies addressing age as a risk factor, it was not possible to conduct a more detailed analysis or to draw definitive conclusions regarding the influence of age on the incidence of musculoskeletal injuries among military personnel.

It is possible that the training experience accumulated by military personnel with age acts as a protective factor[29], such that injuries among younger personnel may be more frequently associated with overuse. In contrast, older personnel tend to engage in less physical exercise and operational activity, resulting in reduced exposure to load carriage tasks and other high-risk activities for musculoskeletal injury, and a higher likelihood of experiencing acute injuries compared to younger personnel[29].

Among the lifestyle-related risk factors for military personnel, smoking was the most frequently studied, evaluated in four of the ten observational studies included. Smoking is considered an extrinsic risk factor, and according to Reynolds et al. (1999), 39.9% of military smokers sustained musculoskeletal injuries after performing tasks involving load carriage (RR = 1.58; $p < 0.01$)[7]. Similarly, Schuh et al. (2017) reported that smokers had a higher risk of musculoskeletal injury than nonsmokers (RR of 3.39 and 95% CI 1.43-10.80)[19]. The other two studies did not provide precise statistical data on smoking, which precluded a meta-analysis of this risk factor.

Since smoking is a modifiable risk factor that contributes to increased mortality (14.7% of total deaths in Brazil in 2011)[30], and is associated with numerous diseases and high healthcare costs (estimated at 23.3 billion Reais per year for the public health system)[30], it is recommended that future studies investigate the relationship between smoking and the incidence of musculoskeletal injuries in military personnel using more robust statistical data. One hypothesis proposed regarding the association between smoking and load carriage-related musculoskeletal injuries is that high levels of cigarette smoking induce cellular damage[31] and slow wound healing, making musculoskeletal tissues more susceptible to injury, particularly during activities that increase mechanical load on compromised tissues[31], making musculoskeletal tissue more prone to injury, especially when associated with activities that increase the load on these damaged tissues.

Regarding the experimental studies meeting the eligibility criteria, it is important to highlight the limited number of studies on strategies to prevent load carriage-related musculoskeletal injuries. This limitation may stem from several factors: some studies evaluate biomechanics rather than injury outcomes; some do not include load carriage tasks; others involve different populations of military personnel; and some lack randomized controlled trial designs. Therefore, a scientific gap exists in the study of preventive strategies for musculoskeletal injuries in load-carrying military personnel, particularly regarding randomized studies. However, two studies reported reductions in the incidence of musculoskeletal injuries during military load carriage tasks: one evaluating the use of socks to prevent foot injuries[22] and another evaluating antiperspirants to reduce injuries[20]. In contrast, a third study found no significant difference in injury incidence between military personnel using a standard ballistic vest and those using an adapted ballistic vest[8].

Since military operability is closely linked to load carriage tasks, often involving marching, research into preventive strategies can substantially improve service members' performance. Bogerd et al. (2012) evaluated two types of socks and their efficacy in reducing foot injuries[22]. Their results indicated that polypropylene-blend socks led to fewer blisters than polypropylene-only socks[22]. Reynolds et al. (1995) evaluated the use of antiperspirants to prevent foot injuries, reporting that military personnel who applied antiperspirants correctly had fewer blisters than those in the placebo group[20]. The reports of this study show that military personnel who properly used antiperspirants had a lower incidence of blisters on their feet than did those in the placebo group[20]. Despite these favorable results, Yeung et al. (2011) reviewed lower limb injuries in runners and military personnel and concluded that there is no evidence that polyester-padded or double-layer socks are more effective than standard socks in reducing musculoskeletal injuries among military recruits[32].

Palmanovich et al. (2016) hypothesized that a ballistic vest adapted for the female body could reduce stress fractures and overuse injuries[8]. Although the vest was considered more comfortable and better fitting, no significant differences were observed between the intervention and control groups regarding stress fractures, low back pain, or lower limb pain[8]. It is important to note that ballistic vests are essential for body protection, particularly in combat settings, and reduce fatal injuries. However, wearing the vest adds load and increases the risk of musculoskeletal injuries. Konitzer et al. (2008) reported that 24% of military personnel wearing ballistic vests experienced cervical pain ($r = 0.12$; $p < 0.05$), 29% reported lumbar pain ($r = 0.14$; $p < 0.05$), and 27% reported upper limb injuries ($r = 0.15$; $p < 0.05$)[16]. Given the critical role of ballistic vests in protection, the present study encourages future researchers to conduct randomized clinical trials on ballistic vests, examining not only modifications that reduce the incidence of musculoskeletal injuries but also adaptations that do not compromise military tactical performance (e.g., shooting).

Musculoskeletal injuries associated with load carriage significantly impact military personnel, leading to activity restrictions and absences, which directly affect performance. Existing studies evaluating preventive strategies have limitations, including small sample sizes. Therefore, future research should focus on randomized clinical trials with larger sample sizes, ideally conducted within military organizations or under conditions comparable to combat environments. Another limitation of this review is variation in methods for measuring risk factors and a lack of rigor in outcome evaluation across studies, which may have compromised observational data collection and reduced the level of evidence for each risk factor. These limitations also precluded additional meta-analyses, which could have enhanced the review's scientific contribution. Concerning the lack of rigor in outcome evaluation, some studies relied on self-reported questionnaires and interviews, increasing the risk of recall bias, whereas others used medical records and databases, which may underreport injuries or contain inconsistencies due to varied record-keeping practices. Even with electronic medical records, uniform reporting remains a challenge, and minor injuries may go unreported, potentially distorting statistical data relative to actual injury incidence.

Finally, considering the importance of load carriage in military tasks and the relationship between external load and musculoskeletal injury incidence, further studies are needed to better understand the interplay between distance marched under load, appropriate marching equipment (socks, shoes, belts, backpacks), physical conditioning, and their influence on injury incidence during load carriage activities.

Conclusions

The results of the studies included in this systematic review indicate that the main risk factors contributing to musculoskeletal injuries are female sex, smoking, long-distance marching, increased load weight, and prolonged load carriage duration. Based on these findings, the Armed Forces should prioritize reducing modifiable risk factors to decrease musculoskeletal injuries among soldiers performing load carriage tasks.

Currently, evidence on effective preventive strategies remains inconclusive. Therefore, further randomized clinical trials are warranted to provide insights into strategies for preventing musculoskeletal injuries among load-carrying military personnel.

Finally, the authors hope that the conclusions of this systematic review will contribute to improving the physical health of military personnel, reducing healthcare costs, and enhancing overall military performance, thereby increasing operational readiness and the likelihood of mission success.

Acknowledgments

This study was funded by Fundação Carlos Chagas Filho de Amparo à Pesquisa do Estado do Rio de Janeiro (FAPERJ), SEI Process -260003/013303/2024.

References

1. Brasil. Decreto de Lei n. 3.864, de 24 de novembro de 1941. Estatuto dos Militares. Capítulo 1: Finalidade das Forças Armadas. Artigo 2. Available from: https://www.planalto.gov.br/ccivil_03/decreto-lei/1937-1946/del3864.htm. [Accessed Oct. 22, 2025].
2. Orr RM, Pope R. Gender differences in load carriage injuries of Australian army soldiers. BMC Musculoskelet Disord. 2016;17(1):488. doi
3. Orr RM, Pope R, Johnston V, Coyle J. Reported load carriage injuries of the Australian army soldier. J Occup Rehabil. 2015;25(2):316-22. doi
4. Mäkelä JP, Ramstad R, Mattila V, Pihlajamäki H. Brachial plexus lesions after backpack carriage in young adults. Clin Orthop Relat Res. 2006;452:205-9. doi
5. Knapik J, Ang P, Meiselman H, Johnson W, Kirk J, Bensel C, et al. Injuries associated with strenuous road marching. Mil Med. 1992;157(2):64-7. doi
6. Roy TC, Lopez HP, Piva SR. Risk factors for musculoskeletal injuries for soldiers deployed to Afghanistan. Aviat Space Environ Med. 2012;83(11):1060-6. doi
7. Reynolds KL, White JS, Knapik JJ, Witt CE, Amoroso PJ. Injuries and risk factors in a 100-mile (161-km) infantry road march. Prev Med. 1999;28(2):167-73. doi
8. Palmanovich E, Brin YS, Yaffe B, Mosheiff R, Weil Y. The effect of army vest design on the occurrence of stress fractures and overuse injuries in female military recruits. J R Army Med Corps. 2017;163(4):251-4. doi
9. Knapik JJ. Injuries and injury prevention during foot marching. J Spec Oper Med. 2014;14(4):131-5. doi
10. Orr RM, Pope R, Johnston V, Coyle J. Soldier occupational load carriage: a narrative review of associated injuries. Int J Inj Contr Saf Promot. 2014;21(4):388-96. doi
11. Roy TC, Lopez HP, Piva SR. Lifting tasks are associated with injuries during the early portion of a deployment to Afghanistan. Mil Med. 2012;177(6):716-22. doi
12. Knapik JJ, Reynolds KL, Harman E. A systematic review of the effects of physical training on load carriage performance. J Strength Cond Res. 2012;26(2):585-97. doi
13. Roy MAJT, Ritland BM, Sharp MA. Heavy loads and lifting are risk factors for musculoskeletal injuries in deployed female soldiers. Mil Med. 2016;181:e1476. doi
14. Knapik JJ, Reynolds KL, Harman E. Soldier load carriage: historical, physiological, biomechanical, and medical aspects. Mil Med. 2004;169(1):45-56. doi
15. Roy TC, Ritland BM, Sharp MA. A description of injuries in men and women while serving in Afghanistan. Mil Med. 2015;180(2):126-31. doi
16. Konitzer LN, Fargo J, Brininger TL, Reed B. Association between back, neck, and upper extremity musculoskeletal pain and the individual body armor. J Hand Ther. 2008;21(2):143-8. doi

17. Mäkelä JP, Ramstad R, Mattila V, Pihlajamäki H. Brachial plexus lesions after backpack carriage in young adults. Clin Orthop Relat Res. 2006;452:205-9. doi
18. Kim KE, Kim EJ. Incidence and risk factors for backpack palsy in young Korean soldiers. J R Army Med Corps. 2016;162(1):35-8. doi
19. Schuh-Renner A, Canham-Chervak M, Grier TL, Hauschild VD, Roy TC, Jones BH. Risk factors for injury associated with low, moderate, and high mileage road marching in a U.S. Army infantry brigade. J Sci Med Sport. 2017;20 (Suppl):S28-33. doi
20. Reynolds K, Hopp J, Khachatoorian C, Knapik JJ. Effects of an antiperspirant with emollients on foot-sweat accumulation and blister formation while walking in the heat. J Am Acad Dermatol. 1995;33(4):626-30. doi
21. Knapik JJ. Prevention of foot blisters. J Spec Oper Med. 2014;14(2):95-7. doi
22. Bogerd CP, Brühwiler PA, Rossi RM. The effect of two sock fabrics on perception and physiological parameters associated with blister incidence: a field study. Ann Occup Hyg. 2012;56(4):481-8. doi
23. Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ. 2021;372:n71. doi
24. Moola S, Zadow M, Sears K, Sfetcu R, Currie M, Lisy K et al. Conducting systematic reviews of association (etiology): the Joanna Briggs Institute's approach. Int J Evid Based Healthc. 2015;13(3):163-9. doi
25. Deeks JJ, Higgins JPT, Altman DG. Cochrane handbook for systematic reviews of interventions - Chapter 10: analyzing data and undertaking meta-analyses. Londres: Cochrane; 2022. Disponível em: https://training.cochrane.org/handbook/current/chapter-10.
26. Higgins JPT, Thomas J, Chandler J, Cumpston M, Li T, Page MJ, Welch VA. Cochrane handbook for systematic reviews of interventions - Chapter 6: choosing effect measures and computing estimates of effect. Londres: Cochrane; 2023. Available from: https://training.cochrane.org/handbook/current/chapter-06 [Accessed 28 November 2025].
27. Cochrane Collaboration. Cochrane handbook for systematic reviews of interventions - Chapter 13: assessing risk of bias due to missing results in a synthesis. Londres: Cochrane; 2022. Available from: https://training.cochrane.org/handbook/current/chapter-13 [Accessed 28 November 2025].
28. Schünemann H, Brożek J, Guyatt G, Oxman A. GRADE handbook: handbook for grading the quality of evidence and the strength of recommendations using the GRADE approach. Londres: GRADE Working Group; 2013. Available from: https://gdt.gradepro.org/app/handbook/handbook.html [Accessed 28 November 2025].
29. Knapik J, Jones B, Bauman C, Harris J. Physical fitness, age, and injury incidence in infantry soldiers. J Occup Med. 1993;35(6):598-603. doi
30. Pinto MT, Pichon-Rivière A, Bardach A. Estimativa da carga do tabagismo no Brasil: mortalidade, morbidade e custos. Rev Panam Salud Publica. 2015;38(4):398-404. doi
31. Wong LS, Martins-Green M. Firsthand cigarette smoke alters fibroblast migration and survival: implications for impaired healing. Wound Repair Regen. 2004;12(4):471-84. doi
32. Yeung SS, Yeung EW, Gillespie LD. Interventions for preventing lower limb soft-tissue running injuries. Cochrane Database Syst Rev. 2011;7:CD001256. doi

Internet resources

RoB2.0. https://methods.cochrane.org/risk-bias.

Corresponding author

Priscila dos Santos Bunn. Marinha do Brasil, Centro de Educação Física Almirante Adalberto Nunes, Rio de Janeiro, RJ, Brazil.
E-mail: priscilabunn@yahoo.com.br.

Manuscript received on July 16, 2024
Manuscript accepted on June 2, 2025