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The Association Between Lean Body Mass and Military Load Carriage Performance: A Systematic Review and Meta-Analysis

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ADMINISTRATIVE INFORMATION

Support - None.

Review stage at the time of initial registration - Preliminary searches.

Conflicts of interest - None.

INPLASY registration number: INPLASY2026110079

Amendments - This protocol was registered with the International Platform of Registered Systematic Review and Meta-Analysis Protocols (INPLASY) on 23 November 2026 and was last updated on 23 November 2026.

INTRODUCTION

Review question / Objective In military personnel and comparable load-bearing populations, is whole-body lean body mass (LBM) or fat-free mass (FFM) associated with performance on fixed-distance loaded field marches (ruck marches)?
Objectives:
Estimate the pooled correlation between LBM/FFM and loaded-march completion time.
Quantify between-study heterogeneity and the prediction interval for a new cohort.
Test how robust the pooled estimate is to study selection, load, distance, and analytic choices.
Grade the certainty of the evidence and identify gaps for future research.
Population: Healthy adult military personnel, military trainees, and tactical or occupationally comparable adults (ROTC cadets). Studies are eligible regardless of sex. Sex-stratified results will be reported where available.
Exposure: Whole-body LBM or FFM, measured by DXA, hydrostatic weighing, air-displacement plethysmography, skinfolds, or bioimpedance. Absolute kilograms is the primary form. BMI-only and body-mass-only exposures are excluded.
Comparator: Not applicable, because exposure is continuous. Associations are compared across the observed range of LBM/FFM.
Outcome: Completion time (or speed) over a fixed-distance road or trail field march carrying at least 10 kg of external load. The effect measure is the bivariate Pearson correlation (r) between LBM/FFM and march time, reported or recoverable from the paper. A negative r means faster marching with more lean mass.
Study design: Observational studies (cross-sectional, cohort, or baseline data from trials) with an extractable bivariate correlation. Treadmill, indoor, or vest-only tasks; non-march tasks (runs, stretcher or drag); binary-only analyses; and multivariable-only results are excluded.

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Rationale Loaded foot marching is a core military task. Soldiers routinely carry 30 kg or more over distance, and the ability to do so quickly and without injury affects mission performance and musculoskeletal injury risk. Marching performance is typically assessed as completion time over a fixed distance, and several occupational standards and training programs are built around it.

Body composition is a plausible determinant of loaded-march performance. Lean mass provides the muscular capacity to support and move an external load, while load is carried against body mass as a whole. Because absolute load is fixed while body size varies, individuals with more lean mass may be better able to tolerate the same load at a lower relative cost. Primary studies have tested this in different cohorts, loads, and distances, and most report that greater lean mass is associated with faster march times. The reported correlations are modest to moderate, are based on small samples, and use different measurement methods and march conditions. Several studies also report body mass or BMI rather than lean mass, which cannot separate lean from fat tissue.

No prior review has quantitatively synthesized the bivariate association between whole-body LBM/FFM and fixed-distance loaded-march time. Existing reviews address load carriage biomechanics, physiology, or injury more broadly, or cover physical fitness predictors without pooling lean-mass correlations. Individual studies are too small to estimate the strength and consistency of this association precisely or to say whether it holds across loads, distances, and populations.

A pooled estimate with its heterogeneity and prediction interval would show whether lean mass is a reliable correlate of march performance. It would also inform body composition assessment, nutrition, and resistance-training priorities in recruit and operational populations and identify evidence gaps, particularly in female cohorts and for standardized loads. Registering the protocol before the formal search and fixing the eligibility, extraction, and analysis rules in advance limits selective inclusion and analytic flexibility.

Condition being studied This review addresses loaded foot-march performance, a physical work capacity in military and tactical populations, rather than a disease. Loaded marching (ruck marching) is walking or hiking over roads or trails while carrying external loads such as body armor, a rucksack, weapons, and equipment, commonly 15 to 45 kg or more. Performance is usually measured as the time taken to complete a fixed distance or as speed over that distance.

The factor of interest is body composition, specifically whole-body lean body mass (LBM) or fat-free mass (FFM): the non-fat component of body mass, including skeletal muscle, organs, bone, and water. It is estimated by dual-energy X-ray absorptiometry, hydrostatic weighing, air-displacement plethysmography, skinfold equations, or bioimpedance.

Poor loaded-march performance matters operationally because it limits mobility and mission readiness. It is also relevant to health because high load carriage is linked to musculoskeletal injury, fatigue, and attrition in training. Understanding whether lean mass relates to march performance may help inform body composition assessment, selection standards, nutrition, and strength training for military personnel.

The review studies the association between lean mass and road march time. It does not evaluate treatment effects or diagnose a medical condition.

METHODS

Search strategy Databases: PubMed/MEDLINE, Embase, Scopus, Web of Science Core Collection, SPORTDiscus (EBSCO), CINAHL (EBSCO), and the Cochrane Central Register of Controlled Trials. Grey literature: Defense Technical Information Center (DTIC), U.S. Army Research Institute of Environmental Medicine technical reports, National Academies Press reports, and OpenGrey/ProQuest Dissertations.

Dates and language: Inception to the date of search. English-language full texts. Non-English records will be noted and translated where feasible.

Concepts and terms. Free-text terms are searched in the title, abstract, and keywords, with controlled vocabulary (MeSH, Emtree) added where available.

Concept 1, loaded marching: ("load carriage" OR "loaded march*" OR "ruck march*" OR "rucksack" OR "road march*" OR "foot march*" OR "forced march*" OR "loaded walk*" OR "backpack*" OR "weighted march*" OR "military load*" OR "combat load*" OR "external load*")

Concept 2, lean mass: ("lean body mass" OR "lean mass" OR "fat-free mass" OR "fat-free mass" OR "lean tissue" OR "body composition" OR "muscle mass" OR DXA OR DEXA OR "dual-energy X-ray" OR "hydrostatic weighing") OR "air displacement" OR "bod pod" OR "skinfold" OR "bioimpedance"

Concept 3, population: (military OR soldier* OR army OR marine* OR "special operations" OR recruit* OR cadet* OR ROTC OR infantry OR "armed forces" OR "service member*" OR warfighter* OR firefighter* OR "tactical athlete*")

Concepts are combined as 1 AND 2 AND 3. Concept 3 will be dropped in a broader sensitivity search to catch studies that do not name the military in the abstract.

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Example PubMed string:
("load carriage"[tiab] OR "loaded march*"[tiab] OR "ruck march*"[tiab] OR rucksack[tiab] OR "road march*"[tiab] OR "foot march*"[tiab] OR "forced march*"[tiab] OR backpack*[tiab] OR "external load*"[tiab] OR "combat load*"[tiab]) AND ("lean body mass"[tiab] OR "lean mass"[tiab] OR "fat-free mass"[tiab] OR "body composition"[tiab] OR "Body Composition" [MeSH] OR DXA[tiab] OR DEXA[tiab] OR skinfold*[tiab] OR bioimpedance[tiab]) AND (military[tiab] OR soldier*[tiab] OR army[tiab] OR "Military Personnel" [MeSH] OR recruit*[tiab] OR cadet*[tiab] OR ROTC[tiab])
Equivalent strings for the other databases will be adapted and saved in full as supplementary material.
Supplementary searching: Backward and forward citation chasing of all included studies and of relevant prior reviews, hand-searching of reference lists, and screening of Military Medicine, Journal of Strength and Conditioning Research, Ergonomics, and European Journal of Applied Physiology for relevant titles. Authors will be contacted for missing correlation coefficients where feasible.
Screening and records: Records will be exported to a reference manager, de-duplicated, and screened by title and abstract and then full text against the eligibility criteria. The date, platform, interface, and number of records retrieved for each database will be recorded and reported in the PRISMA flow diagram.

Participant or population Included: Healthy adults aged 18 years or older who perform loaded foot marching as part of military or comparable occupational duty. This includes active-duty and reserve military personnel, military recruits and trainees, officer candidates and ROTC cadets, and tactical populations such as special operations personnel or other occupational groups that march with military-style loads, provided the study describes a loaded field march.
Studies are eligible regardless of sex, branch of service, rank, or nationality. Mixed-sex cohorts are eligible, and sex-stratified correlations will be extracted separately where reported and used in subgroup or sensitivity analyses.
Excluded: Participants with a diagnosed medical, musculoskeletal, or metabolic condition that is the focus of the study (injury or rehabilitation cohorts, for example). Children and adolescents. Studies of recreational hikers or backpackers with no military or occupational load context. Elite or competitive athletes studied in a sport setting without a loaded-march task.
Unit of analysis: One independent cohort per effect size. If several papers report the same participants, they will be treated as one cohort and the most complete report used.

Intervention Not applicable. This review does not evaluate an intervention.

Comparator Not applicable. This is an observational review of a continuous exposure, so there is no comparator intervention or control group.

Study designs to be included Observational studies reporting a bivariate (Pearson) correlation between whole-body lean/fat-free mass and fixed-distance loaded field-march time: cross-sectional studies, cohort studies, and baseline data from trials or training studies. Experimental or intervention studies are eligible only for pre-intervention baseline data. Excluded: reviews, case reports, conference abstracts without extractable data, qualitative studies, and studies reporting only multivariable models, binary comparisons, BMI or body mass.

Eligibility criteria Additional inclusion criteria
The outcome is completion time (or speed) over a fixed-distance road or trail field march.
External load of at least 10 kg carried during the march (body armor, rucksack, weapons and equipment count toward load).
Exposure is whole-body LBM or FFM measured by a stated method. Absolute kilograms is the primary form.
The paper reports a bivariate Pearson correlation between LBM/FFM and march time or gives data from which it can be computed. Where a Spearman correlation is reported, it will be extracted and flagged for sensitivity analysis.
Full text is available in English. Peer-reviewed articles, technical reports, and theses are eligible if the data are extractable.
Additional exclusion criteria
Treadmill, laboratory, indoor, or weighted-vest-only tasks.
Tasks that are not marches: runs, stretcher carries, casualty drags, obstacle courses, and timed lifts.
Marches under 10 kg of external load.
Time-trial distances that are not fixed or self-paced durations without a defined distance.
Segmental lean mass only (for example, leg lean mass) with no whole-body value.
Studies reporting only body mass, BMI, body fat percentage, or multivariable model results with no extractable bivariate correlation.
Duplicate reports of the same cohort (the most complete report is used) and narrative reviews.
Multiple marches or loads: One effect size per independent cohort. If a cohort completed

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marches at several distances or loads, the rule pre-specified in the Data extraction section will be applied, and the other conditions will be used only in sensitivity analyses.

Information sources Electronic databases: PubMed/MEDLINE, Embase, Scopus, Web of Science Core Collection, SPORTDiscus (EBSCO), CINAHL (EBSCO), and the Cochrane Central Register of Controlled Trials (CENTRAL). Searches run from database inception to the date of the final search, which will be recorded and reported.
Grey literature: Defense Technical Information Center (DTIC), U.S. Army Research Institute of Environmental Medicine technical reports, National Academies Press reports, and ProQuest Dissertations & Theses. Conference abstracts will be screened but included only if the correlation is extractable.
Trial and protocol registers: ClinicalTrials.gov, the WHO International Clinical Trials Registry Platform, OSF Registries, and INPLASY to identify unpublished or ongoing studies and related reviews
Citation searching: Backward (reference lists) and forward (citing articles, via Scopus or Google Scholar) searching of all included studies and of relevant prior reviews.
Journal hand-searching: Recent issues of Military Medicine, Journal of Strength and Conditioning Research, Ergonomics, and European Journal of Applied Physiology.
Contact with authors: Corresponding authors will be emailed to request missing correlation coefficients, sample sizes, load or distance details, and unpublished data. Non-response after one follow-up request will be recorded, and the study excluded if no usable correlation can be extracted.
Existing evidence base: A set of studies identified before registration through informal searching and the investigators' own files will be re-screened against the same criteria alongside the formal search results.

Main outcome(s) Primary outcome: The pooled correlation (r) between whole-body lean body mass or fat-free mass (absolute kg) and completion time over a fixed-distance loaded field march carrying at least 10 kg of external load. A negative r means that more lean mass is associated with a faster (shorter) march time.
Timing: Marches are measured once per cohort at the time of testing. If a cohort completed several marches, the pre-specified rule in the Data extraction section picks the primary one, and the others are used only in sensitivity analyses.
Effect measure: Pearson r, Fisher z-transformed for pooling and back-transformed for reporting. Variance is 1/(n − 3). Random-effects REML with the modified Hartung–Knapp confidence interval, plus a 95% prediction interval.

Additional outcome(s) If enough cohorts exist:
Between-study heterogeneity (Q, I^2, τ^2).
Leave-one-out and alternative τ^2 estimator results (DerSimonian–Laird, Paule–Mandel).
Pooled estimates for relative lean mass (% body mass, where available.
Subgroup differences by sex, load, distance, and body composition method, if enough cohorts exist.
Certainty of the evidence (GRADE).
Sex-stratified correlations: Pooled r for male and female cohorts separately, where at least two cohorts per sex are available.
Body composition method: Pooled r by measurement method (DXA, hydrostatic weighing, air-displacement plethysmography, skinfolds, bioimpedance).
Load and distance: Association of load (kg) and load as a percentage of body mass and march distance with the cohort-level correlation, using subgroup or meta-regression analysis only if at least 10 cohorts are available.
Relative lean mass: Pooled r for LBM as a percentage of body mass, or LBM per kilogram of body mass, where reported.
Small-study effects: Funnel plot and Egger-type test, only if at least 10 cohorts are available. Otherwise described qualitatively.
Risk of bias: JBI checklist appraisal of each included study and its effect on the pooled estimate in sensitivity analysis.

Data management Records: Search results from all databases will be exported in CSV format into a reference manager (EndNote), de-duplicated automatically, and then checked manually. A single master log will record each record's source, date retrieved, screening decision, and reason for exclusion, so the PRISMA 2020 flow diagram can be reconstructed from it.
Screening: Title and abstract screening, then full-text screening, will be done against the eligibility criteria in a shared spreadsheet. Screening is completed by two reviewers.
Data extraction: Data will be extracted into a pre-built form in a spreadsheet with locked column definitions. Fields include study identifiers, cohort, sample size, sex, age, load, distance, terrain, body composition method, LBM/FFM values, march time, the correlation coefficient, and any assumptions made. Values that were inferred rather than reported will be flagged.
Storage and version control: Files will be kept in a shared, backed-up folder with dated versions. Original extraction and later corrections will be

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preserved, so changes after registration can be traced.
Analysis files and code: Analysis scripts (Python) and the final dataset will be archived and shared as supplementary material or in a public repository at publication.

Quality assessment / Risk of bias analysis Tool: Each included study will be appraised with the Joanna Briggs Institute (JBI) Critical Appraisal Checklist for Analytical Cross-Sectional Studies, which covers inclusion criteria, description of participants and setting, validity and reliability of exposure and outcome measurement, identification and handling of confounders, and appropriateness of statistical analysis. Cohort studies reporting baseline correlations will be appraised with the same checklist, applied to the baseline cross-sectional data.
Reviewers: Two reviewers will appraise every included study independently. Disagreements will be resolved by discussion and by a third reviewer if consensus is not reached. The agreement between the two reviewers (percent agreement and Cohen's kappa) will be reported.
Review-specific considerations: Items will be interpreted for this topic. Exposure measurement is judged by the body composition method and its validity (DXA and hydrostatic weighing being stronger than skinfold or bioimpedance estimates). Outcome measurement is judged by whether the march distance, load, and terrain were standardized and timed objectively. Confounding is judged by whether load, sex, age, and fitness were comparable or reported.
Scoring and decision rule: Each item is rated Yes (1), No (0), Unclear (0), or Not applicable (excluded from the count). The percentage of applicable items rated "yes" gives the overall judgement:
Low concern: 75% or more of applicable items rated Yes.
Moderate concern: 50% to under 75%.
High concern: under 50%, or a "No" on exposure measurement or outcome measurement regardless of the total.
Use of the ratings: No study will be excluded on quality alone. In sensitivity analysis the pooled estimate will be recalculated without high-concern studies. Risk of bias will also be considered when grading the certainty of evidence (GRADE).

Strategy of data synthesis Effect size: The effect size is the bivariate Pearson correlation (r) between whole-body LBM or FFM (absolute kg) and loaded-march completion time. One effect per independent cohort is used. Correlations are Fisher z-transformed ($z = \operatorname{atanh} r$) with variance $1/(n - 3)$, pooled, and back-transformed for reporting. Where a paper reports only a significant or non-significant result without a coefficient, the author will be contacted. If no coefficient can be obtained, the study is described narratively and not pooled.
Model: Random-effects meta-analysis using restricted maximum likelihood (REML) to estimate between-study variance (τ^2). Because few cohorts are expected, the primary confidence interval uses the modified Hartung–Knapp adjustment (t distribution with $k - 1$ degrees of freedom, with the variance factor floored at 1). A 95% prediction interval (t distribution with $k - 2$ degrees of freedom) is reported. Meta-analysis is run only if at least three independent cohorts are eligible. With fewer, results are summarized narratively.
Heterogeneity: Q test, I^2, and τ^2, interpreted with caution because of the small number of cohorts.
Sensitivity analyses:
Leave-one-out analysis.
Alternative τ^2 estimators (DerSimonian–Laird, Paule–Mandel).
Omission of studies is of high concern on risk-of-bias appraisal.
Substituting alternative marches or load conditions for cohorts that completed more than one, following the pre-specified rule.
Excluding studies where sample size or correlation was inferred rather than reported.
Subgroup analysis and meta-regression: By sex, body composition method, and load and distance, only if at least two cohorts per subgroup (and at least 10 cohorts for meta-regression) are available. These are exploratory.
Small-study effects: Funnel plot and Egger-type test if at least 10 cohorts, otherwise a qualitative assessment.
Certainty of evidence: GRADE, starting at low certainty for observational studies and rated for risk of bias, inconsistency, indirectness, imprecision and publication bias.
Software: Python (NumPy, SciPy, and statsmodels), with analysis code shared as supplementary material.

Subgroup analysis Subgroup analyses are exploratory, pre-specified, and run only if at least two independent cohorts are available in each subgroup. With fewer, the subgroup results are described narratively and not pooled or compared.
Planned subgroups:
Sex: male-only, female-only, and mixed-sex cohorts. Sex-stratified correlations are used where reported.
Body composition method: DXA and hydrostatic weighing (reference methods) versus skinfold or bioimpedance estimates.

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External load: lighter versus heavier loads, split at the median load of the included cohorts, and load as a percentage of body mass where reported.
March distance: shorter versus longer marches, split at the median distance of the included cohorts.
Population: active-duty personnel versus recruits, cadets, and other trainees.
Method: Subgroup pooled estimates use the same random-effects model as the primary analysis. Differences between subgroups are tested with a between-subgroup Q test (a test for subgroup differences), and interpreted with caution. Meta-regression on continuous load or distance is run only if at least 10 cohorts are available.

Sensitivity analysis Sensitivity analyses are pre-specified and will be reported alongside the primary estimate, regardless of whether they change the result.
Leave-one-out: The pooled correlation is recalculated, omitting each cohort in turn, to test whether any single study drives the result.
Alternative τ^2 estimators: The primary REML estimate is compared with DerSimonian–Laird and Paule–Mandel, and the Hartung–Knapp interval is compared with the standard Wald interval.
Risk of bias: The pooled estimate is recalculated after removing cohorts rated at high concern in the JBI appraisal.
Inferred data: Cohorts whose sample size or correlation had to be inferred rather than read directly from the paper are removed.
Multiple marches or loads: For cohorts that completed several marches or loads, the pooled estimate is recalculated with each alternative condition in place of the primary one, following the rule fixed in the Data extraction section.
Eligibility boundary: Cohorts that meet the eligibility criteria only marginally (for example, a load near 10 kg, a shorter march distance, or a Spearman correlation) are removed or added to test whether the decision about inclusion changes the result.
Sample size: Cohorts with small samples are removed.
Any analysis added after the data are seen will be labelled "post hoc" in the report.

Language restriction Yes. English-language full texts only. Non-English records identified in the search will be listed and, where feasible, translated and assessed.

Country(ies) involved United States.

Other relevant information Reporting guidelines: The review will follow PRISMA 2020 and MOOSE for observational studies. The completed PRISMA checklist and flow diagram will be reported, and the protocol will be cited in the final report.
Stage of review at registration: A pilot extraction was done on a small, non-systematic set of studies identified through informal searching and the investigators' files to test the feasibility of the question and the extraction form. The formal multi-database search, deduplicated dual screening, risk-of-bias appraisal, and final data extraction have not been completed. Because some candidate studies were known to the investigators before registration, all of them will be re-screened against the same eligibility criteria as the formal search results, and any difference between the pilot set and the final included set will be reported.
Pre-specified rules: The eligibility criteria, effect measure, extraction rules (including the rule for choosing one march or load per cohort), synthesis model, and sensitivity analyses are fixed in this protocol. Analyses added after seeing the data will be labelled post hoc.
Amendments: Any change to the protocol after registration will be recorded as a dated amendment in the registry, with the reason, and reported in the methods of the final paper.
Data and code sharing: The extraction dataset, search strings, and analysis code (Python) will be shared as supplementary material or in a public repository at publication.
Planned publication: The results are intended for submission to a peer-reviewed military or sports medicine journal, such as Military Medicine.
Conflicts of interest and funding: "None"
Current review status: Ongoing.

Keywords lean body mass; fat-free mass; load carriage; ruck march; military; body composition; meta-analysis; systematic review.

Dissemination plans The findings will be submitted for publication in a peer-reviewed journal, with Military Medicine as the intended target. The registration number will be cited in the manuscript.
Results may also be presented at military health, sports medicine, or human performance conferences. A plain-language summary will be made available to military training and human performance practitioners, and the extraction dataset, search strings, and analysis code will be shared as supplementary material or in a public repository.
If the review is not published, the registry record will be updated with the final status and a brief summary of the findings.

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