Journal of Athletic Training 2025;60(5):359–371
doi: 10.4085/1062-6050-0526.23

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Risk Factors for Patellofemoral Pain in the Military: Systematic Review With Meta-Analysis

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Background: The main cause for military training attrition is musculoskeletal injuries to the knee, such as patellofemoral pain (PFP).

Objective: To identify which factors increase the risk of PFP occurrence in military personnel.

Design: Systematic review with meta-analysis.

Data Sources: Searches were performed in MEDLINE/PubMed, CINAHL, Embase, SPORTDiscus, Web of Science, Scopus, and OpenGray databases.

Study Selection: Included studies included military personnel and had a prospective cohort design investigating at least 1 variable as a risk factor for PFP.

Data Extraction: Extraction was performed by 2 independent evaluators, and the data were separated between the military personnel who developed PFP and those who did not.

Data Synthesis: Meta-analyses were performed using standardized mean differences (SMDs) and 95% CIs, and levels of recommendation were determined.

Results: From 11 articles, this review grouped 7518 military personnel, of whom 572 (7.61%) developed PFP. We found moderate evidence that isokinetic knee-extensor weakness at 60°/s predicts PFP in the military (SMD = −0.69; 95% CI = −1.02, −0.35). A larger frontal-plane knee-projection angle during the single-legged squat was also identified as a risk factor for PFP in male military personnel (SMD = 0.55; 95% CI = 0.14, 0.97) with a moderate level of evidence. We found moderate evidence that sex, body mass index, isometric knee-extensor strength, and isokinetic knee-flexor strength do not predict PFP in military personnel. Finally, we found strong evidence that age and body mass do not predict PFP in this population.

Conclusions: Deficits in isokinetic knee-extensor strength and a greater frontal-plane knee-projection angle are risk factors for PFP in military personnel. Given that these are modifiable factors, these aspects should be considered in injury-prevention interventions in the military.

Key Words: knee joint, anterior knee pain, biomechanics, relative risk, military force

Key Points

- A total of 572 of 7518 military personnel developed patellofemoral pain, for an incidence of 7.61%.
- Knee-extensor weakness and a greater frontal-plane knee-projection angle during the single-legged squat were identified as risk factors that may predispose military recruits to develop patellofemoral pain.
- Identifying modifiable risk factors is the first step for injury prevention, and this knowledge can contribute to the development of preventive programs during military training.

Military training demands a combination of psychological and physical skills.[1] While attempting to induce favorable musculoskeletal adaptations, the training stimulus may result in injury due to cumulative stress.[2,3] Musculoskeletal injuries may limit the individual's ability to perform activities of daily living, recreational exercise, and occupational duties, which could be detrimental to those serving in the military.[4] Military recruits seem to be particularly more affected by musculoskeletal injuries, with 1 in every 4 recruits dropping out from elite military training due to such injuries.[2] In this context, understanding factors associated with the most common injuries in this population is important.

Studies have shown that the major cause of attrition of basic military training in countries such as the Netherlands is musculoskeletal injuries to the knee.[2,5] Knee injuries affect 5.04 per 100 military personnel per year, and this incidence reaches 62.2 injuries per 100 military personnel per year when only elite military personnel are considered.[2] Among all musculoskeletal injuries that affect this population, patellofemoral pain (PFP) is one of the most common.[4] *Patellofemoral pain* is defined as diffuse anterior knee pain located around or behind the patella, which is aggravated by at least 1 activity that loads the patellofemoral joint during weight bearing (eg, squatting, running, stair ambulation, and jumping).[6] The prevalence of PFP among military personnel has been reported to be 13.5%.[3] These injuries generate absenteeism from military duties, in addition to bringing high financial costs of hundreds of millions of dollars per year.[7,8]

Individuals with PFP may report symptoms lasting for years, which could reduce physical and work capacity along with quality of life.[4,6] Researchers have suggested that the cause of PFP is multifactorial, with several factors associated with a higher risk of developing this condition. Biomechanical, anthropometric, physiological, and psychosocial factors have been associated with the development of PFP.[6,9] Identifying potential modifiable risk factors is essential for injury prevention, and this is relevant because of the potential not only to improve quality of life but also to benefit the military forces, reducing days off and restrictions on the performance of military duties.[10,11]

Researchers have conducted systematic reviews addressing risk factors for PFP in the general population, but no reviews have had a specific focus on the military population.[9,12] For clinical decision-making and resource allocation for health conditions, clinicians need an understanding of the risk factors for PFP in this specific population, which can provide a basis for evidence-based preventive strategies. The primary purpose of our review was to analyze risk factors for PFP in military personnel. A secondary objective was to analyze the incidence of PFP in this population.

METHODS

This systematic review was conducted according to the reporting guidelines of Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA)[13] and Meta-analyses of Observational Studies in Epidemiology (MOOSE).[14] The systematic review was prospectively registered in the PROSPERO database (CRD42021260843).

Search Strategy

The search words used in this review were based on those used in previous studies, with words related to PFP and risk factors based on those suggested by Neal et al[9] and words related to military personnel based on those used by Dijksma et al.[5] The search strategy for all databases is detailed in the Supplemental Table. The databases used in this study were MEDLINE/PubMed, CINAHL, Embase, SPORTDiscus, Web of Science, and Scopus. We also consulted OpenGray, an online database that collects and makes available gray literature from Europe. Hand searching of the reference lists was conducted for potential additional studies that fit the inclusion criteria. The searches were carried out between database inception and January 2023. No language restriction was used.

Study Selection

Search results were exported to Rayyan (Qatar Computing Research Institute) software, and duplicates were removed manually. Two independent evaluators (E.A.B.R. and D.F.M.M.) read the titles and abstracts and determined whether the studies met the inclusion criteria. For this review, the inclusion criteria were as follows: (1) studies with populations composed entirely or in part of military personnel, provided that the latter were in a subgroup so their data could be differentiated from the others, and (2) studies with a prospective cohort design investigating at least 1 variable as a risk factor for PFP.

Data Extraction

The same 2 independent evaluators completed data extraction and separated the data by military personnel who developed PFP and those who did not. Extracted data included the following: descriptive data of the population; author and year of publication; duration of follow-up; definition of PFP; incidence of PFP; and independent variables related to biomechanical, anthropometric, physiological, or psychosocial characteristics or a combination. Disagreements were first resolved by consensus, and, in case of persistence, a third evaluator (S.J.C.A.) was consulted. The Cohen κ index was used to verify the agreement of the evaluators regarding the articles that were included in the review.[15]

Risk of Bias

The included studies were assessed for risk of bias using the Newcastle-Ottawa Scale (NOS).[16–18] The NOS is divided into 3 domains: selection, comparison, and outcome.[18] The domains comprise 8 categories relating to methodological quality, and each study was given a score out of a maximum of 9 points (Table 1). This stage was also carried out by the 2 independent evaluators (E.A.B.R. and D.F.M.M.), with disagreements resolved by consensus. In case of persistent divergence, a third evaluator (S.J.C.A.) was consulted.

Data Analysis

For the statistical analyses, mean and SD were extracted for each continuous-scale variable. When similar variables were expressed in different scales, standardized mean differences (SMDs) and 95% CIs were determined. This allowed us to have a standardized result of the effect size that the assessed risk factor has on the probability of causing PFP.[19] The effect sizes were categorized as *small* ($\leq$0.590), *moderate* (0.60–1.19), or *large* ($\geq$1.20).[20]

Using the software package RevMan 5.0 (The Cochrane Collaboration), we tabulated data from similar variables in >1 study and generated meta-analyses with the respective forest plot. *High heterogeneity* was considered when $I^2 \geq 50\%$.[21,22] Given the small number and high heterogeneity of the studies, the random-effects model was used because a fixed-effects model likely would increase the chances of a type 1 error.[9]

Level of Evidence Recommendation

The level of recommendation of the evidence was determined based on the statistical analyses and risk-of-bias

Table 1. Newcastle-Ottawa Scale[18]

Category	Item	No. of Stars[a]
Selection	S1: Representativeness of the exposed cohort	0–1
	S2: Selection of the nonexposed cohort	0–1
	S3: Ascertainment of exposure	0–1
	S4: Demonstration that outcome of interest was not present at start of study	0–1
Comparison	C1: Comparability of cohorts on the basis of the design or analysis	0–2
Outcome	O1: Assessment of outcome	0–1
	O2: Was follow-up long enough for outcomes to occur	0–1
	O3: Adequacy of follow-up of cohorts	0–1

[a] Scores are classified as *low* (0–3 stars), *medium* (4–6 stars), or *high* (7–9 stars).

analyses. Criteria adapted from van Tulder et al were used (Table 2).[23]

RESULTS

The search yielded 824 articles for title and abstract review. After duplicates were removed and eligibility criteria were evaluated, 11 articles remained for data extraction (Figure 1).[24–34] The agreement index between the evaluators was 93% ($\kappa = 0.811$, $P = .002$) in the evaluation of the articles for data extraction. This review included 7518 military personnel, of whom 572 (7.61%) developed PFP. The characteristics of the selected studies are detailed in Table 3.

In the risk-of-bias analysis, all studies had a score $\geq$7, which was classified as *high quality* (Table 4). The NOS score had a mean interrater agreement of 93.25% (range, 82%–100%), indicating excellent interrater reliability. Of the 8 items on the NOS, item C1 (comparability of cohorts on the basis of the design or analysis) had the largest number of disagreements in interrater reliability, followed by item S4 (demonstration that the outcome of interest was not present at the start of the study).

Anthropometric Variables

Regarding anthropometric variables, we grouped data for sex,[24–26] height,[26–32] body mass,[26–32] age,[26,27,30,31] and body mass index (BMI).[27,28,32] We found a moderate level

Table 2. Level of Recommendation

Level	Criteria
Strong	$\geq$3 studies $\geq$2 studies of high methodological quality Statistical homogeneity
Moderate	(1) >1 study $\geq$1 study of high methodological quality Statistical heterogeneity or (2) >1 study Moderate or low quality Statistical homogeneity
Limited	(1) 1 study of high methodological quality or (2) 2 studies of moderate or low quality Statistical heterogeneity
Very limited	1 study of moderate or low quality

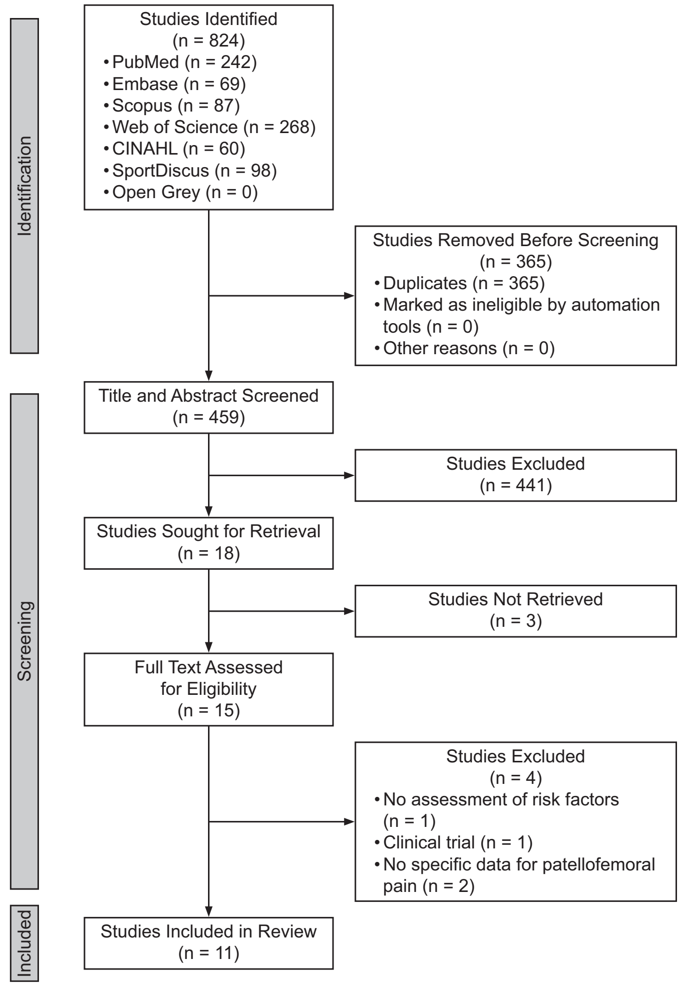


Figure 1. Flowchart of study selection.

of evidence, based on 3 articles, that sex is not a risk factor for PFP in military personnel (risk ratio = 1.12; 95% CI = 0.64, 1.94; Figure 2A).[24–26] Although the studies were of high quality, the heterogeneity was quite high ($I^2 = 83\%$). In these 3 studies, among those who developed PFP, the percentage of men (62%) was higher.

We observed that height is not a risk factor for PFP in the military ($I^2 = 57\%$; SMD = −0.03; 95% CI = −0.27, 0.20) with a moderate level of evidence (Supplemental Figure A).[26–32] A strong level of evidence indicated that body mass is not a risk factor for PFP in this population ($I^2 = 0\%$; SMD = 0.13; 95% CI = −0.02, 0.28) based on the results of 7 studies (Figure 2B).[26–32] A strong level of evidence, based on 4 articles, indicated that age is not a risk factor for PFP in this population ($I^2 = 1\%$; SMD = 0.04; 95% CI = −0.18, 0.26; Supplemental Figure B).[26,27,30,31] We observed a strong level of evidence that BMI is not a risk factor for PFP in military personnel ($I^2 = 47\%$; SMD = 0.20; 95% CI = −0.14, 0.53; Supplemental Figure C).[27,28,32]

Strength

Muscle strength was prospectively assessed in military personnel in 5 studies, which allowed the variables to be grouped. In these studies, the strength of the knee flexors, knee extensors, or both were evaluated, with different

Table 3. **Study Characteristics**

Study, y (Country)	PFP Participants, No. (Sex)	Sample Size, No.	Follow-Up Period	Incidence of PFP, % (% Sex)	Definition of PFP	Evaluated Variables	Main Results
Alrayani et al,[27] 2023 (Saudi Arabia)	37 (M)	315	12 wk	11.17	Retropatellar pain during ≥2 of the following activities: jumping/hopping, squatting, stairs, and running. Must demonstrate 2 of the following clinical criteria (with scores >3/10): pain during direct compression of patella against femoral condyle while knee is in full extension, tenderness on palpation of posterior surface of patella, pain on resisted knee extension from 90° of flexion to full extension, or pain during isometric contraction of the quadriceps against resistance on the suprapatellar resistance with 15° of knee flexion. These issues must have been present for 2 consecutive days. No symptoms in examination of knee ligaments; bursae; menisci; synovial plica; iliotibial band; Hoffa fat pad; and hamstrings, quadriceps, and patellar tendons.	Isometric strength: knee extensors and hip abductors Kinematic variables: FPKPA; Q-angle; and hip-adduction, knee-flexion, ankle-dorsiflexion, hip-adduction, and foot-eversion angles	Baseline measurements of FPKPA >5.2° during single-legged squat task were predictive of PFP (2.2 times greater risk).
Boling et al,[25] 2009 (United States)	40 (16 M, 24 F)	1319 (806 M, 513 F)	1–2.5 y	3.00 (1.98 M, 4.68 F)	During evaluation, must demonstrate retropatellar knee pain during ≥2 of the following activities: ascending/descending stairs, hopping/jogging, prolonged sitting, kneeling, and squatting Negative findings on examination of knee ligament, menisci, bursa, and synovial plica. Must demonstrate 1 of the following during evaluation: pain on palpation of medial or lateral patellar facet or pain on palpation of anterior portion of medial or lateral femoral condyle.	Kinematic variables: hip-flexion, hip-adduction, knee-flexion, knee-valgus, and knee-IR angles Kinetic variables: vertical ground reaction force (%BW), hip-abduction moment (%BW × height), hip-ER moment (% BW × height), knee-extension moment (%BW × height), knee-varus moment (%BW × height) Isometric strength: knee flexion, knee extension, hip extension, hip IR, hip ER, and hip abduction Alignment variables: Q-angle and navicular drop	Participants who developed PFP had less hip-abduction strength, less knee-flexion and -extension strength, lower vertical ground reaction force, lower knee-extension moment, lower hip-ER moment, and greater navicular drop.
Boling et al,[24] 2021 (United States)	188 (94 M, 94 F)	3893 (2448 M, 1445 F)	1–4 y	4.83 (4.00 M, 7.00 F)	During evaluation, must demonstrate (1) retropatellar knee pain during ≥2 of the following activities: ascending/descending stairs, hopping/jogging, prolonged sitting, kneeling, and squatting and (2)	Kinematic variables: 3D hip and knee kinematic data at both IC and 50% of stance phase during jump-landing task (jump forward to 50% of height followed by maximum vertical	In male cadets, landing with less knee flexion and greater hip ER increased the risk of developing PFP. In female cadets, landing

Table 3. Continued From Previous Page

Study, y (Country)	PFP Participants, No. (Sex)	Sample Size, No.	Follow-Up Period	Incidence of PFP, % (% Sex)	Definition of PFP	Evaluated Variables	Main Results
					negative findings on examination of knee ligament, menisci, bursa, and synovial plica. Must demonstrate 1 of the following during evaluation: pain on palpation of medial or lateral patellar facet or pain on palpation of the anterior portion of the medial or lateral femoral condyle.	jump) Isometric strength: knee extension, knee flexion, hip ER, hip IR, hip abduction, and hip extension Alignment variables: Q-angle and navicular drop	with less hip abduction and greater knee IR increased the risk of developing PFP.
Duvigneaud et al,[28] 2008 (Belgium)	26 (F)	62	6 wk	42.00	Retropatellar pain during ≥2 of the following activities: jumping/hopping, squatting, stairs, and running. Must demonstrate 2 of the following clinical criteria (with a minimum VAS of 3/10): pain during direct compression of patella against femoral condyle while knee is in full extension, tenderness on palpation of posterior surface of patella, pain on resisted knee extension from 90° of flexion to full extension, or pain during isometric contraction of the quadriceps against resistance on suprapatellar resistance with 15° of knee flexion. No symptoms during examination of knee ligaments; bursae; menisci; synovial plicae; iliotibial band; Hoffa fat pad; and hamstrings, quadriceps, and patellar tendons.	Anthropometric variables: body mass, height, BMI Isokinetic strength: PTKneeFlex at 60°/s (CON) PTKneeFlex at 240°/s (CON) PTKneeExt at 60°/s (CON) PTKneeExt at 240°/s (CON) PTKneeFlex at 30°/s (ECC) PTKneeExt at 30°/s (ECC) PTKneeExt at 60°/s normalized to BW PTKneeExt at 240°/s normalized to BW PTKneeExt at 60°/s normalized to BMI PTKneeExt at 240°/s normalized to BMI (PTKneeFlex at 60°/s)/(PTKneeExt at 60°/s) (PTKneeFlex at 240°/s)/PTKneeExt at 240°/s Performance tests: single-leg hop test and sports participation	Female recruits with decreased quadriceps muscle strength were more likely to develop PFP. Greater sports participation was a protective factor for PFP in this population.
Hetsroni et al,[33] 2006 (Israel)	61 (sex not discriminated)	405	4 mo	15.00	Physical examination of knee was performed to determine patellofemoral tenderness. Examinations were conducted by 1 orthopaedic surgeon. Individuals with symptoms related to blunt trauma to patella were excluded from study.	Kinematic variables: standing calcaneotibial angle, maximum foot-pronation angle, range of motion of pronation, time to maximum pronation, pronation speed, and duration of support phase	No association was found between anterior knee pain and static or dynamic foot-pronation variables.
Milgrom et al,[29] 1991 (Israel)	60 (M)	390	15 wk	15.00	Recruits were questioned about knee pain. Patellofemoral compression was performed. Medial, lateral, superior, and inferior patellar borders were palpated individually with pressure from fingertips	Anthropometric variables: height, body mass, hip ER, thigh circumference, calf circumference, medial intercondylar distance, tibial length, lower limb length (right and	Male recruits who developed PFP had shorter medial tibial intercondylar distance, performed larger number of push-ups, and had

Table 3. Continued From Previous Page

Study, y (Country)	PFP Participants, No. (Sex)	Sample Size, No.	Follow-Up Period	Incidence of PFP, % (% Sex)	Definition of PFP	Evaluated Variables	Main Results
					to determine whether tenderness was present. Knees were tested for signs of instability or meniscal abnormalities. Recruits who had both subjective and objective findings in either patellofemoral joint and did not have a history of trauma or symptoms before army service were considered to have PFP.	left), foot width, and foot length Isometric strength: isometric knee-extension strength at 85° of knee-flexion and knee-extension strength/body mass Performance tests: 2-km run time, push-ups, and sit-ups for 60 s	greater isometric knee-extension strength than those who did not develop PFP.
Nakagawa et al,[30] 2020 (Brazil)	14 (M)	127	6 wk	10.40	Anterior knee or retropatellar pain of insidious onset, aggravated by ≥2 activities that load patellofemoral joint during weight bearing on flexed knee (eg, squatting, stair ambulation, jogging/running, and hopping/jumping). Pain during squatting maneuver; tenderness of medial or lateral posterior surface, or both, of the patella on palpation; and negative findings on examination of knee ligament or tendon, menisci, bursa, and synovial plica. Mechanism of injury could not be related to traumatic blow to knee joint or acute injurious incident.	Anthropometric variables: age, height, and body mass Kinematic variables: FPKPA during single-legged squat Dynamic balance: maximum reaches and symmetry during YBT, anterior reach, posteromedial reach, posterolateral reach, anterior asymmetry, posteromedial asymmetry, posterolateral asymmetry, and compound reach	Greater asymmetry in posterolateral direction on YBT (≥4.08 cm) and greater FPKPA during single-legged squat (≥4.81°) increased risk for developing PFP in male recruits.
Rauh et al,[34] 2010 (United States)	53 (F)	748	18 mo	7.10	All injuries were diagnosed by a sports medicine physician, and orthopaedic International Classification of Diseases, 9th revision, clinical modification code for PFP (719.46) was recorded in recruit's medical record.	Alignment variables: knee extension, ankle dorsiflexion, hindfoot eversion, femoral IR, Q-angle, knee alignment, length difference, pelvic width/femur length, and foot arch index	Q-angle ≥20°, femoral IR ≤25° or ≥46°, and knee hyperextension ≥6° increased risk of PFP in female recruits.
Thijs et al,[26] 2007 (Belgium)	36 (25 M, 11 F)	84 (65 M, 19 F)	6 wk	42.80 (38.46 M, 57.89 F)	Must meet 2 of the following criteria: pain on direct compression of the patella against femoral condyles with knee in full extension, tenderness of the posterior surface of the patella on palpation, pain on resisted knee extension, or pain with isometric quadriceps muscle contraction against suprapatellar resistance with knee in 15° of flexion. No symptoms during examination of knee ligaments; menisci; bursae; synovial plicae; Hoffa fat pads;	Anthropometric variables: age, height, and body mass Plantar pressure variables: plantar pressure, mediolateral pressure data, pressure distribution in feet, displacements of center of pressure during step, and foot contact time during step	3 intrinsic gait-related factors were predictive factors for development of PFP: (1) more laterally directed pressure distribution at initial foot contact; (2) reduced time to maximum pressure at fourth metatarsal; and (3) delay in shifting center of pressure in lateromedial direction during

Table 3. Continued From Previous Page

Study, y (Country)	PFP Participants, No. (Sex)	Sample Size, No.	Follow-Up Period	Incidence of PFP, % (% Sex)	Definition of PFP	Evaluated Variables	Main Results
					iliotibial bands; and hamstrings, quadriceps, and patellar tendons.		forefoot contact phase of gait.
Van Tiggelen et al,[32] 2004 (Belgium)	31 (M)	96	6 wk	32.00	Retropatellar pain during ≥2 of the following activities: jumping/hopping, squatting, stairs, and running. Demonstrates 2 of the following clinical criteria (minimum VAS of 3/10): pain during direct compression of patella against femoral condyle with knee in full extension, tenderness on palpation of posterior surface of patella, pain on resisted knee extension from 90° of flexion to full extension, or pain during isometric contraction of quadriceps against suprapatellar resistance with 15° of knee flexion. No symptoms during examination of knee ligaments; bursae; menisci; synovial plicae; iliotibial band; Hoffa fat pad; and hamstrings, quadriceps, and patellar tendons.	Anthropometric variables: height, mass, and BMI Isokinetic strength: PTKneeFlex at 60°/s (CON) PTKneeFlex at 240°/s (CON) PTKneeExt at 60°/s (CON) PTKneeExt at 240°/s (CON) PTKneeExt at 60°/s (CON) normalized to BW PTKneeExt at 240°/s (CON) normalized to BW PTKneeExt at 60°/s (CON) normalized to BMI PTKneeExt at 240°/s (CON) normalized to BMI	Male recruits with lower knee-extensor torque (normalized to BW and BMI) were at greater risk of developing PFP.
Van Tiggelen et al,[31] 2009 (Belgium)	26 (M)	79	6 wk	32.00	Retropatellar pain during ≥2 of the following activities: jumping/hopping, squatting, stairs, and running. Demonstrates 2 of the following clinical criteria (minimum VAS of 3/10): pain with direct compression of patella against femoral condyle with knee in full extension, tenderness on palpation of posterior surface of patella, pain on resisted knee extension from 90° of flexion to full extension, or pain during isometric contraction of quadriceps against suprapatellar resistance with 15° of knee flexion. No symptoms during examination of knee ligaments; bursae; menisci; synovial plicae; iliotibial band; Hoffa fat pad; and hamstrings, quadriceps, and patellar tendons.	Anthropometric variables: age, height, and body mass Electromyographic variables: onset of electromyographic activation of VMO–VL	Participants who developed PFP demonstrated delayed onset on electromyographic activity of VMO versus VL during functional task (rocking back on heels) when compared with participants who did not develop PFP.

Abbreviations: 3D, 3 dimensional; BMI, body mass index; BW, body weight; CON, concentric; ECC, eccentric; ER, external rotation; F, female; FPKPA, frontal-plane knee-projection angle; IC, initial contact; IR, internal rotation; M, male; PFP, patellofemoral pain; PTKneeExt, peak knee-extension torque; PTKneeFlex, peak knee-flexion torque; VAS, visual analog scale; VL, vastus lateralis; VMO, vastus medialis oblique; YBT, Y-Balance Test.

Table 4. Newcastle-Ottawa Scale Results

Study, y	Scale[a] S1	S2	S3	S4	C1	O1	O2	O3	Results	Classification
Milgrom et al,[29] 1991	1	1	1	1	1	1	1	1	8	High
Van Tiggelen et al,[32] 2004	1	1	1	1	2	1	1	1	9	High
Hetsroni et al,[33] 2006	1	1	1	1	0	1	1	1	7	High
Thijs et al,[26] 2007	1	1	1	1	0	1	1	1	7	High
Duvigneaud et al,[28] 2008	1	1	1	1	2	1	0	1	8	High
Boling et al,[25] 2009	1	1	1	1	2	1	1	1	9	High
Van Tiggelen et al,[31] 2009	1	1	1	1	0	1	1	1	7	High
Rauh et al,[34] 2010	1	1	1	1	2	1	1	1	9	High
Nakagawa et al,[30] 2020	1	1	1	1	0	1	1	1	7	High
Boling et al,[24] 2021	1	1	1	1	2	1	1	1	9	High
Alrayani et al,[27] 2023	1	1	1	1	2	1	1	1	9	High

[a] Scale abbreviations are defined in Table 1.

angles of the knee joint.[25,27–29,32] In 2 studies,[28,32] isokinetic evaluations were performed, and in the 3 other studies, the evaluations were isometric.[25,27,29] In studies that evaluated knee-extensor strength in isometric contraction, we observed a moderate level of evidence that this variable does not predict PFP in military personnel (I^2 = 66%; SMD = −0.27; 95% CI = −0.58, 0.04; Supplemental Figure D).[25,27,29]

In studies that evaluated knee-flexor strength in concentric isokinetic evaluations, we observed a moderate level of evidence that the variable does not predict PFP in this population at a speed of either 60°/s (I^2 = 0%; SMD = −0.09; 95% CI = −0.42, 0.24; Supplemental Figure E) or 240°/s (I^2 = 0%; SMD = −0.10; 95% CI = −0.43, 0.22; Supplemental Figure F).[28,32] In studies that evaluated knee-extensor strength in a concentric isokinetic assessment normalized to body weight, a moderate level of evidence indicated that knee-extensor weakness predicts PFP in military personnel, at speeds of both 60°/s (I^2 = 0%; SMD = −0.61; 95% CI = −0.94, −0.28; Figure 2C) and 240°/s (I^2 = 0%; SMD = −0.53; 95% CI = −0.87, −0.20; Figure 2D).[28,32] In studies that evaluated knee-extensor strength in a concentric isokinetic evaluation normalized to BMI, we observed a moderate level of evidence that knee-extensor weakness predicts PFP, at speeds of both 60°/s (I^2 = 0%; SMD = −0.69; 95% CI = −1.02, −0.35; Supplemental Figure G) and 240°/s (I^2 = 0%; SMD = −0.51; 95% CI = −0.84, −0.18; Supplemental Figure H).[28,32]

Alignment Variables

Alignment variables, such as the frontal-plane knee-projection angle (FPKPA) and the static Q-angle during a single-legged squat, could be grouped from the results of 3 studies.[25,27,30] A moderate level of evidence indicated that a greater FPKPA during the single-legged squat task is a risk factor for PFP in male military personnel (I^2 = 41%; SMD = 0.55; 95% CI = 0.14, 0.97; Figure 2E).[27,30] A moderate level of evidence, based on the results of 2 studies, indicated that the Q-angle is not a risk factor for PFP in this population (I^2 = 28%; SMD = 0.20; 95% CI = −0.07, 0.47; Supplemental Figure I).[25,27]

Of all studies evaluated, only Hetsroni et al[33] and Rauh et al[34] presented variables that could not be grouped with those of any other study. Hetsroni et al assessed variables related to subtalar pronation during walking, not observing any relationship between these variables and the development of PFP in military personnel.[33] Rauh et al classified the foot arch index as *normal*, *low*, or *high* based on criteria that they determined.[34] This made the combination of their results with those of other studies unfeasible.

DISCUSSION

The purpose of this systematic review was to identify risk factors for PFP in military personnel. The main result was that the strength of the knee extensors, normalized to body weight or BMI, is a predictor of PFP in military personnel. In addition, we found that FPKPA during a single-legged squat task is a predictor of PFP in male military recruits. However, considering the small number of studies and variables, as well as the high heterogeneity of results, the level of recommendation of the evidence was moderate for most results.

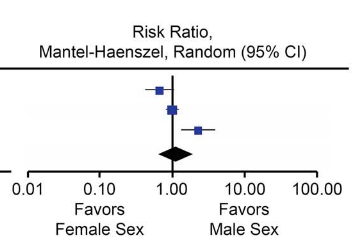
Incidence

The incidence of PFP in this review was 7.61%, demonstrating that this condition affects approximately 8 out of 100 military personnel. This result is similar to that observed in another review, in which an incidence of PFP of 11% was observed in subgroups of individuals from a military population.[9] However, in a review, Smith et al observed incidence rates of 9.7 to 571.4 cases per 1000 people per year in different military populations.[3] This large variability may have resulted from the different characteristics of the military population in different categories of activity. A lower incidence of PFP was observed in countries where good physical fitness is a requirement for military recruitment.[3] In military conscripts, Taanila et al found that low levels of physical fitness (determined using a series of physical tests, including the 12-minute run test, push-ups, sit-ups, pull-ups, etc) increased the risk of musculoskeletal injuries by >3 times.[35] This finding may be a consequence of the fact that a group with a higher level of physical fitness is probably more adapted to intense periods of physical activity, which would reduce the risk of injury.[35] The abrupt increase in training load can be a factor that increases the risk of injury. Already-trained individuals tend to adapt better to the training load imposed by military training compared with individuals with less physical capacity

A

Study (Year)	Male Events, No.	Male Total, No.	Female Events, No.	Female Total, No.	Weight, %	Risk Ratio, Mantel-Haenszel, Random (95% CI)
Boling et al[25] (2009)	16	40	24	40	31.9	0.67 (0.42, 1.05)
Boling et al[24] (2021)	94	188	94	188	38.7	1.00 (0.82, 1.22)
Thijs et al[26] (2007)	25	36	11	36	29.4	2.27 (1.33, 3.89)
Total	135	264	129	264	100.0	1.12 (0.64, 1.94)

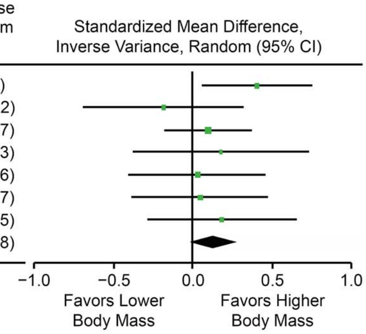
Heterogeneity: $\tau^2 = 0.19$, $\chi^2_2 = 11.93$, $P = .003$, $I^2 = 83\%$
Test for overall effect: $Z = 0.40$, $P = .69$



B

Study (Year)	Injured Group Mean ± SD, kg	Injured Group Total, No.	Uninjured Group Mean ± SD, kg	Uninjured Group Total, No.	Weight, %	Standardized Mean Difference, Inverse Variance, Random (95% CI)
Alrayani et al[27] (2023)	71.05 ± 17.38	37	65.82 ± 12.23	278	19.1	0.40 (0.06, 0.75)
Duvigneaud et al[28] (2008)	60.2 ± 9.3	26	61.9 ± 8.7	36	8.9	−0.19 (−0.69, 0.32)
Milgrom et al[29] (1991)	70.2 ± 9.7	60	69.3 ± 9.5	330	29.9	0.09 (−0.18, 0.37)
Nakagawa et al[30] (2020)	68.74 ± 6.62	14	66.63 ± 12.44	121	7.4	0.17 (−0.38, 0.73)
Thijs et al[26] (2007)	67.6 ± 8.41	36	67.4 ± 7.63	48	12.1	0.02 (−0.41, 0.46)
Van Tiggelen et al[32] (2004)	70.6 ± 10.8	31	70.2 ± 7.7	65	12.4	0.05 (−0.38, 0.47)
Van Tiggelen et al[31] (2009)	72.1 ± 8.96	26	70.5 ± 8.52	53	10.2	0.18 (−0.29, 0.65)
Total		230		931	100.0	0.13 (−0.02, 0.28)

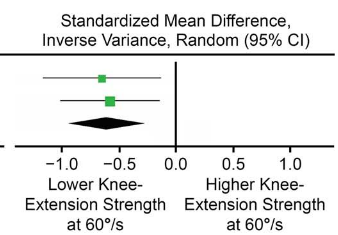
Heterogeneity: $\tau^2 = 0.00$, $\chi^2_6 = 4.46$, $P = .62$, $I^2 = 0\%$
Test for overall effect: $Z = 1.68$, $P = .09$



C

Study (Year)	Injured Group Mean ± SD, N·m/kg	Injured Group Total, No.	Uninjured Group Mean ± SD, N·m/kg	Uninjured Group Total, No.	Weight, %	Standardized Mean Difference, Inverse Variance, Random (95% CI)
Duvigneaud et al[28] (2008)	1.97 ± 0.3	26	2.2 ± 0.38	36	41.4	−0.65 (−1.17, −0.13)
Van Tiggelen et al[32] (2004)	2.58 ± 0.41	31	2.82 ± 0.41	65	58.6	−0.58 (−1.02, −0.14)
Total		57		101	100.0	−0.61 (−0.94, −0.28)

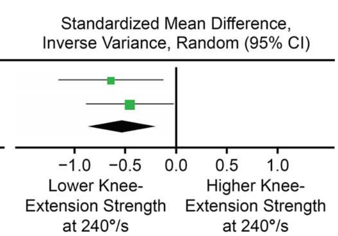
Heterogeneity: $\tau^2 = 0.00$, $\chi^2_1 = 0.04$, $P = .84$, $I^2 = 0\%$
Test for overall effect: $Z = 3.58$, $P < .001$



D

Study (Year)	Injured Group Mean ± SD, N·m/kg	Injured Group Total, No.	Uninjured Group Mean ± SD, N·m/kg	Uninjured Group Total, No.	Weight, %	Standardized Mean Difference, Inverse Variance, Random (95% CI)
Duvigneaud et al[28] (2008)	1.04 ± 0.18	26	1.15 ± 0.16	36	41.1	−0.64 (−1.16, −0.13)
Van Tiggelen et al[32] (2004)	1.4 ± 0.21	31	1.5 ± 0.22	65	58.9	−0.46 (−0.89, −0.02)
Total		57		101	100.0	−0.53 (−0.87, −0.20)

Heterogeneity: $\tau^2 = 0.00$, $\chi^2_1 = 0.29$, $P = .59$, $I^2 = 0\%$
Test for overall effect: $Z = 3.15$, $P = .002$



E

Study (Year)	Injured Group Mean ± SD, °	Injured Group Total, No.	Uninjured Group Mean ± SD, °	Uninjured Group Total, No.	Weight, %	Standardized Mean Difference, Inverse Variance, Random (95% CI)
Alrayani et al[27] (2023)	7.36 ± 8.78	37	3.78 ± 9.2	278	63.4	0.39 (0.05, 0.73)
Nakagawa et al[30] (2020)	6.05 ± 5.64	14	0.5 ± 6.74	113	36.6	0.83 (0.27, 1.40)
Total		51		391	100.0	0.55 (0.14, 0.97)

Heterogeneity: $\tau^2 = 0.04$, $\chi^2_1 = 1.71$, $P = .19$, $I^2 = 41\%$
Test for overall effect: $Z = 2.60$, $P = .009$

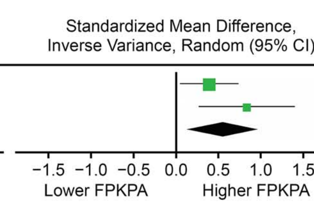


Figure 2. Forest plots detailing the relationships of different variables between injured and uninjured individuals. A, Sex. B, Body mass. Isokinetic strength of knee extensors at C, 60°/s normalized to body weight, and D, 240°/s normalized to body weight. E, Frontal-plane knee-projection angle (FPKPA).

due to previous adaptations associated with muscle memory.[36] Discrepancies in the incidence of PFP in military recruits of distinct countries may be due to these groups being submitted to different training methods, but unfortunately the studies provided little detail on that aspect. More detailed information on volume, frequency, and intensity of training is needed to better understand the relationship between military training and the occurrence of injuries such as PFP.

Strength

In our study, decreased concentric isokinetic knee-extensor strength was found to be a predictor of PFP in military personnel. This finding corroborates the results of other systematic reviews with different populations (ie, adolescents, recreational runners, and civilian adults).[9,12] The quadriceps plays a key role in the knee joint because quadriceps activation is important for patellar stabilization during dynamic activities, leading to optimal patellar tracking.[37] Greater quadriceps strength also allows more energy dissipation, thus reducing stress on the patellofemoral joint.[38] These findings may help explain why rehabilitation programs involving quadriceps strengthening have good results in individuals with PFP.[38] Quadriceps muscle strengthening appears to be one of the most important aspects of PFP treatment, with authors of several studies observing beneficial results of interventions including quadriceps strengthening in reducing pain and improving function in individuals with PFP.[38–40] The identification of quadriceps weakness as a risk factor for PFP in military personnel emphasizes quadriceps strengthening as an aspect to be highlighted in prevention programs before the beginning of military training. This preventive strengthening program must fit the initial physical conditions of these soldiers at entry, such as the volume, intensity, and frequency of activities to which individuals were exposed before recruitment. These variables may directly influence quadriceps strength and the muscle's ability to adapt to new military training due to molecular muscle memory in response to previous training.[36] However, this information was rarely presented in detail in the studies.

Frontal-Plane Knee-Projection Angle

The FPKPA during the single-legged squat was identified as a risk factor for PFP in male recruits in our review but with a small effect size despite the statistical homogeneity observed. Previous studies[41,42] identified that individuals with PFP present changes in frontal-plane knee movement; however, in the military population, only 2 studies[27,30] assessed whether the FPKPA is a risk factor for PFP. Nakagawa et al observed that an FPKPA $\geq 4.81°$ has a sensitivity of 79% and a specificity of 80% for predicting PFP in male military recruits (hazard ratio = 4.6).[30] Alrayani et al found that an angle $\geq 5.2°$ has a sensitivity of 70% and a specificity of 70% for predicting PFP in male recruits (hazard ratio = 2.2).[27] These findings indicate that the FPKPA is a relevant variable for male recruits, potentially due to the increase in lateralizing forces on the patella, which may increase the contact pressure between the lateral femoral condyle and the lateral facet of the patella, consequently contributing to PFP.[30,43–45]

Anthropometric Variables

The results of this review indicated that sex is not a risk factor for the development of PFP in military personnel. This finding corroborates the findings of a review by Neal et al.[9] However, it conflicts with the finding of Lankhorst et al, who observed that female military personnel have a higher risk of developing PFP when compared with male military personnel.[12] Their conclusion was based on the results of only one study in which, despite no association between sex and PFP, the incidence of this dysfunction in female military personnel was almost twice as high as that of male military personnel.[25] In this review, we identified a small number of studies on the subject, and the results had high heterogeneity. Thus, despite the absence of a causal relationship between female sex and PFP, a larger and more robust investigation of this variable would be important because the total number of female military personnel in studies on the subject is smaller than that of male military personnel. Information about the type, volume, load, and progression of training is also important and should be better detailed in the studies, such as verifying whether both sexes participate in the same training or whether different training courses are used. Generally, military training is of high intensity, with similar activities and objectives and equal exposure for both sexes.[46] However, Bell et al reported that female soldiers tend to start military training with a lower physical capacity compared with male soldiers and that when both have the same level of physical activity, the risks of musculoskeletal injuries are similar.[46] Bergman and Miller suggested that training planned by sex can have better results in terms of minimizing injuries.[47]

Height, body mass, age, and BMI were not predictors of PFP in military personnel. These results corroborate the findings of the review by Neal et al.[9] When analyzing the baseline characteristics of the populations participating in the studies, we found that the variables were very similar because these recruits, who are starting their careers, generally need to meet some anthropometric requirements for admission to the military. In contrast to this result, in their systematic review, Hart et al observed an association between BMI and PFP.[48] Their finding, however, may have occurred because they also included studies with a cross-sectional design.[48] Thus, this association may be due to a possible decrease in physical activity levels after the onset of symptoms.

Strengths, Limitations, and Future Studies

Our study had strengths and limitations. The NOS was chosen because it is a valid scale and is widely used in cohort assessments.[49,50] Margulis et al[17] reported that the NOS is recommended by the Cochrane Collaboration in its handbook for systematic reviews of this nature.[21] The NOS is the most used scale for analyzing the risk of bias in observational studies; however, it is considered a limited tool because it covers few fields and can generate arbitrary results due to warranting the same grade to studies with different qualities.[16,17,51]

The search strategy involved 6 databases and 1 gray database, which makes this review more comprehensive when compared with other systematic reviews.[9,12] The great heterogeneity of variables evaluated in the studies was a challenge, and we could group only 14 of 74 variables for meta-analyses. Most variables were evaluated separately, and considering the multifactorial characteristic of PFP, further studies are needed to analyze the interactions between risk factors.[44] Based on our search strategy, we found no study that assessed whether psychological factors are a risk factor for PFP in military personnel. Given that, in their review, Maclachlan et al emphasized the importance of these aspects, future studies should be done to consider the possibility of psychological aspects, such as pain catastrophizing and anxiety, being potential risk factors for PFP in military personnel.[52]

Finally, the population in the included studies was restricted to military recruits (ie, soldiers at the beginning of their careers). The generalization of these results to other categories of military personnel, such as elite groups and administrative groups, among others, should be done with caution. In future studies, other categories of the military should be included in the sample, which may generate more comprehensive results for risk factors for musculoskeletal injuries such as PFP in this population. Understanding risk factors is an important step in developing preventive interventions.[53] To our knowledge, only one study has investigated the effects of an exercise-based intervention (quadriceps and gluteal strengthening and lower limb stretches) to reduce PFP in the military.[38] Although complex, prevention studies are of paramount importance, and future research should be done to investigate whether an intervention addressing known risk factors can effectively decrease the incidence of PFP in the military.

CONCLUSIONS

This systematic review demonstrated that a deficit in knee-extensor strength evaluated isokinetically is a predictor of PFP in military personnel, with a moderate level of evidence and a small to moderate effect size. We also identified that a greater FPKPA during a single-legged squat is a predictor of PFP in military personnel, with a moderate level of evidence. Quadriceps strengthening and strategies to decrease the FPKPA, such as strengthening the hip abductors, controlling subtalar hyperpronation, and movement pattern training with oral instructions, may be important for the prevention of PFP in this population. Future prospective studies should be done to evaluate whether these therapeutic approaches prevent PFP in military personnel.

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SUPPLEMENTAL MATERIAL

Supplemental Figure. Forest plot detailing the relationships of each variable between injured and uninjured participants. A, Height. B, Age. C, Body mass index. D, Isometric strength of the knee extensors. Isokinetic strength of the knee flexors at E, 60°/s, and F, 240°/s. Isokinetic strength of the knee extensors at G, 60°/s normalized to body weight, and, H 240°/s normalized to body weight. I, Q-angle.

Supplemental Table. Search strategy.

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