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Original Research

The Relationship Between Lower-Body Strength and Power, and Load Carriage Tasks: A Critical Review

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ABSTRACT

International Journal of Exercise Science 12(6): 1001-1022, 2019. The purpose of this review was to critically appraise articles that have investigated the association between lower-body strength and power during load carriage in tactical personnel. Literature databases were searched with specific search terms, yielding 921 articles. Additional studies found from article reference lists were also assessed for eligibility. Out of these articles, 16 met the inclusion/exclusion criteria and were critically appraised. Articles were assessed by the Downs and Black evaluation tool with inter-rater agreement determined by Cohen's kappa and final results graded according to the Kennelly quality grading system. Of the 940 identified articles, 16 studies met the criteria for inclusion in this review. The average score of the eligible articles was 58%, considered to be of fair quality by the Kennelly grading system. The strength and volume of evidence reviewed suggests that: measures of lower-body strength and power can predict load carriage performance and appear to be important physical factors for load carriage ability, and that load carriage tasks negatively impact the performance of leg strength and power. Together these findings suggest that leg strength and power should be important considerations for tactical personnel training and assessment, as well as managing the impact of load carriage on tactical performance.

KEY WORDS: Fitness, military, police, firefighter, tactical

INTRODUCTION

Tactical personnel, which include law enforcement, fire and rescue, emergency first responder and military personnel, are frequently required to wear personal protective equipment (PPE) and carry equipment and tools as part of their occupation. This equipment is important for protection and enhancing operational capabilities (32, 38). While carrying these loads, tactical personnel are often required to perform in unpredictable and dangerous environments (32, 38). Although this equipment is essential for success, greater loads may negatively impact occupational performance (3, 6) and increase risk of injury (6).

The load carriage requirements of various tactical personnel have been described in the literature (32, 34, 38). For example, several investigators reported the average loads carried by soldiers during conflicts in Afghanistan were around 45 kg (32, 38). It has also been reported that general duties police officers can carry loads of around 10 kg daily (1), while specialist police members can carry loads in excess of 40 kg (34). Firefighters have been found to carry similar loads of approximately 22 kg (5). These loads can create a significant physiological burden for tactical personnel and may negatively impact performance in occupational tasks. For example, load carriage has been shown to have a negative impact on tactical mobility (6), which in turn may hinder the ability of tactical personnel to rapidly seek cover in dangerous situations (6), increase their exposure to enemy fire (3), and for wildland firefighters to negotiate escape routes (10, 33, 36). Consequently, it is important for tactical personnel to have adequate levels of physical fitness to meet the occupational demands of their job, as well as maintain personnel and public safety while under load.

Research indicates that lower-body strength and power are associated with occupational performance among tactical personnel (19). These attributes have been shown to be essential for performing high-intensity, short-duration activities, such as sprinting, dodging, lifting, carrying, pushing, jumping, and stair climbing, while under load (33, 36). Therefore, to improve occupational performance, lower-body strength and power exercises are often key components of training programs for tactical personnel (16, 22, 24). Furthermore, leg strength and power are frequently assessed within these populations to ensure appropriate levels of lower-body muscular fitness have been attained (4, 7, 8, 17, 25, 31).

Given that load carriage can have a negative impact on the ability of tactical personnel to perform operational task and that lower-body strength and power are associated with occupational task performance, having a better understanding of the relationship between these two measures may inform the future establishment of fitness standards, designing of physical training programs, and planning missions. Therefore, the aim of this review was to critically appraise the literature investigating relationships between lower-body strength and power and load carriage performance within tactical populations and summarize the findings.

METHODS

Protocol

Three sequential search strategies were employed to capture articles for this critical review. These strategies included: 1) a comprehensive search of literature databases, 2) the review of reference lists of relevant articles, and 3) requesting articles from known experts in this field. Eight literature databases were searched for relevant journal studies using key search terms entered into each database in combinations with relevant search filters (see Table 1 and Table) 2).

Table 1. Details of the databases used, filters, and articles yielded throughout the data collection process.

Database	Filters	Duplicates	Number after Inclusion	Number after Exclusion
CINAHL	Academic Journals	11	23	2
EBSCOhost	Academic Journals	43	296	11
SPORTSDiscus	Academic Journals	28	29	0
Cochrane		9	10	0
Embase		1	1	0
ProQuest	Search anywhere except full text, Scholarly Journals	26	155	5
Medline (through Web of Knowledge)		39	185	11
PubMed		82	222	4

Table 2. Databases and Search terms.

Database	Search Term
CINAHL EBSCOhost SPORTSDiscus Cochrane Embase ProQuest	(Air Force OR Armed Forces Personnel OR Army OR Army Personnel OR Coast Guard OR Emergency response OR Enforcement Officer OR Fire and Rescue Personnel OR Fire Fighter OR Firefighter OR Law enforcement OR Marines OR Military OR Navy OR Paramilitary OR Police OR Sailor OR Soldier OR Special operations OR Special weapons and tactics OR SWAT OR Tactical) AND (((Load OR Pack OR Ruck OR Weight) AND (Bearing OR Carriage OR Carry OR Carrying OR March OR Marching)) OR (Weightbearing OR Loadbearing OR Load-bearing OR Weight-bearing)) AND (Mid-thigh pull OR Deadlift OR Mid-thigh pull OR Power OR Squat OR Strength OR Vertical jump)
Medline (through Web of Knowledge) PubMed	("Police"[Mesh] OR "Military Personnel"[Mesh] OR "Firefighters"[Mesh] OR Air Force OR Armed Forces Personnel OR Army OR Army Personnel OR Coast Guard OR Emergency response OR Enforcement Officer OR Fire and Rescue Personnel OR Fire Fighter OR Firefighter OR Law enforcement OR Marines OR Military OR Navy OR Paramilitary OR Police OR Sailor OR Soldier OR Special operations OR Special weapons and tactics OR SWAT OR Tactical) AND (((Load OR Pack OR Ruck OR Weight) AND (Bearing OR Carriage OR Carry OR Carrying OR March OR Marching)) OR ("Weight-Bearing"[Mesh] OR Weightbearing OR Loadbearing OR Load-bearing OR Weight-bearing)) AND ("Muscle Strength"[Mesh] OR Mid-thigh pull OR Deadlift OR Mid-thigh pull OR Power OR Squat OR Strength OR Vertical jump)

From this initial capture of the literature, duplicate articles were removed to avoid replication of results. The remaining articles were then assessed by title and abstract against the inclusion criteria for eligibility. The criteria for inclusion were: (a) the article was published in English, (b) the intervention was performed on healthy human subjects from a tactical population, and (c) the article reported on associations between lower-body strength and power during load carriage. Following inclusion, full texts of the studies were obtained to assess them against the exclusion criteria. These exclusion criteria are listed in Table 3.

Table 3. Article exclusion criteria.

Criterion	Comments
Did not include load carriage as an assessment	Defined as carrying a load specific to their occupation
Did not include healthy human subjects	Defined as participants with no physically limiting cardiorespiratory, musculoskeletal, medical or mental health conditions
Used subjects that were not tactical personnel	Defined as law enforcement, firefighters, emergency workers or military personnel
Did not include measures of lower-body strength or power	Defined as a movement utilizing primarily leg strength or power and is not significantly limited by upper body ability

Following exclusion, the remaining articles were collated, and their reference lists reviewed to identify potential additional sources of information. Finally, researchers in the area of tactical performance were contacted and requested to provide any relevant articles known to them on the topic being investigated. Additional articles that were not captured through the database search were also subjected to the same inclusion and exclusion criteria detailed above. All eligible full text articles identified were then reviewed and critiqued.

Statistical Analysis

The methodological quality of each eligible article was assessed using the Downs and Black evaluation tool (11). This tool uses a checklist to evaluate study quality of both randomized and non-randomized research studies (11). The checklist consists of 27 items in total, which are grouped into five major areas of analysis: reporting quality, external validity, internal validity – bias, internal validity – confounding and statistical power (11). Within this checklist, 25 of the 27 items are scored on a scale of "0" to "1" points, with a "*yes*", associated with meeting a given criterion, equating to 1 point and "*no/unable to determine*" to 0 points. Item 5 scores the detailing of confounders as follows: *yes* equating to 2 points, *partially* equating to 1 point and *no* to 0 points. Statistical power assessed in item 27 is graded on a scale up to 5 points depending on the level of power on the original scale. For this review it was modified to score as "*yes"* being awarded 1 point if the study detailed sufficient power to detect a clinically important effect or "*no/unable to determine"* as 0 points (11). This modification has been used in previous reviews (39) to negate potential bias in scoring caused by ambiguous wording (13). The critical appraisal scores for eligible articles were calculated as a percentage by totaling the raw score of an article, dividing by 28 (total possible score) and multiplying by 100. All articles were independently rated by two authors (DG and RO) with the level of inter-rater agreement measured by a Cohen's Kappa analysis of all raw scores (27 scores per paper). For the final scores of the articles, any disagreements in points awarded were settled by consensus of the authors.

The raw scores from the Downs and Black (11) evaluation tool were then subjected to the grading system proposed by Kennelly (18) to grade the quality of each article. Kennelly's (18) proposed quality grading system rates studies based on the original Downs and Black (11) checklist score out of a possible 32 points, and is as follows: 14 or fewer points are considered to be poor, 15 to 19 points are considered to be fair, and 20 or greater points are considered to be good (18). As this review modified the original Downs and Black (11) checklist score to a maximum of 28 points, the Kennelly (18) grades were modified to percentages (by dividing the grade out of 32 and multiplying by 100) in order to allow for comparison. On this basis, the grading scores below 46.9% led to the study being classified as being of 'poor' methodological quality, 46.9–62.5% of 'fair' methodological quality, and above 62.5% of 'good' methodological quality.

RESULTS

After the initial literature search, a total of 921 potential articles were identified (Figure 1). An additional 19 articles from other sources were also identified and evaluated. After 258 duplicate articles were removed, 682 articles were subjected to the inclusion criteria. A total of 658 articles were excluded based on their title and abstract not meeting inclusion criteria. The 43 remaining articles were retrieved, and their full text were subjected to further scrutiny against the exclusion criteria. Twenty-seven of these additional articles met the exclusion criteria and were removed. Once this process was complete, a total of 16 articles were found to be eligible for critical appraisal.

Table 4 summarizes the participants, measures of lower-body strength or power assessed, load carriage tasks performed, results, and the critical appraisal scores for each of the 16 reviewed articles. The mean Downs and Black (11) score for the reviewed articles was 58%, which is considered to be of "fair" quality based on the Kennelly grading system (18), with a range from 43% (15) to 71% (20, 21, 30). The level of agreement between raters as determined by the Kappa analysis was k=0.76 equating to a *substantial agreement* between raters (40). Within the Downs and Black (11) scores, the studies scored well in the area of reporting and internal validity – bias sections. Areas in which points were mostly frequently lost included: reporting confounding variables, reporting adverse effects, explicit reporting of *p*-values obtained, population source, population representation, facilities used for interventions, blinding of participants and researchers, intervention groups, randomization, adjustment for confounding variables and power calculations for sample sizes.

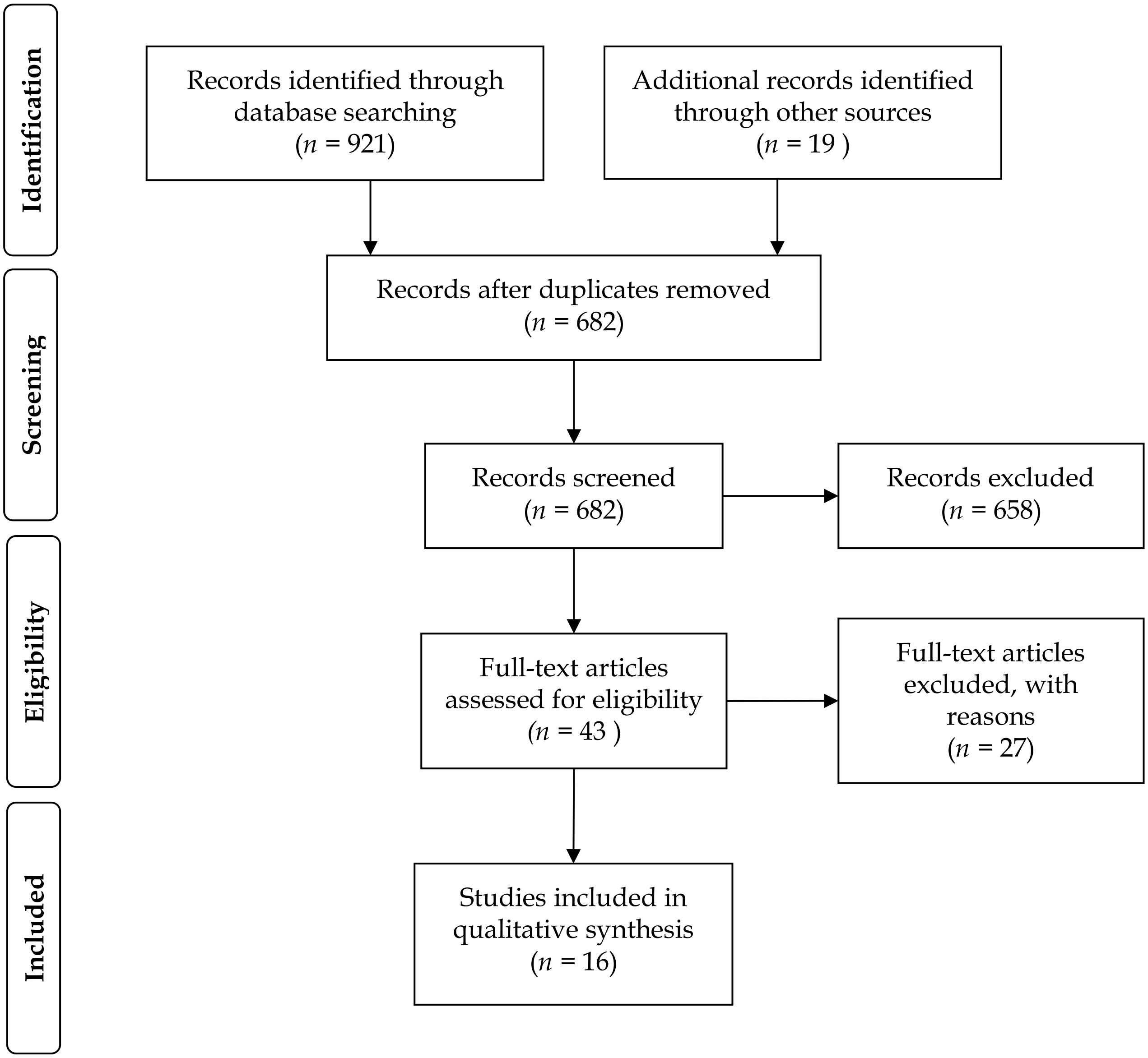

Figure 1. PRISMA flowchart of literature search process.

Study participants came from a variety of different tactical populations, including: fire and rescue (4), law enforcement (10), but were predominantly military personnel (Army, Marines and Navy) (2, 12, 14, 15, 17, 20, 21, 23, 26, 28-30, 35, 37) . Occupational experience within the participant's respective areas of work ranged from trainees and recruits (4, 14, 28, 29) to active service personnel (2, 10, 12, 15, 20, 21, 23, 30, 35) and one study which investigated highly trained "elite" soldiers (37). The sex of study participants were mostly males. Four studies included both male and female participants (2, 4, 29, 35), three studies did not report sex (12, 21, 30), and no study investigated only females.

Table 4. Summary of relevant articles and critical scores.

Study	Participants	Lower-body strength / power assessment(s)	Load carriage task(s)	Results	Critical appraisal scores*
Beckett and Hodgdon 1987 (2)	102 active-duty Navy personnel (64 men and 38 women) who were cleared of limiting medical conditions and were able to score ≥76 kg on an isometric lifting-strength screening test	Vertical jump (VJ) height Broad jump (BJ) distance from a static start These were both also converted into units of power	51.4 m shuttle box carry (BC) task (34 kg) for 5 min then 1 min rest then another 5 min shuttle. The total distance covered for the two 5min shuttles was recorded. This was converted into units of power	BC power correlated with VJ, VJ power, BJ and BJ power (r = 0.45, 0.41, 0.39 and 0.42 respectively, all $p < 0.01$) BJ power contributed to the prediction model for BC power in combination with 2.4 km run time (r^2 change = 0.08), where run time accounted for 45% of the variance in BC power	57%, fair
Dempsey et al. 2014 (9)	52 healthy male participants from the New Zealand Southern Region District Police force	Countermovement vertical jump (VJ) height 0.75 m drop landing (DL) followed by a vertical jump measuring the height achieved	Addition of a stab-resistant body armour vest (7.65 kg)	Loaded VJ height decreased compared to unloaded (41.33 vs 46.94 cm respectively, $p < 0.001$) Loaded DL height decreased compared to unloaded (39.31 vs 44.65 cm respectively, $p < 0.0001$)	57%, fair
Blacker et al. 2016 (4)	137 trainees from United Kingdom Fire and Rescue Services (127 males and 10 females) and 50 trained firefighters (31 males and 19 females)	Standing broad jump (SBJ) distance	Rural simulation (hose or pump carry tasks of 15-33kg along 50m shuttle totaling 525 or 1025m) Domestic simulation (hose, child and adult carry tasks of 15-55kg totaling 30 or 150m) Both tests included a short (selection test) and long version (field test), the two test distances are included above	SBJ did not significantly contribute to the regression model used to predict the rural simulation SBJ improved the regression model in conjunction with body mass for the domestic simulation field test over VO_2 max alone (r = 0.910 vs 0.841 respectively). It did not significantly contribute to the regression model used to predict the domestic simulation selection test	50%, poor

Fallowfield et al. 2012 (14)	12 male Royal Marine recruits from Commando Training Centre Royal Marines in Lympstone, United Kingdom	Vertical jump (VJ) height Vertical jump power	19.3km load carriage event in tactical gear (31.0kg) lasting 270min	VJ height decreased by 8 ± 9% following load carriage event (0.37 vs 0.34m, $p < 0.001$) VJ power decreased by 5 ± 5% following load carriage event (3821 vs 3647 Watts, $p < 0.001$)	61%, fair
Dziados et al. 1987 (12)	49 volunteers from A, C and D Companies, 1/502 Infantry, 2nd Brigade of the 101st Airborne Division (Air Assault), Ft. Campbell, KY	Isokinetic strength of knee extension (KE) and knee flexion (KF) measured at 60°/s, 180°/s and 300°/s, recording the peak torque. The right leg was assessed	16 km loaded march (18kg) over primarily flat asphalt with a few sections of hills completed as fast as possible	KF at 60°/s, 180°/s and 300°/s significantly correlated with march time (r = -0.34, $p < 0.01$; r = -0.42, $p < 0.03$ and r = -0.34, $p < 0.01$ respectively) KF at 180°/s independently best predicted loaded march performance from the step-wise multiple regression analysis (r^2 = 0.18) KE at 60°/s, 180°/s and 300°/s correlated with march time (r = -0.21, -0.13 and -0.14 respectively)	68%, fair
Hackney et al. 1991 (15)	62 male United States marines	30s Wingate maximum effort (absolute 5s peak power, W; and relative 5s peak power, W/kg body weight)	Packs and weapon carried (20-25kg) during military field operations (MFO) tasks (including marches, rock climbing and infantry combat maneuvers) over 96-120h period in a cold (snow) or non-cold environment	MFO significantly decreased Wingate absolute peak power by 4.5% in combined (cold and non-cold) overall effects ($p < 0.01$) Absolute peak power significantly decreased following MFO in both cold and non-cold groups ($p < 0.01$) Relative peak power significantly decreased following MFO in both cold and non-cold groups (3.1 and 1.6% respectively, $p < 0.05$)	43%, poor
Knapik et al. 1990 (20)	96 male soldiers from the 2nd battalion, 17th Infantry Regiment, 6th Infantry Division	Isometric knee extension (KE), knee flexion (KF) and plantar flexion (PF) strength measured	Completed a 20km road march as fast as possible carrying a rucksack, uniform, weapon, helmet and load carriage	VJ height did not significantly correlate with road march time (r = -0.14)	71%, good

	(Light), Ft Richardson AK	at 120°, 160° and 120° respectively Isokinetic knee extension, knee flexion and plantar flexion strength measured at 0.52 and 3.14rad/s, recording both peak torque and total work Peak power recorded during 30s Wingate test Vertical jump (VJ) height	equipment (approximately 46kg total) over mostly flat roads and a 5km area of rolling hills with water and food available at 5km checkpoints	Isometric KE, KF and PF significantly correlated with road march time ($r = -0.22$, -0.27 and -0.24 respectively, all $p < 0.05$) Isokinetic peak torque for KE and PF at 0.52rad/s significantly correlated with road march time ($r = -0.27$ and -0.24 respectively, both $p < 0.05$) Isokinetic peak torque for KF at 0.52rad/s correlated with road march time ($r = -0.18$) Isokinetic total work for KE and KF at 0.52rad/s correlated with road march time ($r = -0.27$, $p < 0.05$ and $r = -0.17$ respectively) Isokinetic peak torque for KE and PF at 3.14rad/s significantly correlated with road march time ($r = -0.22$ and -0.29 respectively, both $p < 0.05$) Isokinetic peak torque for KF at 3.14rad/s correlated with road march time ($r = -0.20$) Isokinetic total work for KE and KF at 3.14rad/s significantly correlated with road march time ($r = -0.25$ and -0.22 respectively, both $p < 0.05$) Wingate peak power significantly correlated with road march time ($r = -0.23$, $p < 0.05$)

				After removing the effect of fat free mass, no isometric or isokinetic measure correlated with road march time (isometric and isokinetic measures strongly correlated with fat free mass; the partial correlations r ranged between 0.43-0.70, all $p < 0.01$)	
Koerhuis et al. 2009 (23)	23 healthy male combat soldiers with no cardiovascular disease, respiratory problems or musculoskeletal complaints	Dynamic isokinetic squat strength starting in standing position to 90° knee flexion to standing again at 40cm/s. The test was repeated 3 times for a maximal and mean force produced Isometric muscle strength of leg extension against a footplate in 50° of knee flexion. The best performance of two tests was used for analysis	Maximum load carriage capacity (MLCC) established through carrying a 20kg backpack on a treadmill at 3km/h and 5% gradient. Every 4 minutes a 7.5kg weight was added to the backpack until exhaustion. If the final load was only carried for 2min of the 4min period, the MLCC was defined as the previous heaviest load carried plus 3.75kg MLCC endurance was tested by walking on a treadmill at 3km/h and 5% gradient with 70%, 80% or 90% MLCC rounded to the nearest 7.5kg for as long as possible	Isometric leg extension significantly correlated with MLCC ($r = 0.53$, $p < 0.05$) Both mean and maximal isokinetic squat strength significantly correlated with MLCC ($r = 0.64$ and $r = 0.62$ respectively, $p < 0.05$) Isometric leg extension combined with lean body mass best predicted MLCC ($r^2 = 0.78$). The predicted MLCC using isometric leg extension and lean body mass predicted endurance time ($r^2 = 0.23$)	64%, fair
Mala et al. 2015 (26)	18 active males (12 from the Army Reserve Officer Training Corps, 6 university students) with no orthopedic, cardiovascular or medical problems	1 repetition maximum (1RM) squat weight Countermovement vertical jump (VJ) power measured from a force plate	Military course (MC) starting in prone position consisting of a 30m sprint, followed by a 27m zigzag run then finishing with a 10m 79.5kg casualty drag while in combat uniform and carrying a rucksack	Peak VJ power significantly correlated with MC time, 5m time, 30m time and casualty drag time ($r = -0.67, -0.66, -0.60$ and -0.64 respectively, $p \leq 0.05$) Squat 1RM significantly correlated with MC time and 5m time ($r =$ -	54%, fair

			(totaling approximately 42kg load). Time for the first 5m of the 30m sprint was recorded	0.62 and -0.70 respectively, $p \leq 0.05$), and with 30m time, zigzag time and casualty drag time ($r = -0.58$, -0.48 and -0.57 respectively, $p \leq 0.01$) The negative correlations indicate that higher strength or power were associated with decreased completion times (better performance)	
Simpson et al. 2006 (37)	20 male soldiers from "elite" units of the British Army's Reserve Forces (10 from the parachute regiment and 10 from an anonymous group)	Concentric isokinetic strength of both hip and knee flexors and extensors. Flexors assessed at 1.57 rad/s and extensors at 1.04 rad/s	3.2 km backpack (20 kg) run over flat tarmac road 29 km time trial march with backpack (20 kg) over hills	Isokinetic strength measurements did not correlate with either load carriage task ($p < 0.05$). The data was not reported	57%, fair
Mello et al. 1988 (30)	28 active duty soldiers from a single rifle platoon from the 7th Infantry Division, Fort Ord. California	Isokinetic strength of knee extension (KE) and knee flexion (KF) through about 90° range of motion measured at 30°/s and 180°/s, including the mean peak torque (PT) value. The dominate leg was assessed	Four load carriage trials over 2, 4, 8 and 12km each carrying a total of 46kg (28kg in a pack and 18kg on the body) to be completed as fast as possible	2 and 4km load carriage performance was not significantly correlated to KE or KF strength 8km load carriage performance significantly correlated with KE PT ($r = -0.508$), KF at 180°/s ($r = -0.537$) and KF PT ($r = -0.608$), all $p < 0.05$ 12km load carriage performance significantly correlated with KE PT ($r = -0.490$), KF at 30°/s ($r = -0.591$) and KF at 30°/s ($r = -0.480$), all $p < 0.05$	71%, good
Martin and Nelson 1985 (29)	16 men and 14 women students in the Army R.O.T.C. Program at Penn State University	Standing long jump distance from a one foot take-off	Participants performed testing in 5 different loading conditions from unloaded to full combat load. Loading amounts were as follows for males and females; load 1 was	Standing long jump performance was significantly different ($p < 0.05$) between each performance at different loads	50%, poor

			0.77 and 0.59kg, load 2 9.41 and 9.07kg, load 3 was 17.59 and 16.95kg, load 4 was 29.93 and 29.29kg, load 5 was 36.73 and 36.09kg respectively. Minor differences between male and female loads were due to clothing sizes.	Performance results decreased in a nearly linear fashion as load carriage increased No numerical statistical data was explicitly reported	
Hunt et al. 2013 (17)	104 male participants that were attending the Australian Army Special Forces Entry Test	Countermovement vertical jump (VJ) height	20km march dressed in pack and webbing (28kg) and carrying a weapon completed within 195 mins	VJ height significantly contributed to the regression model for 20km march performance (adjusted $r^2 = 0.269$, $p = 0.004$)	57%, fair
Marcinik et al. 1987 (28)	72 men receiving 8-week naval basic training	1 repetition maximum (1RM) leg press weight 1RM knee extension weight	Paint bucket carry (22.7kg) over 45.7m including up and down an inclined ladder Shoulder drag of a 75.4kg manikin for 12.8m over the lip of watertight door Combined performance of these two tasks with the time to open and then secure the fittings of an 8-dogged watertight door	Leg press significantly predicted paint bucket carrying performance ($r^2 = 0.4255$, $p < 0.05$) Leg press significantly predicted manikin drag performance ($r^2 = 0.3134$, $p < 0.05$) Leg press significantly predicted combined task performance ($r^2 = 0.5524$, $p < 0.05$) Knee extension was not assessed with load carriage tasks	57%, fair
Rayson et al. 2000 (35)	304 men and 75 women were recruited from the British Army. They came from each Arm and Service and were classified as fully deployable and medically cleared of contraindications	Isometric plantar flexion strength measured in a seated position with the knee angle at 80° and the ankle angle at 90°, measuring the maximum upwards push exerted on a caliper above the knee	Water can carry (20kg) along a 30m shuttle at a pace of 1.5m/s for as long as possible Repetitive lift and carry task (RLC) requiring participants to pick up and carry a box 10m and place on a 1.45m height, then retrieve the box and carry	Plantar flexion strength was one of the 5 highest correlation coefficient for RLC at 44kg, although not significant Plantar flexion strength did not significantly correlate with any load carriage task or rank in the top 5 correlation coefficients for any other load carriage tasks	46%, poor

			it 10m back to the start placing it on the ground (one shuttle). Loads used were 10, 22 and 44kg, and were shuttled at a rate of 6, 3, and 1 shuttles/min respectively Loaded march over 12.8 km flat bitumen course as quickly as possible with either 15, 20 or 25 kg load in rucksack		
Knapik et al. 1991 (21)	89 soldiers from the 2nd battalion, 17th Infantry Regiment, 6th Infantry Division (Light), Ft Richardson AK	Vertical jump (VJ) height	Completed a 20km road march as fast as possible carrying a rucksack, uniform, weapon, helmet and load carriage equipment (approximately 46kg total) over mostly flat roads and a 5km area of rolling hills with water and food available at 5km checkpoints	VJ height before the road march did not significantly change after the road march (45.7 vs 45.0cm respectively, $p = 0.307$)	71%, good

Note: * Critical appraise scores are expressed as the respective article's Downs and Black (11) percentage score, and their Kennelly grade (18). VJ = vertical jump, BJ = broad jump, BC = box carry, SBJ = standing broad jump, VO_2 max = maximum rate of oxygen uptake, DL = drop landing, KE = knee extension, KF = knee flexion, MFO = military field operations, PF = plantar flexion, MLCC = maximum load carriage capacity, 1RM = one repetition maximum, MC = military course, PT = peak torque, RLC = repetitive lift and carry.

Multiple methods were used to measure lower-body strength and power. These can be broadly classified into four different types of movements: isometric tests, isokinetic tests, isotonic compound movements (multiple-joint) or isolated single-joint movements, and measures of lower-body power. The results of these tests were recorded by the maximum amount of load lifted (kilograms), force produced (Newtons), distance or height achieved (metric measurements), and the total work or power performed (watts).

Isometric tests used for assessment included knee extension, knee flexion, and plantar flexion. Knee extension was measured with a knee angle of 120° (20). Additionally, one study looked at isometric leg extension against a footplate resembling an isometric leg press at 50° of knee flexion (23). Knee flexion was measured with a knee angle of 160° (20). Plantar flexion was measured in two studies; one with a joint angle of 120° (20) and the other in a seated position with the knee at 80° and the ankle at 90° (35). However, the exact setup and positioning for these tests were poorly described within the respective articles.

The isokinetic tests in the studies reviewed measured several different joints through ranges of motion. The range of motion assessed was rarely described, with only one article outlining the range of motion performed (30). Specific joint movements measured isokinetically included knee extension, knee flexion, plantar flexion, hip extension, and hip flexion. These were assessed at a variety of different velocities including 30, 60, 180 and 300°/s (12, 30) and at 0.52, 1.04, 1.57 and 3.14 radians per second (20, 37) (which is approximately 30, 60, 90 and 180°/s). One study assessed isokinetic squat strength from a standing position to 90° of knee flexion and returning to standing again at a rate of 40 cm/s (23).

Compound movements assessed included one-repetition maximum squat and leg press, and the only isolated single joint movement assessed was leg extension (26, 28). Mala et al. (26) used previously described methods to assess squat strength which allowed longer recovery time (2-3 minutes) between efforts. Muscular strength assessed by Maricinik et al. (28) only allowed 5 to 10 seconds between efforts while the pin which supported the weights was adjusted.

Lower-body power was assessed in several of the studies reviewed. The majority of tests utilized included a variation of the vertical jump and the broad jump (2, 4, 10, 14, 17, 20, 21, 26, 29). The jumping techniques for these tests varied slightly between studies, but were both measuring either maximum vertical or horizontal displacement of the subject. Some studies also observed or calculated the power or work exerted for the vertical jump via a force plate or equations based on body mass, jump height, and jump time (2, 14, 26). All jump tests begun from a static position, except in one study which included a vertical jump test after starting from a 0.75 m height (10). Two studies also assessed peak power achieved during a 30-second Wingate maximum effort cycling test (15, 20).

The load carriage tasks performed were diverse and often designed to be specific to the occupational requirements of the participants. These tasks broadly fit into three main categories: loaded marches, object carrying, and performance measures under load. Additionally, one study by Koerhuis et al. (23) investigated maximum load carriage capacity, where weight was progressively added into the participant's backpack until exhaustion while walking on a treadmill at a constant 3 km/h with a 5% gradient (23). Koerhuis et al. (23) also investigated the endurance of participants at 70%, 80% and 90% of their established maximum load carriage capacity (23).

Loaded march tasks varied in course terrain, distances travelled, and loads carried. The course terrains were predominately over flat ground or roads with some sections of the courses having hills. Most articles adequately described the terrain participants were required to traverse. Total distances travelled ranged between 2-29 kms, with only one study not specifying the distance travelled (15). The median distance covered in the loaded marches was 14.4 kms and the mean distance was 13.9 kms from the eight studies that reported marching distance (12, 14, 17, 20, 21, 30, 35, 37). Two studies which shared a dataset had resting stations set up with water and food available every 5 kms on the 20 km course (20, 21). Hackney et al. (15) required participants to perform various combat tasks (including marches, rock climbing and infantry combat maneuvers) during the loaded march which was not explicitly detailed. The total loads carried also varied greatly ranging between 18 and 46 kg. The mean load carried was 31.5 kg and the median load carried was 28 kg from each of the load carriage marches performed in the reviewed studies (12, 14, 15, 17, 20, 21, 30, 35, 37).

Several studies had participants perform carrying tasks in which they were required to move an object during a shuttle run, or over a course, as quickly as possible (2, 4, 28, 35). One of these courses required participants to navigate across obstacles frequently encountered during occupational duties (including a water tight door or ladder) (28). Another two studies assessed carrying performance which mimicked occupational tasks involving patient drags or hose carries (4, 28). Loads carried for these tasks ranged between 10 and 75.4 kg. The large range in load carried was due to the varied nature of the carrying task. Total distances travelled also greatly varied, as some tasks required participants to shuttle along a course as many times as possible within a given time frame, while others required participants to complete a course of a set distance as quickly as possible. Each of these load carrying tasks are briefly detailed in Table 4 *(supplemental digital content)*.

Three studies investigated the effects of load carriage on physical performance measures or during a short course. The short course included a 30-m sprint, 27-m zigzag run and a 10-m simulated casualty drag, and was performed while carrying approximately 42 kg of load which consisted of their combat uniform and a loaded rucksack (26). Finally, in two studies, the physical performance measures assessed during load carriage performed involved assessing either a vertical jump or a broad jump equivalent test (10, 29). The loaded conditions ranged between approximately 7.7 and 36.7 kg for these tests. This weight consisted of combat loads including military uniform, webbing, standard military equipment (such as canteen and ammunition cases), helmet, armour vest, backpack and frame, additional loads inside the backpack and a rifle (29).

Measures of lower-body power, excluding the Wingate test, frequently correlated to and predicted load carriage performance; where a higher score for lower-body power was associated with better load carriage performance (2, 4, 17, 26, 29). However, two studies found that lower-body power did not correlate with load carriage performance, or contribute to a regression model over other variables such as a 2.4 km run time when predicting load carriage performance (2, 20). Peak Wingate performance was found to significantly correlate with heavy (46 kg) loaded road march (20 km) performance (20). All of these correlations were observed within naval, fire and rescue, and military populations.

In all but two studies (30, 37), measures of lower-body strength correlated with, or predicted, load carriage performance. One repetition maximum tests for compound (multiple-joint) exercises (e.g., the squat or leg press), both significantly predicted load carriage performance (26, 28).

Isokinetic strength measures using isolated single-joint movements (knee flexion, knee extension and plantar flexion) correlated with load carriage performance and were significant predictors of load carriage time (12, 20, 23, 30). Additionally, Koerhuis et al. (23) found that isokinetic squat strength significantly correlated with the participant's maximum load carriage capacity as determined by prior testing. However, it was found that isokinetic leg strength was not significantly correlated to shorter 2 and 4 km loaded marches by Mello et al. (30), despite correlating with the longer 8 and 12 km marches. Furthermore, isokinetic lower-body strength did not correlate with either of the load carriage tasks performed by "elite" British soldiers (37).

Knapik et al. (20) found that isometric measures of lower-body strength significantly correlated with load carriage performance. Additionally, Koerhuis et al. (23) found that isometric leg strength significantly correlated with maximum load carriage capacity. However, in the study by Rayson et al. (35), although isometric leg strength (measured via plantar flexion) was in the top five highest correlates (the remaining four being overall lifting power, incremental lift to 1.70 m, dynamic arm flexion endurance and dynamic shoulder endurance) with one of the load carriage tasks (a repetitive lift and carry of a 44 kg box), it was not a significant finding or contributor to performance. Isometric plantar flexion strength also did not significantly correlate with the other load carriage tasks performed or rank within their top five correlates (35).

Both the addition of load or completion of a load carriage task was found to significantly decrease leg power output as measured by a variation of the vertical jump (10, 14). Wingate performance was also found to be significantly reduced by loaded marching tasks (15). However, this finding was not observed by Knapik et al. (21) in which infantry soldier vertical jump height was not changed significantly following the completion of a 20 km loaded march.

DISCUSSION

Occupational load carriage required by tactical personnel is important for protecting, sustaining, and enhancing operational capabilities (32, 38). Being able to optimally perform in unpredictable and dangerous environments while carrying these loads requires appropriate amounts of lower-body strength and power (27, 32, 38). The requirements for lower-body strength and power are also compounded by the increasing loads carried by tactical personnel in the modern era (22, 32). During occupational tasks, muscular strength and power demands are important components of fitness for the performance of these tasks (27, 33, 36). Importantly, the nature of these tasks are specific to the tactical occupation and as such, can vary greatly (17, 35).

Within the reviewed articles, the tactical populations studied mostly consisted of military personnel (2, 12, 14, 15, 17, 20, 21, 23, 26, 28-30, 35, 37). Few articles investigated firefighters or law enforcement populations, which have different occupational requirements for load carriage tasks (4, 10). Additionally, no articles were found that passed the exclusion criteria which had participants from emergency services. This population bias towards military personnel was reflected by the designs of the load carriage tasks assessed within the studies. Many of the studies investigating military populations involved loaded marches over long distances, which are not as occupationally relevant for firefighters or law enforcement populations. In contrast, the study observing fire and rescue personnel required them to perform tasks designed by a panel of experts that aimed to mimic their occupational activities (4). Due to this, the reviewed observations will have most relevance to military personnel over other tactical populations. Furthermore, the sample sizes of the populations studies varied, which may limit the statistical power and implications of the results. Many articles did not describe any power calculations used to determine the appropriate number of participants required for statistical analysis (2, 4, 10, 12, 14, 15, 17, 20, 21, 23, 28-30, 35, 37). Finally, there was a lack of female participants in the review studies, although this is typical of much tactical research due to the nature of the professions (7, 8, 25, 31).

Assessments of lower-body strength and power can be used to evaluate the fitness, and to possibly predict performance ability, among tactical personnel (19). The articles reviewed employed a variety of different methods to assess lower-body strength and power. Both isolated single-joint and compound (multiple-joint) movements were utilized to assess either isometric, isokinetic, or isotonic leg muscular performance. Many of these tests required expensive specialized equipment to perform muscle strength assessments (12, 20, 23, 30, 35, 37). Such equipment, particularly isokinetic machines, would not be readily available for the assessment of tactical personnel (12, 20, 23, 30, 37). As such, these measures may not serve as practical tests to be used within tactical populations for either performance assessment, fitness testing or selection criteria. Isotonic measures of strength are generally easier to perform and require non-specialized equipment to assess. However, only two articles investigated isotonic measures of strength, which were the one repetition maximum squat or the leg press (26, 28). A maximum squat or leg press effort can be easily utilized to assess lower-body strength in tactical populations. All that is required is to perform these tests is access to common gym equipment which are frequently used for their physical training (16, 22, 41). Tests for leg power consisted mostly of either a vertical jump for maximum height or broad jump for maximum distance (2, 4, 10, 14, 17, 20, 21, 26, 29). These tests are both simple and inexpensive which can be easily incorporated into any testing or assessment batteries for tactical personnel.

The load carriage tasks required to be performed by participants varied greatly between studies. Further, there was no clear standards that had been defined for the requirements of a load carriage task. Several of the studies aimed to develop specific load carriage tasks criteria for subsequent personnel to perform for assessment purposes (4, 17, 35). Also, some studies used load carriage tasks that were either similar to, or already being utilized, as an assessment or training drill specific to the population tested (12, 14, 28). The highly varied use of different load carriage tasks may have implications for the extrapolation of the correlations found, due to the significantly different load carriage tasks tactical personnel may be required to perform. Assuming similarities between them may not always be appropriate depending on the task in question. However, although the load carriage tasks varied across the multiple studies reviewed, the associations between lower-body strength and power with load carriage performance remained similar. Therefore, this may indicate that for tasks requiring load carriage, both leg strength and power are important contributing factors to performance.

Several practically relevant and consistent results were found between measures of lower-body strength and power during load carriage. Firstly, both leg strength and power are good predictors of load carriage performance across a varied number of tasks (2, 4, 12, 17, 20, 23, 26, 28-30, 35). Overall, the majority of the studies reviewed found that leg strength or power correlated with and predicted load carriage performance with a reasonable degree of accuracy. This suggests two importance considerations for tactical personnel. Firstly, that tactical populations can use measures of leg strength or power for physical assessments for entry admission, deployment, or predicting occupational performance. Secondly, that leg strength and power are important components of fitness required for optimal load carriage performance. The reviewed findings suggest that by improving lower-body strength and power, load carriage performance can be improved which may result in a multitude of benefits for tactical populations (2, 4, 12, 23, 28). Such benefits of both screening and lower-body strength and power conditioning would include better outcomes for the load carriage events, decreased risk of injury and improved work efficiency (6).

Lower-body strength and power were also found to be consistently reduced after load carriage tasks or with the addition of load carriage equipment (10, 14, 15). This is an important consideration for tactical personnel who will be required to perform a multitude of different tasks during load carriage. If a substantial load carriage task is completed and the following duties demand high levels of leg strength or power (e.g., sprinting, dodging, lifting, carrying, pushing, jumping, and stair climbing) (27, 33, 36), then the performance of personnel will be reduced. This can put these personnel at higher risk for injury or decreased success with load carriage tasks (6). As such, and where possible, the amount of recovery following load carriage tasks should be considered in order to best maintain occupational performance. Where this is not a viable option, it could be recommended that the leg strength and power requirements for tactical personnel prior to these tasks be optimized, in order to compensate for predicted decreases in performance after load carriage.

Some studies however did not find associations between lower-body strength and power with load carriage (20, 30, 35, 37). Other variables assessed within the studies were shown to be stronger predictors of load carriage performance, and these were predominately measures of aerobic fitness (2, 20). One study found that isokinetic measures of leg strength only correlated with longer distance (8 and 12 km) loaded marches but not with shorter distance (2 and 4 km) marches. Mello et al. (30) suggested the reason behind this might be that other variables, such as anaerobic power, may be a more significant factor during shorter loaded marches due to the different metabolic demands. Another study did not find significant correlations between vertical jump performance and load carriage performance (20). However, other measures of leg strength taken within the study significantly correlated with the performance of the load carriage task (20). This suggests that it is important to investigate both leg strength and power in tactical populations to predict load carriage performance. Finally, Knapik et al. (21) did not find significant changes in vertical jump performance following a 20 km load carriage (4 6kg) task. This finding was suggested to be explained by the 10 to 15-minute interval between the completion of the load carriage task and completion of the vertical jump testing. This is of note given the aforementioned discussion regarding the need to allow for some recovery following a load carriage task prior to the performance of other occupational tasks. Additionally, the authors suggest that low-intensity aerobic load carriage tasks may not have a large impact on the performance of personnel as higher-intensity anaerobic tasks do (21). Taken together, although not all studies reviewed found clear and significant correlations between lower-body strength and power with load carriage, the available information tends to suggest that both leg strength and power are important factors for the performance of load carriage tasks. The importance of leg strength and power can vary depending on the duration, intensity, loads and specific tasks required to be performed during load carriage. The majority of the reviewed studies revealed a positive correlation between leg strength and power and load carriage performance. In accordance with this, leg strength and power should be considered for fitness training and assessment of tactical personnel required to carry loads.

The overall quality of the studies assessed was fair as assessed by the Downs and Black evaluation tool (11) and Kennelly grading system (18). The reviewed articles generally reported their information well with assessments and interventions clearly described and data clearly reported. Sections that studies performed poorly in included reporting any adverse effects that had occurred due to the load carriage tasks and the reporting of exact probability values rather than as a threshold for significance (2, 4, 10, 15, 20, 26, 28, 29, 35, 37). Most studies performed poorly on the external validity section due to the participants not being representative of the larger population they were selected from (2, 4, 10, 14, 15, 17, 23, 26, 28, 29, 35, 37). Internal validity for bias scored well due to the high compliance of participants, the types of statistical analysis used and the general type of the study (2, 4, 10, 14, 15, 17, 23, 26, 28, 30, 37). Studies did not perform as well on certain questions of the confounding selection bias section predominately due to the general types of studies used. Only two studies performed a power analysis to derive an appropriate sample size required to prevent the artificial inflation of the alpha level (26, 35). Few studies were primarily investigating relationships between leg strength and power and load carriage. The few that were investigating those associations were performed well being clearly described and discussed (12, 14, 20, 26, 30). Those that investigated the associations not as a primary measure were not as clearly described, although the explanation of the methods and statistical analysis used were clear. More high-quality primary research investigating the relationships between leg strength and power during load carriage, as well as optimal recovery periods, is required.

Tactical personnel are often required to perform occupational load carriage tasks. Performance of these tasks are related to the individual's lower-body strength and power. Through assessing lower-body strength or power, load carriage performance may be estimated. As such, measures of lower-body strength and power should be considered an important assessment tool for screening tactical personnel for occupational duties. Additionally, lower-body strength and power appear to be negatively affected by load carriage tasks and therefore should be important considerations for tactical personnel training.

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