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The Impact of Occupational Load Carriage on Carrier Mobility: A Critical Review of the Literature

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Military personnel and firefighters are required to carry occupational loads and complete tasks in hostile and unpredictable environments where a lack of mobility may risk lives. This review critically examines the literature investigating the impacts of load carriage on the mobility of these specialist personnel. Several literature databases, reference lists, and subject matter experts were employed to identify relevant studies. Studies meeting the inclusion criteria were critiqued using the Downs and Black protocol. Inter-rater agreement was determined by Cohen’s \( \kappa \). Twelve original research studies, which included male and female participants from military and firefighting occupations, were critiqued (\( \kappa = .81 \)). A review of these papers found that as the carried load weight increased, carrier mobility during aerobic tasks (like road marching) and anaerobic tasks (like obstacle course negotiation) decreased. As such, it can be concluded that the load carried by some specialist personnel may increase their occupational risk by reducing their mobility.

1. INTRODUCTION

For specialist personnel, e.g., military soldiers, firefighters, and police officers, occupational load carriage is a fundamental requirement for the performance of daily tasks. Soldiers may be required to carry heavy backpacks, wear personal protective equipment (PPE), e.g., helmets and body armour, while carrying various weapon systems [1]. Firefighters may have to carry self-contained breathing apparatus (SCBA) and wear heavy PPE, e.g., turnout gear, while having to manipulate heavy hand-held loads, e.g., charged hoses [2]. Specialist police officers may likewise be required to carry loads that consist of body armour and vests and carry firearms and other specialized equipment, e.g., riot shields [3]. While research suggests that some specialist personnel are heavier, stronger, and fitter than their predecessors [4, 5, 6], the loads that these personnel are required to carry are likewise increasing [6, 7, 8]. As an example, during World War I, American and Australian military soldiers carried an average load of 30–40 kg [6], whereas during recent conflicts in Afghanistan, soldiers have carried an average load of 44–48 kg [6, 9, 10].

While the occupational loads carried by these specialists may be required to minimize the risks associated with their performance of tasks in unpredictable and hostile environments [6, 10], the survival of these specialists and their subsequent mission success can depend on their mobility [11]. For military soldiers, reductions in mobility have been shown to alter the tactics of warfare [12, 13], impact on mission success [14], and lead to soldiers receiving combat wounds [15] and suffering mortalities [16]. For firefighters, the loads they carry have been claimed to notably restrict movement across the knees and arms [10], and increase
the time taken to negotiate emergency escape routes in the wilderness [17]. For police officers, the ability to pursue and apprehend an offender is thought to be impeded [18]. As such, while potentially a means of reducing occupational risk [19], the occupational loads carried by specialist personnel may instead form a source of occupational risk by reducing their mobility. On this basis, the aims of this article were to (a) critically review literature investigating the impact of load carriage on the mobility of specialist personnel and (b) to report on the findings within this literature as to what the impacts of occupational load carriage on specialist personnel were.

2. METHODS

Three search strategies were employed for this review. Firstly, several literature databases were used to search for relevant original research articles using keywords within search engines relevant to each database. Table 1 describes the databases explored and keywords used. Secondly, reference lists of the articles acquired in the initial search were reviewed with previously unidentified articles noted and sourced. Finally, fellow colleagues with research experience in this field were contacted and requested to provide additional literature for review. This literature was typically in the form of military technical reports.

Following removal of all duplications, articles were subjected to the specific inclusion criteria, these being (a) studies reported in the English language; (b) published in 1990 or later; (c) involving human participants carrying an external load in backpacks, or in the form of ballistic vests, clothing and protective equipment, or within the hands; and (d) investigations that specifically considered the impact that carriage of these loads had on mobility. In this review, mobility was defined as the physical movement of a person in a straight line, multidirectional, or negotiating obstacles over distance. Studies assessing mobility on a stationary machine (treadmill) were

<table>
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included. Several of these inclusion criteria (see Table 1) were applied during the initial database search as part of the relevant search engine’s filtering process while the remaining criteria were applied manually.

The methodological quality of the selected articles was assessed with the Downs and Black protocol [20]. The Downs and Black protocol employs a checklist that permits the assessment of both randomized and nonrandomized studies of health care interventions [20]. The checklist addresses five major areas of analysis including reporting quality, external validity, bias, confounding, and statistical power. The Downs and Black checklist is a 27-item checklist that is predominantly scored on a scale of 1 = yes or 0 = not usable to determine. However, there are two questions that are rated on a greater scale. The first one (item 5 in the reporting subscale) can be scored 0–2 points, with 1 point awarded for partially detailing confounds and 2 points for definitively detailing confounds. The second one (item 27 in the power subscale) can be scored 0–5 points based on sample size with larger sample sizes worth more points. Scores were converted to a percentage of the total score by dividing each article’s score by 32 (total possible score) and multiplying by 100%. All studies were independently rated by the two authors (SC, RO) with the level of agreement measured with Cohen’s κ analysis of all raw scores (27 scores per paper). For final scores, any disagreements in points awarded were settled by consensus.

3. RESULTS

From the primary search, a total of 172 potential articles were identified for review (see Figure 1). Additionally, another seven articles were included after the secondary search. Five additional articles

were captured from fellow colleagues. In total, 149 articles were excluded based on preliminary reviews of their titles and abstracts, and subsequent irrelevance or duplication. A further 23 articles were excluded following analysis of their full text as they did not meet the relevant inclusion criteria. A total of 12 publications investigating the impact of load carriage on parameters of mobility were retained.

The $\kappa$ statistic for inter-rater agreement of study methodological quality was .81, indicating an almost perfect agreement [21]. Table 2 shows the methodologies, major findings, and critical appraisal quality scores for the investigations that met the review criteria. The methodological quality scores were generally high, $M (SD)$ of 73.92 (5.56), ranging from 66% [22, 23, 24] to 84% [25, 26]. The most noted limitations of these studies when viewed through the lens of the Downs and Black protocol [20] was the inability to blind either the participants or assessors to the various load carriage interventions and difficulty in randomising intervention groups.

**Notes.** CAS = critical appraisal score, ALICE = all-purpose lightweight individual carrying equipment, PPE = personal protective equipment, SCBA = self-contained breathing apparatus.
### Study Participants Load Carried Tasks Major Findings CAS (%)

**[25]** 15 special forces soldiers (male only) ALICE pack + experimental double pack (34, 48, 61 kg) 6 individual road marches of 20 km road march time increased with increase in load \((p < .001)\) rest times increased with increase in load; average rest times for 34-, 48-, and 61-kg conditions were 2.1 ± 3.2, 11.5 ± 13.8, and 15.7 ± 11.2 min, respectively, for ALICE pack; and 3.3 ± 4.10.1 ± 11.4, 22 ± 11.2 min, respectively, for double pack 78

**[26]** 89 light infantry soldiers (male only) rucksack, uniform, weapon, helmet and boots (~46 kg) single 20-km road march no change in vertical jump 8% increase in fatigue 38% decrease in vigour 84

**[27]** 11 soldiers (male only) unloaded (0 kg); tactical vest (8.7 kg) + 3 versions of extremity armour (5.6–6.4 kg) 10- min walk (1.39 m/s) 10-min run (2.43 m/s) repetitive box lift and carry 5 30-m rushes obstacle course run (straight sprints, hurdles, zigzag runs, stair climbing, wall climbing) increase in sprint and obstacle course run time in all loaded conditions decrease in number of box lifts in loaded conditions 75

**[28]** 15 special forces soldiers (male only) ALICE pack + experimental double pack (34, 48, 61 kg) 6 individual road marches of 20 km road march time increased with increase in load \((p < .01)\) 69

**[29]** 21 special forces soldiers (male only) ALICE pack + experimental double pack (34, 48, 61 kg) 6 individual road marches of 20 km obstacle course run (straight sprints, hurdles, zigzag runs, stair climbing, wall climbing) road march time increased with increase in load \((p < .01)\) 24.3%–26.3% slower with 48 vs. 34 kg 50.0%–52.3% slower with 61 vs. 34 kg no significant change in obstacle course time 81

**[30]** 24 firefighters (male only) standard PPE + one of 4 SCBA (either 5.4 or 9.1 kg in varied sizes) 9.8-m walk at 2 speeds (normal/ fast) in 3 obstacle conditions (no obstacle, 10-, 30-cm obstacles) with 2 trials of each bottle mass, but not size, affected clearance rate of obstacles 10-cm obstacle not contacted in any scenario 42% of subjects hit 30-cm obstacle carrying 9.1-kg bottles an increased incidence of obstacle contact at faster speed 75

**[31]** 12 military police work soldiers (female only) body armour (14 kg) + additional equipment loads (27 and 41 kg) 6 individual road marches of 3.2 km with each loaded condition tested twice 19% increase in time to cover distance with 27 vs. 14 kg \((p < .05)\) 44% increase in time to cover distance with 41 vs. 14 kg \((p < .05)\) 75

**Notes.** CAS = critical appraisal score, ALICE = all-purpose lightweight individual carrying equipment, PPE = personal protective equipment, SCBA = self-contained breathing apparatus.
The participants involved in the studies were diverse and involved males only [2, 25, 26, 27, 28, 29, 30], females only [11, 31], or both genders [22, 23, 24]; active duty military soldiers/officers [22], light infantry soldiers [26, 27], special forces soldiers [25, 28, 29], noncombat soldiers [23, 24]; and firefighters [2, 30]. In all included publications, tasks and loads carried were clearly outlined. The reported loads carried varied in type and included tactical vests and body armour [11, 22, 27, 28, 32], military uniforms with and without additional loading such as backpacks and firearms [23, 24, 25, 26, 28, 29], and firefighting PPE with and without SCBA [2, 30]. The loaded conditions in the reported studies ranged in load weight from 5.5 to 61 kg.

A variety of mobility outcomes were measured to assess the impacts of load carriage on both aerobic [22, 23, 25, 26, 28, 29, 31] and anaerobic [2, 11, 22, 24, 27, 29, 30] performance. Aerobic outcome measures included strenuous road marching tasks over distances of 3.2 [31], 10 [23], and 20 km [25, 27, 28, 29] and a maximal incremental treadmill assessment [22]. Anaerobic measures for mobility included 30-m sprints [24, 27], specific tests such as a rope pull and dummy drag [22], and obstacle course tasks [11, 27, 29]. For the studies that investigated the impact of load on obstacle course time, the courses were almost identical [11, 27, 29]. In two instances, the impact of load on mobility was assessed over an extremely short distance due to the nature of the gait assessment being undertaken [2, 30], this being completion of a single step-over obstacle. Given these outcome measures, all studies observed a reduction in mobility with increases in external load weight. The negative consequence of carrying increasing load weights varied from slower overall performance times [11, 22, 23, 24, 25, 26, 27, 28, 29, 31] to decreases in foot clearance when stepping over an obstacle [2, 30].

4. DISCUSSION

From strategic tactics in World War I [12, 13] to chasing militia in East Timor [14], the load carried by soldiers has been claimed to reduce soldier mobility and the mobility of their unit during military operations [33]. Given the quality and volume of evidence discussed in this review, occupational load carriage can indeed be considered to negatively impact upon the mobility of specialist personnel when carrying loads and performing tasks. Most notably, the evidence suggests that as the weight of the carried load increases, the mobility of the carrier, in terms of time to move a given distance, and time and ability to complete an obstacle course, decreases.

All seven separate studies investigating the time taken to complete a given distance while carrying loads observed that as the carried loads increased, so too did the time taken to complete the distance [23, 24, 25, 27, 28, 29, 31]. In these studies, loads ranged from 5.5 [27] to 61 kg [29], and distances from 30 m [24, 27] to 20 km [26, 29]. As an example, in Knapik, Johnson, Ang, et al.’s study, where soldiers carried 61 kg for a distance of 20 km, completion times increased by 82 min (7%) compared to the same task with a 34-kg load [29]. More recently, Treloar and Billing noted a decrease in the soldier speed with completion times during “break contact” drills increasing by 2 s (32% slower) over a distance of 30 m carrying a load of 26 kg [24].

Considering these results, it is well established in the literature that as a given load weight increases, so too does the metabolic cost required to carry that load [5]. As such, increases in metabolic costs associated with increases in load weight are likely to have a negative effect on completion times for road marches over a given distance. As identified in the studies that compared more than one loaded condition [22, 29, 30, 31], there was a decrease in mobility as the weight of the load carried increased. As an example, in Pandorf, Harman, Frykman, et al.’s study, female participant times to complete a 3.2-km loaded run increased by 19% when the load increased from 14 to 27 kg and by 44% when the load increased to 41 kg [31]. Similarly, Harper, Knapik, and de Pontbriand observed male and female participant times, over a longer distance of 10 km, to increase by 4% when loads increased from 18 to 27 kg and by 23% when loads increased from 18 to 36 kg [23]. Moreover, a subsequent
analysis yielded a significantly longer march time with the 36-kg load compared to either 18- or 27-kg loads [23]. These results suggest that as the weight of the carried load increases, the associated decrease in mobility may be more pronounced.

Increases in load weight were also observed to decrease the mobility of load carriers when negotiating obstacles. Four papers observed decreases in speed when required to complete both individual obstacles and a series of obstacles when participants carried occupational loads [11, 27, 29, 31]. Pandorf et al. observed a decrease in speed (25%, $M = 1.4$ s) completing four hurdle step-over obstacles spaced 2.1 m apart when carried backpack loads increased from 14 to 27 kg; overall time taken to negotiate four obstacles increased by 47% ($M = 17.4$ s) [31]. In addition to decreases in speed, three studies found that the numbers of participants able to successfully negotiate individual obstacles decreased as the load weight carried increased [11, 30, 34]. In Frykman, Harman, and Pandorf’s study, where participants had to negotiate a 137-cm high wall carrying load, only 55% (6 of 11) of the participants successfully negotiated the wall with a 14-kg load and 27% (3 of 11) with a 27-kg load [11]. These findings are unsurprising given research by Ricciardi, Deuster, and Talbot, who identified a significant reduction in the performance of strength based assessments when participants wore body armour (10 kg) [32]. In their study, mean male pull-up ability and mean female sustained hang ability decreased by over 60% when participants wore body armour. In another study of interest, Park, Hur, Rosengren, et al. used obstacles to simulate debris faced by firefighters fighting fires [30]. They found that loads of 9.1 kg led to 42% of participants (10 of 24) making contact, at least once, with a 30-cm obstacle while stepping over it. Soldiers could be expected to face similar debris in battle-damaged buildings or areas.

A further aspect for consideration is that of the physical space taken up by equipment associated with increases in load weight. Two studies considered the potential for increases in load size to affect obstacle course performance [30, 31]. In one study, Pandorf et al. observed a twofold increase in time to complete a 3.7-m crawl obstacle when the carried load increased from 14 to 27 kg [31]. Pandorf et al. considered the increase in physical space taken up by the additional load equipment to have been a contributing factor to the reduced performance by decreasing crawl space and altering movement technique. However, these results contrast with those of Park et al. [30]. In Park et al.’s study, participants carried four different sized SCBA (two weighing 5.1 kg and two weighing 9.1 kg) while walking up to and over an obstacle [30]. When their results were subjected to a statistical analysis, it was observed that, although associated with increases in load weight, increases in times to negotiate the obstacle were independent of load size. However, it should be noted that Park et al.’s study employed only a single step-over obstacle, lighter loads (5.4 and 9.1 kg), and smaller sized loads.

5. CONCLUSION

Organizations responsible for specialist personnel, who by nature of their occupations may be required to carry loads, can take advantage of this review. Credible research evidence suggests that occupational load carriage negatively impacts upon the carrier’s mobility when performing both aerobic and anaerobic tasks. Furthermore, the degree of mobility impairment may be influenced by the weight of the load and by the potential increases in physical space taken up by the load. On this basis, the requirement for specialist personnel, e.g., military personnel, firefighters, and police officers, to carry load may increase their occupational risk by reducing their speed of movement and potentially impeding their ability to successfully negotiate obstacles. As such, the impacts of carried occupational loads on the mobility of specialist personnel must be considered prior to their undertaking of tasks in potentially hostile and life threatening environments.

REFERENCES


