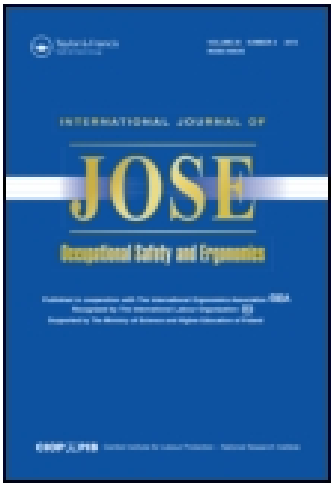

International Journal of Occupational Safety and Ergonomics

Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/tose20

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

Simon D. Carlton[a] & Robin M. Orr[a]

[a] Bond University, Gold Coast, QLD, Australia

Published online: 08 Jan 2015.

To cite this article: Simon D. Carlton & Robin M. Orr (2014) The Impact of Occupational Load Carriage on Carrier Mobility: A Critical Review of the Literature, International Journal of Occupational Safety and Ergonomics, 20:1, 33-41, DOI: 10.1080/10803548.2014.11077025

To link to this article: http://dx.doi.org/10.1080/10803548.2014.11077025

International Journal of Occupational Safety and Ergonomics (*JOSE*) 2014, Vol. 20, No. 1, 33–41

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

Simon D. Carlton
Robin M. Orr

Bond University, Gold Coast, QLD, Australia

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 κ. *Twelve original research studies, which included male and female participants from military and firefighting occupations, were critiqued (*κ = *.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.*

load carriage mobility specialist personnel military firefighters

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

Correspondence should be sent to Robin Orr, Department of Health Sciences and Medicine, Bond University, Gold Coast, Queensland, Australia 4229. E-mail: rorr@bond.edu.au.

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 1. Details of Literature Search: Databases Used, Search Terms, and Inclusion Filters (if Available)

Database	Search Terms	Filters	No. After Inclusion	No. After Exclusion	Total No.	Duplicates	New Articles
PubMed	"Load carriage" AND (military OR "tactical response unit" OR "special weapons and tactics" OR "SWAT" OR "special operations" OR "emergency response")	1990–2012 English humans clinical trials RCT review	42	13	13	0	13
CINAHL	"Load carriage" AND (military OR "tactical response unit" OR "special weapons and tactics" OR "SWAT" OR "special operations" OR "emergency response")	1990–2012 English humans	26	26	12	8	4
Web of Science	"Load carriage" AND (military OR "tactical response unit" OR "special weapons and tactics" OR "SWAT" OR "special operations" OR "emergency response")	1990–2012 English humans	50	41	16	11	5
EBSCO	"Load carriage" AND (military OR "tactical response unit" OR "special weapons and tactics" OR "SWAT" OR "special operations" OR "emergency response")	2000–2012 English humans peer-reviewed	54	43	16	15	1

Notes. The Cochrane Library http://www.thecochranelibrary.com and PEDro http://www.pedro.org.au/ were also searched with same search strategy as above and provided no results. PubMed = http://www.ncbi.nlm.nih.gov/pubmed, CINAHL = http://www.ebscohost.com/nursing/products/cinahl-databases/cinahl-complete, Web of Science = http://thomsonreuters.com/web-of-science/, EBSCO = http://www.ebsco.com/, RCT = randomized controlled trial.

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 = *no/unable 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

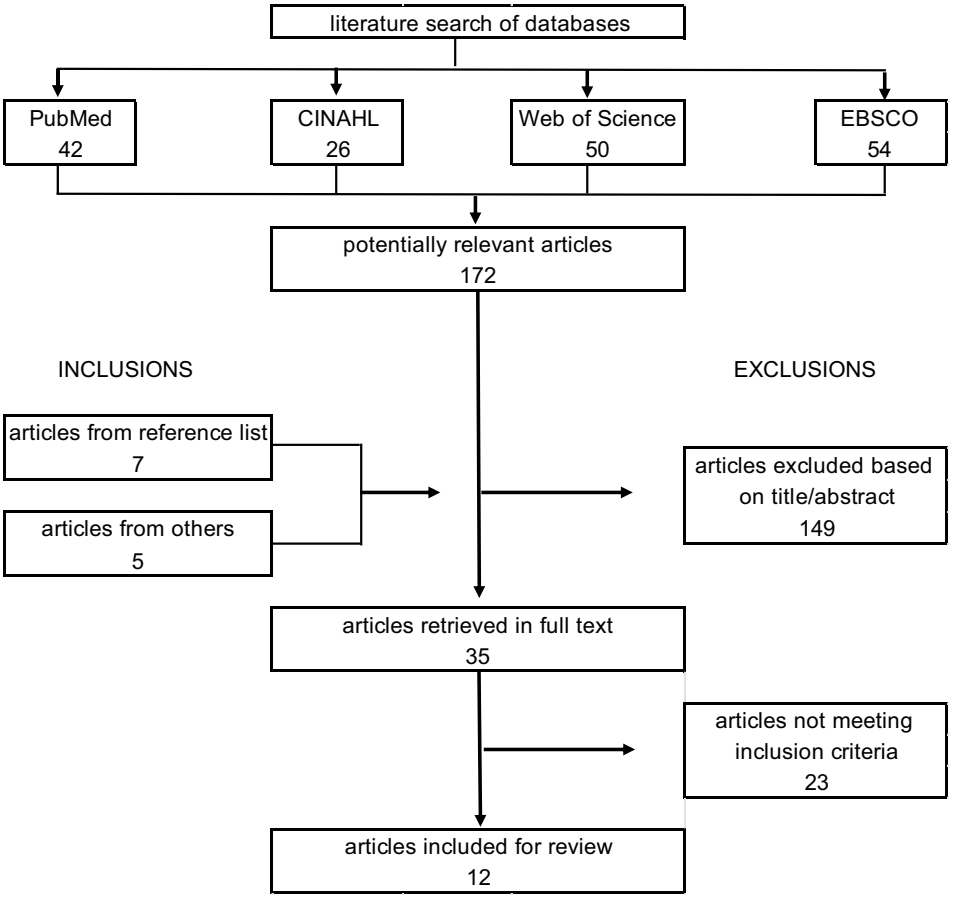

Figure 1. A flow chart of the literature review process. *Notes.* PubMed = http://www.ncbi.nlm.nih.gov/pubmed, CINAHL = http://www.ebscohost.com/nursing/products/cinahl-databases/cinahl-complete, Web of Science = http://thomsonreuters.com/web-of-science/; EBSCO = http://www.ebsco.com/.

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 κ 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.

TABLE 2. Summary and Critical Appraisal of Included Articles in This Review

Study	Participants	Load Carried	Tasks	Major Findings	CAS (%)
[2]	59 firefighters (male only)	standard PPE + SCBA (20.6 kg); enhanced PPE + SCBA (19 kg)	8-m gait assessment with station uniform negotiating a 30-cm obstacle; gait assessments before and after 18 min of firefighting specific drills in PPE	PPE resulted in significantly slower speed, shorter step lengths, and larger step widths compared to wearing only station uniform with PPE there were increased movement errors negotiating obstacle	72
[11]	11 military police work soldiers (female only)	body armour (14 kg) + additional equipment (27 kg)	6-station obstacle course (straight sprints, hurdles, zigzag runs, low crawling, wall climbing)	48% increase in time to complete obstacle course with 27 vs. 14 kg	75
[22]	21 active duty military soldiers (19 male, 2 female)	unloaded (0 kg); Kevlar vest (9.8 kg)	maximal incremental treadmill stress test 274-m shuttle run test box agility test rope pull and dummy drag test	treadmill time significantly reduced in loaded condition (14.4 ± 1.5 vs. 16.4 ± 1.6 min, $p < .001$) increase in shuttle run time when loaded ($p < .001$) no differences in upper limb power tests	69
[23]	34 medical officer soldiers (19 male, 15 female)	personal equipment and rifle (18 kg) + additional backpack (27 and 36 kg)	3 individual road marches of 10 km	males 21% faster than females in all conditions ($p < .01$) 4% increase in time to cover distance with 18 vs. 27 kg ($p < .01$) 23% increase in time to cover the distance with 18 vs. 36 kg ($p < .01$)	66
[24]	17 noncombat soldiers (12 male, 5 female)	combat uniforms and boots + webbing, weapon, combat body armour and helmet (±21.6 kg)	break contact drill of 5 30-m sprints at 44-s intervals on grass surface starting from prone position	31.5% increase in performance time when loaded ($p < .01$) decrease in performance over 5 sprints in both conditions	69

Notes. CAS = critical appraisal score, ALICE = all-purpose lightweight individual carrying equipment, PPE = personal protective equipment, SCBA = self-contained breathing apparatus.

TABLE 2. (*continued*)

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 82% increase in fatigue 38% decrease in vigour	84
[27]	11 soldiers (male only)	unloaded (0 kg); tactical vest (8.7kg) + 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

1. Orr R, Pope R, Johnston V, Coyle J. Load carriage and its force impact. Australian Defence Force Journal. 2011;(185):52–63.

Retrieved December 4, 2013, from: http://www.adfjournal.adc.edu.au/UserFiles/issues/185%202011%20Jul_Aug.pdf.

2. Park K, Rosengren KS, Horn GP, Smith DL, Hsaio-Wecksler ET. Assessing gait changes in firefighters due to fatigue and protective clothing. Saf Sci. 2011;49(5): 719–26.
3. Danaher K. SWAT teams takes on fire and smoke. Police: The Law Enforcement Magazine. 2001;25(12):4. Retrieved December 4, 2013, from: http://www.policemag.com/channel/swat/articles/2001/12/swat-takes-on-fire-smoke.aspx.
4. Knapik JJ, Sharp MA, Darakjy S, Jones SB, Hauret KG, Jones BH. Temporal changes in the physical fitness of US Army recruits. Sports Med. 2006;36(7):613–4.
5. Knapik JJ, Reynolds KL, Harman E. Soldier load carriage: historical, physiological, biomechanical, and medical aspects. Mil Med. 2004;169(1):45–56.
6. Orr RM. The history of the soldier's load. Australian Army Journal. 2010;VII(2): 67–88. Retrieved December 4, 2013, from: http://www.army.gov.au/Our-future/DARA/Our-publications/Australian-Army-Journal/~/media/Files/Our%20future/DARA%20Publications/AAJ/2010Winter/AAJ_Vol7_No2_Winter2010.ashx.
7. Beekley MD, Alt J, Buckley CM, Duffey M, Crowder TA. Effects of heavy load carriage during constant-speed, simulated, road marching. Mil Med. 2007; 172(6):592–5.
8. Knapik JJ, Harman EA, Steelman RA, Graham BS. A systematic review of the effects of physical training on load carriage performance. J Strength Cond Res. 2012; 26(2):585–97.
9. Task Force Devil Combined Arms Assessment Team. The modern warrior's combat load. Dismounted operations in Afghanistan. April–May 2003. U.S. Army Centre for Army Lessons Learned. Retrieved December 4, 2013, from: http://thedonovan.com/archives/modernwarriorload/ModernWarriorsCombatLoadReport.pdf.
10. Son SY, Lee JY, Tochihara Y. Occupational stress and strain in relation to personal protective equipment of Japanese firefighters assessed by a questionnaire. Ind Health. 2013;51(2):214–22.
11. Frykman PN, Harman EA, Pandorf CE. Correlates of obstacle course performance among female soldiers carrying two different loads. In: Soldier mobility: innovations in load carriage system design and evaluation (Report ADA394945). 2001. p. 9-1–9. Retrieved December 4, 2013, from: http://www.dtic.mil/dtic/tr/fulltext/u2/p010994.pdf.
12. Lothian NV. The load carried by the soldier. J R Army Med Corps. 1921;37: 241–63, 342–51, 448–58.
13. Lothian NV. The load carried by the soldier. J R Army Med Corps. 1922;38:9–24.
14. Breen B. Mission accomplished, East Timor. Crow's Nest, NSW, Australia: Allen & Unwin; 2001.
15. Bernton H. Weight of war: military struggles to lighten soldiers' load. The Seattle Times. 2011 Feb 13:Sect. A:1. Retrieved December 4, 2013, from: http://seattletimes.com/html/localnews/2014217586_weightofwar14.html.
16. Marshall SLA. The soldier's load and the mobility of a nation. Quantico, VA, USA: The Marine Corps Association; 1980.
17. Ruby BC, Leadbetter GW 3rd, Armstrong DW, Gaskill SE. Wildland firefighter load carriage: effects on transit time and physiological responses during simulated escape to safety zone. International Journal of Wildland Fires. 2003;12(1):111–6.
18. Beards S, Woods W, Stubbs D, David G. Problems associated with police equipment carriage with body armour, including driving. In: Bust PD, editor. Contemporary ergonomics. London, UK: Taylor & Francis; 2008. p. 23–8.
19. Spellman FR, Bieber RM. Physical hazard control: preventing injuries in the workplace. Plymouth, UK: Government Institutes; 2011.
20. Downs SH, Black N. The feasibility of creating a checklist for the assessment of the methodological quality both of randomised and non-randomised studies of health care interventions. J Epidemiol Community Health. 1998;52(6):377–84.

Retrieved December 4, 2013, from: http://jech.bmj.com/content/52/6/377.long.

21. Viera AJ, Garrett JM. Understanding interobserver agreement: the kappa statistic. Fam Med. 2005;37(5):360–3.
22. DeMaio M, Onate J, Swain D, Morrison S, Ringleb S, Naiak D. Physical performance decrements in military personnel wearing personal protective equipment (PPE). In: Human performance enhancement for NATO military operations (science, technology and ethics) (RTO-MP-HFM-181). 2009. p. P2-1–6. Retrieved December 4, 2013, from: https://www.cso.nato.int/pubs/rdp.asp?RDP=RTO-MP-HFM-181.
23. Harper WH, Knapik JJ, de Pontbriand R. Equipment compatibility and performance of men and women during heavy load carriage. Proceedings of the Human Factors and Ergonomics Society Annual Meeting. 1997;41(1):604–8.
24. Treloar AK, Billing DC. Effect of load carriage on performance of an explosive, anaerobic military task. Mil Med. 2011; 176(9):1027–31.
25. Knapik JJ, Ang P, Meiselman H, Johnson W, Kirk J, Bensel C, et al. Soldier performance and strenuous road marching: influence of load mass and load distribution. Mil Med. 1997;162(1):62–7.
26. Knapik J, Staab J, Bahrke M, Reynolds K, Vogel J, O'Connor J. Soldier performance and mood states following a strenuous road march. Mil Med. 1991;156(4):197–200.
27. Hasselquist L, Bensel CK, Corner B, Gregorczyk KN, Schiffman JM. Understanding the physiological, biomechanical, and performance effects of body armor use. In: Proceedings of the Army Science Conference (26th). 2008. Retrieved December 4, 2013, from: http://www.dtic.mil/dtic/tr/fulltext/u2/a504354.pdf.
28. Johnson RF, Knapik JJ, Merullo DJ. Symptoms during load carrying: effects of mass and load distribution during a 20-km road march. Percept Mot Skills. 1995;81(1): 331–8.
29. Knapik J, Johnson R, Ang P, Meiselman H, Bensel C, Johnson W, et al. Road march performance of special operations soldiers carrying various loads and load distributions (Technical report X-93). Natick, MA, USA: U.S. Army Research Institute of Environmental Medicine; 1993. Retrieved December 4, 2013, from: http://www.dtic.mil/dtic/tr/fulltext/u2/a269198.pdf.
30. Park K, Hur P, Rosengren KS, Horn GP, Hsiao-Wecksler ET. Effect of load carriage on gait due to firefighting air bottle configuration. Ergonomics. 2010;53(7): 882–91.
31. Pandorf CE, Harman EA, Frykman PN, Patton JF, Mello RP, Nindl BC. Correlates of load carriage and obstacle course performance among women. Work. 2002; 18(2):179–89.
32. Ricciardi R, Deuster PA, Talbot LA. Metabolic demands of body armor on physical performance in simulated conditions. Mil Med. 2008;173(9):817–24.
33. Mayville WC. A soldier's load. Infantry. 1987;77(1): 25–8. Retrieved December 4, 2013, from: http://www.benning.army.mil/infantry/magazine/issues/1987/JAN-FEB/pdfs/JAN-FEB1987.pdf.
34. Park K, Hur P, Rosengren KS, Horn GP, Hsiao-Wecksler ET. Changes in kinetic and kinematic gait parameters due to fire-fighting air bottle configuration. In: North American Congress on Biomechanics (NACOB). 2008. Abstract retrieved December 4, 2013, from: http://www.asbweb.org/conferences/2008/abstracts/579.pdf.