Load carriage

An integrated risk management approach

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ABSTRACT

Military load carriage (LC) gives rise to substantial risks to soldier health, tactical performance and mission success. The aim of this paper was to extract and synthesise the key findings of a series of LC research reports previously published by the authors. Five reviews and six studies were included, with key findings extracted and synthesised in tabulated and critical narrative form. The weight of a soldier's load is a source of risk for soldier injuries and tactical task performance. The resulting level of risk is influenced by risk modifiers (like speed of march, terrain grade and task type and duration) and risk controls (like administrative controls and physical conditioning). In the Australian context, these risk controls were limited, with soldiers carrying heavier loads than those mandated by doctrine and policy, and LC conditioning not meeting best practice. The diversity of LC contexts, combined with the influence of risk modifiers and risk controls, means that levels of risk associated with LC are not consistent and must be assessed on a case-by-case basis. Load weight and marching routes (terrains, gradients), distances, speed and duration are all potentially treatable sources of LC-related risk. Potential risk treatments include not only commanders directly addressing these specific sources of risk to the extent feasible, on a case-by-case basis, when planning or conducting LC tasks, but also improving administration controls (ie doctrine and policies) and personal protection (ie the physical conditioning of the soldier) as part of the hierarchy of controls. Practical application would involve commanders developing and implementing dedicated LC doctrine and policies and implementing and enforcing LC conditioning programs that meets best practice.

KEY WORDS

Load carriage, risk management, soldier, conditioning, military.

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Soldiers must carry military equipment and move, on foot, over various terrains for long and continuous periods. While the equipment carried is often crucial to mission success and survival, its weight is a source of risk to the soldier (2, 8, 11). The loads imparted by stores and equipment carried by the soldier have been found to cause injury to the musculoskeletal, nervous and integumentary systems of the human body (2, 8, 11). In addition these loads can impact on mobility, lethality and general duties performance during tactical operations (3, 9), thus increasing risks to the soldier of injury or death and affecting the safety and effectiveness of their team and mission (7). Of most concern, history suggests that these loads are increasing (2, 4). On this basis, load carriage (LC) is a notable source of risk to military soldiers and to their teams and missions.

'Risk' can be defined as the chance of something happening that will have an impact on objectives (14), with the key objective in this instance being the successful completion of an assigned mission involving LC, with a minimum of casualties and other adverse outcomes. With complex interactions of injury risks, tactical performance risks, and mission risks arising from LC, it is vital that a suitable framework to support identification, analysis and management of these risks and their interactions is routinely employed in operational decision-making and that such a framework provides a scaffold for rigorous and focused research that can inform this decision-making.

The Risk Management Framework (RMF) is a nationally and internationally recognised framework (13, 14) which allows the input, analysis, and evaluation of all relevant contextual and risk information, including that derived from research. It provides outputs which can

inform design of treatments for identified risks in a manner commensurate with the military approach to risk management. The RMF is essentially a five-step process with two parallel processes continually feeding into these steps (13, 14). The RMF and its constituent steps are depicted in Figure 1.

Using the RMF as a scaffold, the aim of this focused review was to draw together and synthesise key findings from a series of reviews and studies that were recently conducted by the authors to inform risk management in operational LC. These reviews and studies (4-9, 11, 12) investigated the context of contemporary military LC within the Australian Regular Army (ARA), risks arising from LC, and current and potential risk management strategies.

METHODS

Approach to the Problem

The current research involved critical synthesis of the findings of a series of LC reviews and studies (4-12) previously conducted and published by the authors to systematically address the steps of the RMF (Figure 1) for operational LC. The results of the reviews and studies were extracted and critically synthesised, using the RMF as a scaffold to organise the synthesis of key findings and make the findings accessible for commanders to use in each stage of the LC risk management process.

Subjects

Several of the included studies (5, 9, 12) used selected elements of data derived from a wide-ranging survey of selected, currently serving Australian Army personnel from operational

units, conducted in 2010 (9). Detailed respondent demographics as they apply to each study can be found in the parent documents (5, 9, 12). In the studies which used selected elements of the survey data, that data was in some cases augmented by other sources of information, to provide a means of triangulation through which the validity and reliability of survey responses could be assessed. These other sources of information included injury surveillance data (11), documentation of unit training programs (5) and army doctrines and policies (5).

Ethics approval for the program of research was granted by the Australian Defence Human Research Ethics Committee (Protocol 569-09), and the Behavioural and Social Sciences Research Ethics Committee of the University of Queensland (Project number 2009001820) and all subjects were informed of the benefits and risks of the investigation prior to providing informed consent to participate in the study.

Procedures

In the first stage of the critical synthesis of the study results, key design features and findings from each of the included studies were systematically extracted and tabulated (Table 1), using the RMF as a scaffold for tabulation. The key findings were then further synthesised, using a critical narrative approach that considered risk analyses, risk prioritisation, and evidence-based risk control strategies derived from the included studies. This latter phase of the synthesis of findings from included studies identified the key learnings provided when the study findings were considered as a whole, within the structure of a modified RMF (Figure 1).

INSERT FIGURE 1 HERE

The risk analysis technique for this program of research revolved around a risk-ranking matrix, designed to estimate the levels of severity of each identified risk through the use of consequence scales and likelihood scales. Risk prioritisation and determinations were made based on a risk tolerance threshold. Risk modifiers were drawn from the information provided in the preceding reviews and studies and were used to inform risk control measures in accordance with a hierarchy of controls (13).

Statistical Analyses

Details of the statistical approach taken for each of the studies can be found in their parent documents (5, 9, 11, 12). Across all studies, analyses were performed using SPSS v20.0 with alpha levels set at 0.05.

RESULTS

The data sources, results and key findings of the included reviews and studies are summarised in Table 1. In this Table, each included review and study is also allocated to the step of the RMF it serves, as the first stage in the synthesis of the key findings. The findings of the included reviews and studies are further synthesised in narrative form in the Discussion section, which follows.

INSERT TABLE 1 HERE

DISCUSSION

Table 1 constitutes a quick reference guide to available research evidence regarding the LC context, risks arising from LC and existing risk controls, to inform each step in risk management for LC. Within Step 1 of the RMF (Figure 1), included reviews and studies that contributed to establishing the context of LC events (Table 1) found that increasing loads increased the energy expenditure of the carrier for any given task and alter their movement biomechanics (5). For Australian soldiers, these loads were found to be increasing across time and varied among different trades and tasks (4, 12). The reported loads were also commensurate with those of other allied nations (4, 12). Step 2 in the framework identified both injuries and reductions in tactical task performance as key risks to the carrier. In addition, current risk controls, being physical conditioning and control of LC practices through doctrines and policies, appeared to be limited (Table 1)(5). When analysed and evaluated as part of steps 3 and 4 of the RMF (Figure 1), LC was considered to be a notable source of risk to the soldier through both physical injury and reduced tactical task performance. However, the use of risk modifiers (like speed of march, gradient and terrain type) had the potential to influence the level of risk associated with a given load (5). Likewise the risk controls of physical training and policy had the potential to more strongly influence the level of risk from LC. The level of risk that would be associated with any specific LC event was therefore not consistent – as context and other factors changed or were altered, risk level also changed. Nevertheless, one consistent theme that did emerge was the primary, negative impact of load weight on the load carrier, and it should be noted that despite developments in materials and technology, soldier loads are continuing to increase over time (4).

Given the negative impact of load weight, risk treatment options to further reduce these risks to a level of risk that is *'as low as reasonably possible'* are required. Risk treatment options to lower the level of risk in LC should continue to include steps to limit load weight. Additional

risk controls (13) should also be identified or developed as a means of avoiding or reducing the impact of the identified LC risks. These risk controls may address a variety of LC factors, from personnel to equipment and environment. With a variety of risk controls potentially available, the hierarchy of controls can be used to rank the risk control methods from most to least preferred. The hierarchy of controls employed in the international RMF (13) provides six levels of risk control, being elimination, substitution, isolation, engineering controls, administrative controls and personal protective devices/measures. While listed from most preferred to least preferred treatment options, where possible a combination of multiple treatment approaches is preferred (13).

With soldiers having been consistently required to carry loads over three millennia (4), a short term solution of eliminating the soldier's load is clearly not viable. Furthermore, research identifying increases in load over time suggest that even elimination of some elements that make up the soldier's load is not a viable long term solution at this stage. In terms of substituting the load, there is no known substitution for load weight, and thus substitution does not present a workable risk control in the current military LC context at this time. It should be noted that the replacement of heavier equipment with lighter alternatives is not considered 'substitution' of the risk source, as technological or engineering interventions form the basis of the control. These types of controls are further discussed below. For the load carrying soldier, isolating the load being carried from the soldier would require separation of soldiers from their key tools of trade – tools responsible for lethality, protection and sustainment. Therefore, the use of isolation as a risk control is likewise of limited value for controlling soldier LC weights. However, considering this further, if administrative controls are effective, there is potential in some LC contexts to remove a portion of the soldiers load to a vehicle or other LC assistive device.

When considering engineering controls, history would suggest that this is not a viable solution for controlling LC risks at the current time. Changes in the nature of warfare and technological equipment and weaponry have not reduced the solder's load over the last three millennia, but rather have continued to increase it (4). Nevertheless, some possible options in this regard are proposed later in this section. Administrative controls and personal protective devices/measures (in this case the level of physical conditioning of the soldier) appear to be the current *modus operandi* for LC risk treatment in the military. However, this program of research found that both of these measures were limited, with breaches in administrative controls evident in both the Australian soldier LC context and those of allied nations, and the physical conditioning of soldiers as a means of making the person more resistant to harm or degradation in tactical performance not meeting recognised best practice.

Considering the limitations surrounding the application of the *hierarchy of controls* to LC, three potentially viable risk treatments considered in this program of research were: (a) LC doctrine and policy implementation or revision; (b) improved LC physical conditioning; and (c) load weight reduction. While other potential risk treatments (like nutritional supplementation) may form the impetus for future research, the scope of the current program of research remained within the bounds of contemporary Australian Army practice, in order to ensure that the resulting risk treatment recommendations could be readily adopted by commanders.

Together, tailored doctrines and policies can provide a form of administrative control by reducing and controlling soldiers' exposure to risk by means of prescribing work procedures (14). However, the current program of research identified two flaws in current efforts to apply

this risk control, being limited guidance available to inform commanders of optimal LC practices, and the available LC guidance being vague and dispersed across several doctrines. Research evidence involving U.S. soldiers in Afghanistan reported similar difficulties with load weights breaching U.S. doctrine (15). On this basis, for doctrines and policies to be an effective risk control for LC, two elements need to be addressed. First, not only do detailed and relevant LC doctrine and unit LC policies be established, as has recently been the case in the Australian Army (1), but these doctrine and policies must be enforced. Second, consideration should be given to shifting the locus of control for LC event decision-making down the chain-of-command, to unit and sub-unit commanders who are at the impact point for these decisions, thus allowing operational flexibility which would still ensure practice complied with overarching guidance.

The use of LC conditioning to prepare soldiers for LC is not new (4) and has been found to be effective (2, 6). However, to be effective, conditioning protocols should match evidence based best practice. A dedicated LC training session should be conducted a minimum of once per fortnight, with loads and durations progressing up to those required in the field or on operations (6). In addition, the types of LC sessions should mimic those required in field and operational settings rather than constituting a single continuous march along a flat road (6). Units should ensure that their physical training programs are structured to meet these criteria and are a mandatory requirement for their personnel, if this risk treatment is to be effective.

The final potential risk control is that of load reduction. Soldier load weights can be reduced through two approaches, these being a permanent reduction in load weight and the temporary transfer of a portion of load weight to another LC system. A permanent reduction in load weight can be achieved through reductions in the need for soldiers to carry equipment or, more likely,

the reduction in load weight of a given item – provided the latter is not replaced with another load item, which appears to typically be the case. A temporary transfer of load can be achieved through the use of other systems capable of carrying load or the use of an augmented LC system to transfer load away from the structure of the soldier. Key mechanisms behind these approaches to load weight reduction include both technological advances (e.g. production of lighter body armour) and changes to logistic practices (e.g. the use of vehicles to carry soldier stores). On this basis, reduction of soldier load weight, while currently not a proven viable solution, could become a risk treatment with dedicated and continuing investment.

MILITARY APPLICATIONS

LC presents as a complex source of risk, with varying influencing factors. For the commander or member charged with physically preparing soldiers for a LC task, the nature of the LC event and risk modifiers (including speed of march, terrain, duration and load placement) need to be considered alongside the load weight. Where possible, administrative controls (policy and doctrines) should provide guidance on how much load should be carried as well as ways to manage and control the interface between the soldier and the nature of the LC context. Furthermore, a dedicated LC conditioning program needs to be developed along a LC conditioning continuum, with sufficient stimulus and including one dedicated LC session per week, with loads and durations progressing to meet task requirements and the event itself commensurate with the tasks required.

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FIGURE LEGENDS:

Figure 1: The original risk management framework and the framework modified for this research program (modified from Standards Australia Working Group (13, 14)).

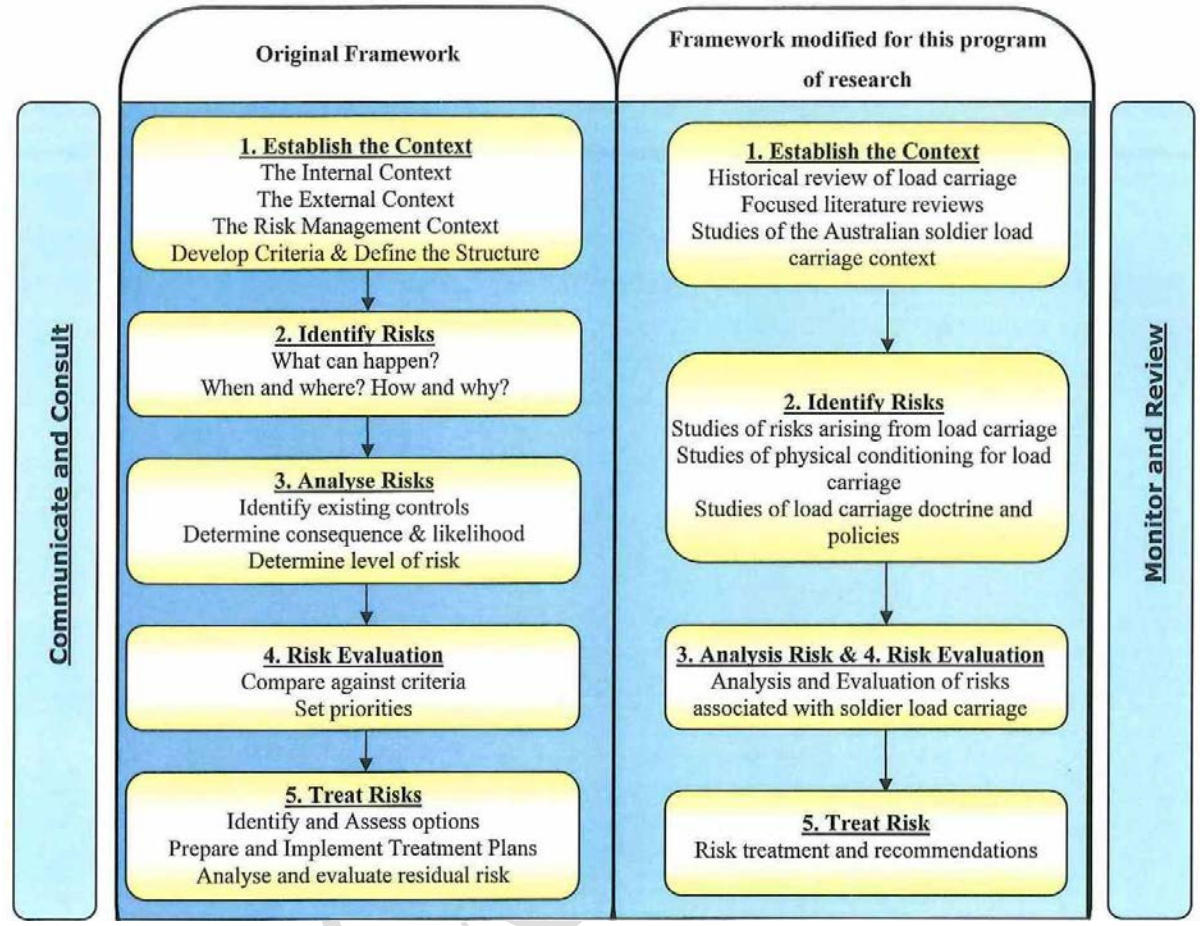

Table 1: An overview of review and study results across the program of research affiliated with their RMF step.

RMF Step	Review/ Study	Data Sources	Subjects	Key Results	Key Findings
Establishing the context	Historical review of LC (4)	Literature search; historical site field research.	N/A	• Data collected to saturation point and divided into distinct time periods • Loads carried by pre-musket soldiers (700 BC – 1651 AD): 27-32kg. • Loads carried by musketeers (1702 AD – 1865 AD): 23-34kg. • Loads carried through the world wars (1914 AD – 1945 AD): 27-28kg. • Loads carried through modern conflicts (1950 AD – present): 22-55kg.	• Changes in the context of warfare might not reduce the soldier's load or requirement to carry heavy loads over long distances. • Excessive loads can cause injury and lead to loss of life. • Soldiers will find a way to reduce excessive loads. • Absolute loads are increasing • Relative (to body weight) loads are similar between current conflicts and those of Roman Legionnaires
	Focused literature reviews of specific aspects of LC (6-8, 10)	Reports of prior research, sourced from database searches, hand-searches of reference lists, requests to key researchers.	N/A	• Total of 7,943 papers identified + 56 papers gathered from colleagues & journal article reference lists. • Removal of duplicates & not meeting inclusion criterion reduced total numbers to 317. • Exclusion criteria, reduced total numbers to 157 papers (145 original research papers and 12 military technical	• ↑ in load =↑ in energy expenditure • ↑ in incline =↑ in energy expenditure • ↑ in speed = ↑ in energy expenditure • Different terrain types influence energy expenditure

				reports) and 17 conference papers.	• LC known to cause injuries to skin, musculoskeletal system, nervous system. • Loads on hands and feet have higher energy cost than back and hips • Different load placement in pack = different energy cost • LC increases forward lean and spinal load • LC changes spatiotemporal gait parameters and ↑ ground reaction forces • LC can ↓ marksmanship and grenade throw performance • ↓ mobility with LC • Can ↓ attention-to-task
	Studies of the Australian Soldier LC context (12)	Army personnel self-report, via online survey.	• 338 respondents (♂= 93%: ♀= 7%). • 171 respondents reported carrying loads on combat operations (♂ = 96%: ♀ = 4%)	• Total mean load (2001-2010) = 47.7±21.0 kg • Mean load range by year = 40.7 to 50.9 kg • PO =28.4±10.0 kg; MO=56.7±15.3 kg • Significant differences between corps for MO load, F(5,260)=11.8, p=.001: Armoured corps 61.2±19.0 kg; Infantry corps 60.9±15.7 kg; Engineer corps 59.4±15.0 kg; Artillery corps 58.1±16.9 kg; with all these significantly	• Average absolute load carried by Australian soldiers is increasing • Loads commensurate with allied nations. • Loads carried during physical training & field training were lighter than operational loads • Different corps carried different loads and conducted different tasks with these loads • Female soldiers typically carried lighter absolute loads but similar relative (to body weight) loads when compared to male soldiers.

			• 50% of 171 had more than one deployment = 308 deployments in total	heavier than 'other' corps mean=42.4±15.6 kg. • No significant diffs between Signals corps, at 54.4±19.0 kg, and other corps • Different corps carried significantly different loads, (F(5,150)=3.31, p=.007) for a single task of patrolling with Infantry having heaviest (MO 52.8±17.1 kg) and Signals the lightest (MO 30.6±12.3 kg) • ♀ carried significantly lighter absolute loads (26.4±13.3 kg) than ♂ (39.0 kg±17.5 kg: t(99)=-2.02, p=.045). • No gender differences in load found when load was relative to body weight (BW; ♀ 43%±21% BW: ♂ 47%±21% BW; t(99)=-0.60, p=.55). • Loads were carried across various terrain types and grades	
Identify Risks	Studies of risks arising from LC for the	Army personnel self-report, via online survey; Defence Injury surveillance database (data from 1	Self-Reported Injuries & performance • 116 (34%) reported sustaining at	Self-reported LC injuries: • 48% (n=56) suffered a LC injury during initial training (32% of these reinjured within 12 months; 52% of these reinjured at some time during their career).	• LC injuries are a frequent occurrence in training and operational contexts • Lower limbs most common site of LC injuries – commensurate with studies of injuries that occur in a single LC task

	Soldier (5, 9, 11)	Jan 2009 to 31 Dec 2010)	least one LC injury during their military career (♀=8%: ♂= 92%) • 203-217 responses on operational task performance + 107 responses under additional 'other tasks' Reported Injuries • 1,954 injury records extracted with 404 LC injuries identified	• 61% of injuries to the lower limbs, 27% to the back, 9% to the upper limbs. • 39% of injuries to bones and joints, 36% to muscles and tendons, 15% to ligaments • 28% injuries from Field training exercises, 14% from physical training 38% from endurance marching (conducted as part of field training or physical training) Reported LC Injuries (injury surveillance system): • minor injuries = 91%, incapacity = 1%, serious personal injury = 7%* • 56% to the lower limbs, 26% to the back, 13% to the upper limbs. • 62% = Marching, 13% = patrolling, combat training = 12%, Physical Training = 6%. • No difference between self-reported and reported sites of injuries, $\chi^2(6)=3.90$, $p=0.31$ • Heat related injuries = 7 % of all injuries and 31 % of serious personal injuries.	• Once injured from LC, more likely to be reinjured. • Heat related injuries a significant issue but not found in other studies. • Soldier self-perceptions of task performance following LC mirror those of objective research on tactical performance following LC, with mobility most negatively impacted.

				Self-reported impacts of LC on tactical performance: • Mobility impact rated -1.24 on a -2 to +2 scale of impact • Grenade throw impact rated -.99, Administrative impact -.96, Marksmanship impact -.95 • Attention-to-task impact -.80 & impact on other tasks (including driving) rated -.86	
	Studies of soldier Physical Training for LC (5)	Army personnel self-report, via online survey; Army Unit physical training documentation/ programs.	• 338 respondents (♂= 93%: ♀= 7%) • 6 Training institution program • 8 Operational unit programs	Self-Reported Physical Training • 41% of respondents completed LC training in last 14 days • 19% no LC activity in 91+ days • PO *m*=15.5±10.8 kg (± 10% reported wearing body armour) • MO *m*=36.3 kg±12.0 kg (± 5% wore body armour) • LC: 42% = on roads, 39%= dirt or grass (39%) • 79% LC < 2 hours duration • 60% LC= endurance marching as activity (88% in Marching Order) Training Institutions programs • Two basic employment training institutions had a	• Both self-reported and unit LC physical training programs did not meet recognised best practice. • Frequency was often below recommended 1 session per 14 days • Intensity was lighter than and durations shorter than field or operational requirements • In several instances no specific LC was conducted. • Current physical training may not be preparing soldiers for field and operational requirements and may leave them at greater risk of injury and reduced task performance.

				dedicated LC PT program for LC conditioning, • 1 in 4 reviewed corps training institutions built on this initial LC conditioning and extended it. Operational Unit programs • 50% included LC oriented PT (75% of these units were training for their annual Combat Fitness Assessment) • Ranged in length from 6 weeks to 15 weeks with frequency 2-5 times per week. • Longest sessions ranged up to 120 minutes	
	Studies of LC policies, doctrine and their influence in soldier LC (5)	Army personnel self-report, via online survey; Army Unit policies; Army Doctrine documents.	• 338 survey respondents (♂= 93%: ♀= 7%) • 22 Doctrine documents • 6 of 8 Units provided unit policies	Self-Reported • 54% considered their loads to be heavier than those designated in unit orders, 28% considered their loads matched unit orders. • Loads for mounted patrols (71%) and foot patrols (60%) most frequently reported to be heavier than loads specified in unit policies. • Loads for static patrols most frequently (47%) reported as matching unit policies.	• Soldiers often reported that the loads they carried were heavier than unit policies • Breach of policies also reported amongst US soldiers in Afghanistan in prior research • Doctrinal information on LC was dispersed across several documents and non-specific • Unit policies did not provide specific LC guidance apart from generic equipment lists. • Reasons for differences between mandated loads and carried loads may include doctrine and

				• Loads for administrative tasks most frequently (46%) rated as lighter than loads specified in unit policies. Doctrines • 8 Doctrines reported on LC or porterage activities (infantry corps-specific doctrine = 5; all-corps publications =3) Unit polices • Unit policies were limited to providing detailed unit equipment load lists • 2 unit policies mentioned auditing of soldier loads to be carried	unit policies not being adhered to, and doctrinal/ policy guidance not meeting requirements of commanders and individuals on military operations

PO = Patrol Order (web belt with various pouches). MO = Marching Order (Patrol Order with a large backpack). BW= Body Weight.

* Does not equal 100% due to rounding.