NORTH ATLANTIC TREATY ORGANIZATION

SCIENCE AND TECHNOLOGY ORGANIZATION

AC/323(HFM-238)TP/950

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STO TECHNICAL REPORT **TR-HFM-238**

Reducing the Burden on the Dismounted Soldier

(Réduction de la charge des soldats à pied)

Final Report of RTG HFM-238.

Published March 2021

Distribution and Availability on Back Cover



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The NATO Science and Technology Organization

Science & Technology (S&T) in the NATO context is defined as the selective and rigorous generation and application of state-of-the-art, validated knowledge for defence and security purposes. S&T activities embrace scientific research, technology development, transition, application and field-testing, experimentation and a range of related scientific activities that include systems engineering, operational research and analysis, synthesis, integration and validation of knowledge derived through the scientific method.

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The total spectrum of this collaborative effort is addressed by six Technical Panels who manage a wide range of scientific research activities, a Group specialising in modelling and simulation, plus a Committee dedicated to supporting the information management needs of the organization.

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- HFM Human Factors and Medicine Panel
- IST Information Systems Technology Panel
- NMSG NATO Modelling and Simulation Group
- SAS System Analysis and Studies Panel
- SCI Systems Concepts and Integration Panel
- SET Sensors and Electronics Technology Panel

These Panels and Group are the power-house of the collaborative model and are made up of national representatives as well as recognised world-class scientists, engineers and information specialists. In addition to providing critical technical oversight, they also provide a communication link to military users and other NATO bodies.

The scientific and technological work is carried out by Technical Teams, created under one or more of these eight bodies, for specific research activities which have a defined duration. These research activities can take a variety of forms, including Task Groups, Workshops, Symposia, Specialists' Meetings, Lecture Series and Technical Courses.

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Published March 2021

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ISBN 978-92-837-2274-8

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In Memory of Aernout Oudenhuijzen



1966 – 2021

Aernout was a brilliant gentleman. Our RTG honoured his cheerfulness, honesty, openness, cordiality, kindness, humour, professional expertise and experience. The ‘Big Dutchman’ was the life and soul of our RTG and will be hugely missed.

Reducing the Burden on the Dismounted Soldier

(STO-TR-HFM-238)

Executive Summary

Research Task Group (RTG) HFM-238 "Reducing the Burden on the Dismounted Soldier" was set up to establish a coherent and coordinated approach to the problem of soldier physical burden caused by load carriage. This report summarises the group's work: it was prepared for the scientific community to facilitate exploitation of research and to identify knowledge gaps.

The loads carried by the soldiers of participating nations were defined in a table-top exercise, to understand the severity of the problem and determine if differences between loads carried by each nation might help to identify mitigating strategies. For every nation, soldier loads were well beyond long-standing recommended fighting or marching load limits, highlighting a disconnect between doctrine and decisions made on the ground. Average loads ranged from 49 kg to 67 kg depending on the nation and operational scenario. Evidence demonstrated the loads carried were not changed despite differences in threat, environmental conditions and mission characteristics. For example, some nations maintained the same level of personal protection despite a change in threat level. A number of possible mitigations were recommended by the group, including further education, training, reward, technologies and further research.

Strength, cardiovascular fitness and body composition (specifically lean body mass) are significantly associated with load carriage performance. These areas also offer the greatest potential for modification. A compromise between maximal strength/power and endurance capacity is required and is vital for optimizing the performance of soldiers during both short and long-term load carriage tasks. Evidence in the literature is not always equivocal about the ideal soldier characteristics. This is mostly because of an approach only focused on load carriage during marching, and less on high intensity tasks or subsequent task performance following long duration loaded marching.

While the impact of increased load mass is well researched, the influence of bulk and stiffness both require further investigation. It was concluded that the loads carried by dismounted soldiers negatively affect their ability to move, which on the battlefield, may result in increased vulnerability to enemy action and increased susceptibility to injury.

A technology watch explored current "skin-out" technological solutions that could be used to reduce physical burden effects on dismounted soldiers. Four general areas of technology were identified: cooling systems, load mitigation systems, training devices, and load planning tools. The utility of such technologies must be appropriately and independently assessed before they are introduced into service. Due to the rapid rate at which these systems are being developed and matured, it is critical that government researchers work together to evaluate the performance of existing and emerging systems. In doing so, the efficacy and rate at which these technologies are provided to soldiers will be accelerated.

Well intended burden reduction interventions continue to be implemented in isolation (e.g., at a tactical level) across and within many militaries. As such, they lack the built-in mutual dependencies that are critical to achieving systematic and sustainable change. The RTG developed a framework for burden reduction. This used a systems approach, across all levels of influence, throughout the soldier lifecycle and within the DOTMLPFIP framework: the aim was to achieve a compound positive affect on reducing soldier burden. Carrying load has an impact on physical and cognitive aspects of performance. Thus, the RTG recommended that future work also consider the threat of carrying heavy loads on soldier cognition.

Réduction de la charge des soldats à pied

(STO-TR-HFM-238)

Synthèse

Le groupe de recherche (RTG) HFM-238 « Réduction de la charge des soldats à pied » a été créé pour établir une approche cohérente et coordonnée du problème de la charge physique dû au port de matériel par les soldats à pied. Le présent rapport résume les travaux du groupe. Il a été préparé pour la communauté scientifique, de manière à faciliter l'exploitation des recherches et à identifier les lacunes.

Les charges portées par les soldats des pays participants ont été définies lors d'un exercice sur table, afin de comprendre la gravité du problème et déterminer si des différences entre pays pourraient aider à identifier des stratégies d'atténuation. Dans chaque pays, la charge des soldats dépassait de loin les limites recommandées de longue date pour le combat ou la marche, soulignant une déconnexion entre la doctrine et les décisions de terrain. Les charges moyennes allaient de 49 kg à 67 kg, en fonction du pays et du scénario opérationnel. Les éléments collectés indiquaient que les charges portées n'étaient pas modifiées, en dépit des différences de menaces, de conditions environnementales et de caractéristiques des missions. Par exemple, certains pays maintenaient un niveau de protection personnelle identique, malgré le changement de niveau de la menace. Le groupe a recommandé un certain nombre d'atténuations possibles, notamment un renforcement de l'éducation, de la formation, de la rémunération, des technologies et de la recherche.

La force, la santé cardio-vasculaire et la composition corporelle (en particulier une masse corporelle maigre) sont associées de manière importante à la performance en matière de port de charges. Ces domaines sont également ceux qui offrent le plus grand potentiel de modification. Un compromis entre force/puissance maximale et capacité d'endurance est nécessaire et vital pour optimiser les performances des soldats pendant les tâches de port de charge à court et long terme. Les éléments de la littérature ne sont pas toujours équivoques quant aux caractéristiques idéales des soldats. Cela provient principalement d'une approche concentrée sur le port de charge pendant la marche et s'intéressant moins aux tâches de forte intensité ou à la réalisation des tâches qui suivent une marche de longue durée avec une charge.

Alors que l'effet de l'augmentation du poids de la charge a été bien étudié, l'influence du volume et de la rigidité nécessite d'autres recherches. Il a été conclu que les charges portées par les soldats à pied nuisaient à leur mobilité, ce qui pouvait, sur le champ de bataille, accroître leur vulnérabilité aux actions de l'ennemi et aux blessures.

Une revue technologique a examiné les solutions technologiques actuelles de « superposition de couches » pouvant être utilisées pour réduire les effets de la charge physique sur les soldats à pied. Quatre domaines généraux de technologie ont été identifiés : les systèmes de refroidissement, les systèmes d'atténuation de la charge, les appareils d'entraînement et les outils de planification de la charge. L'utilité de ces technologies doit être évaluée de manière appropriée et indépendante avant la mise en service de ces dernières. En raison du rythme rapide auquel ces systèmes sont mis au point et évoluent, il est essentiel que les chercheurs du secteur public travaillent ensemble à l'évaluation des performances des systèmes existants et émergents. L'efficacité et la vitesse à laquelle ces technologies sont fournies aux soldats en seront ainsi renforcées.

Beaucoup d'armées continuent de mettre en œuvre des interventions bien conçues de réduction de la charge, mais de manière isolée (par exemple, au niveau tactique). Ce faisant, elles ne tiennent pas compte des liens inhérents de dépendance mutuelle, cruciaux pour parvenir à un changement systématique et durable.

Le RTG a élaboré un cadre de réduction de la charge, et ce, dans une démarche de système, à tous les niveaux d'influence, tout au long du cycle de vie du soldat et au sein du cadre DOTMLPFIP. Le but était d'obtenir un effet composé positif sur la réduction de la charge des soldats. Le port de charge a des conséquences sur les aspects physiques et cognitifs de la performance. Par conséquent, le RTG recommande que les futurs travaux considèrent également la menace que représente le port de lourdes charges pour la cognition des soldats.



Chapter 1 – INTRODUCTION

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1.1 STATEMENT OF THE PROBLEM

Throughout history, the dismounted soldier has had to carry significant loads. Marshall [1] noted that the infantryman is "a beast of burden" but that his primary function on operations does not actually begin in earnest until that burden is delivered to the appointed place on the battlefield. Soldiers are often required to march great distances with significant loads, over very demanding terrain, often under very challenging environmental conditions. On arrival at the enemy's location, whilst they can doff their packs and much of their sustainment load, they must be fit to fight wearing assault or fighting loads that are still very heavy.

Dismounted soldier burden may be defined as "*the cumulative effect of internal and external stressors on the dismounted soldier that are oppressive, difficult to bear and may elicit a reduction in the performance of military tasks*[1]". There are a number of factors which have contributed to the increase in soldier burden. First of all, wearing Combat Protective Equipment (CPE) has become an essential part of the soldier system. CPE can include specialist clothing, hand wear, footwear, ballistic protective helmet, eyewear, and body armour (predominantly torso protection with add-on protection that may include shoulder, nape, neck and/or groin protection) and hearing protection. Whilst CPE offers important protection from adversaries and the environment, it also contributes to soldier burden through increases in soldier ensemble mass, stiffness and bulk, increased body coverage by impermeable protective materials, as well as some degree of sensory isolation.

In addition to CPE, soldiers are also required to carry and operate specialist equipment, such as weapon and sighting systems, radios, night vision goggles, other sensors, and electronic countermeasures, to name a few. Specialist equipment enhances performance and supports soldiers in achieving their mission objectives, but the introduction of these items has led to a "Christmas Tree" effect where additional items of kit are continually added to the soldier incrementally, perhaps sub-optimally integrated, and collectively increase soldier burden.

As suggested in the literature [2], the nature of counter-insurgency and adaptive dispersed operations can make re-supply difficult, particularly in immature theatres of operation. As a result, sustainment loads are on the rise. Soldiers are reportedly [2] now carrying two to three times the doctrinal loads of ammunition, to ensure they have sufficient ammunition for every possible eventually, possibly due to a lack of confidence in the re-supply system. The situation is exacerbated by the fluid requirement to maintain hydration during operations in hot environments and the range of batteries required to sustain power throughout the mission for the powered devices now carried [2]. Modern militaries maximise the use of mechanised transport, however, terrain and operational conditions have not eliminated the need for dismounted soldiers to transport heavy loads great distances, and the loads carried by NATO soldiers on current operations are believed to be at record highs.

Soldier loads reportedly now greatly exceed established recommended maximum loads (30% of body mass for fighting / assault loads and 45% of body weight for approach march loads respectively based on average soldier body mass) (for a review see Refs. [2], [3]). However, even if these limits are adhered to, soldiers

[1] This definition of dismounted soldier burden in this report was provided by the subject matter experts on HFM-238.

of below average body mass would be considerably overloaded. As others have argued [2], while clothing and CPE is sized to soldiers and is therefore lighter in weight for smaller soldiers, combat supplies such as weapons, ammunition and batteries, among the heavier items carried, weigh the same regardless of the capacity of the soldier carrying them. Anecdotal evidence indicates that, on occasion for some roles and in several NATO nations at least, current combat loads may be approaching the soldier's own body mass. This is further exacerbated as soldiers rarely train with loads representative of those carried on operations [2] perhaps due to a number of factors including: unavailability of latest operational gear, concern over musculoskeletal injury risk by commanders or medical staff, or desire to make training less onerous. As such, the first exposure of soldiers to these extreme loads will often be in an operational theatre when additional physiological stressors will also be present (i.e., challenging climatic environment, enemy threat, psycho-social, energy deficit) [2]. It is therefore not surprising that reducing the burden on the dismounted soldier remains a priority for NATO nations.

1.2 THE CONSEQUENCE OF SOLDIER OVERBURDEN

There is an extensive body of research to understand the contribution of numerous factors on soldier well-being and performance including: human state; activity, equipment, and environmental stressors. (Figure 1-1) [4].

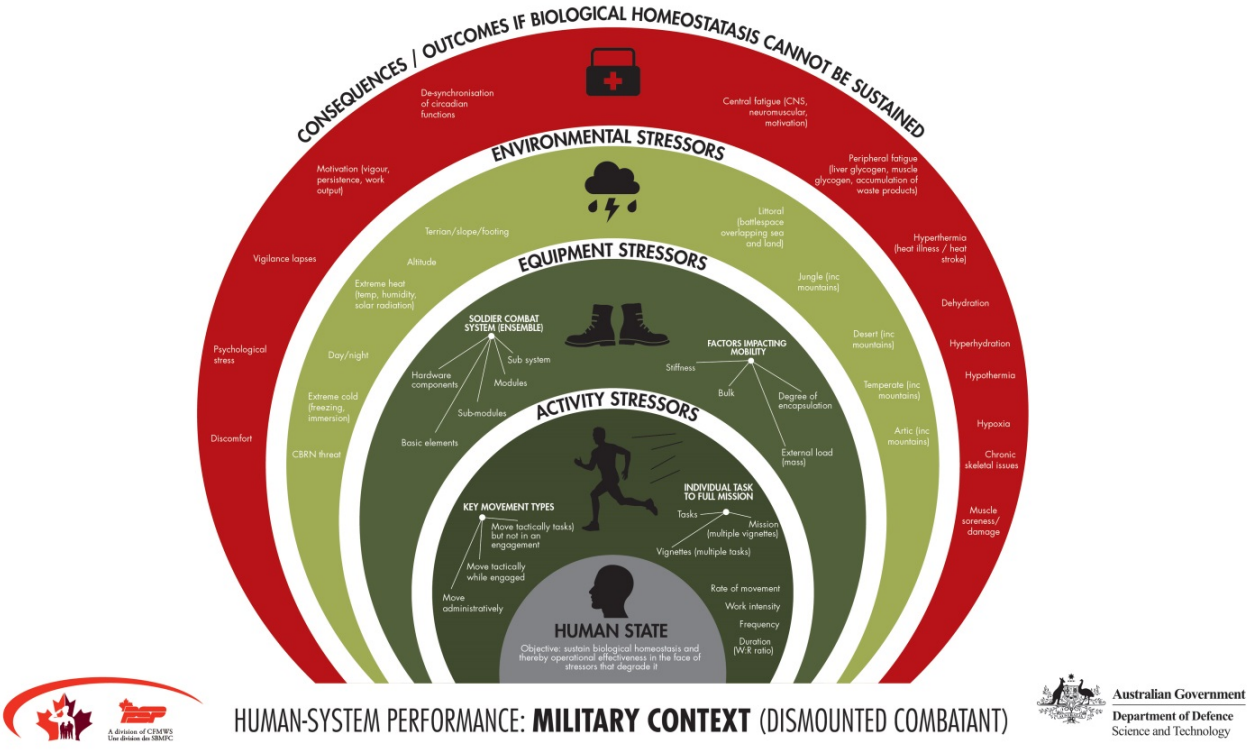


Figure 1-1: Stressors Which Contribute to Soldier Burden. Modified with permission from Billing 2013 [4].

The consequences of soldier load carriage and overburden have been well-reported and can be broadly categorised in terms of the effects that these have on soldier physiology, biomechanics, injury potential, and task performance (physical and/or perceptual and cognitive). Limited published work has also related these consequences to operationally-relevant outcomes such and soldier vulnerability and effectiveness. The following consequences of soldier overload are adapted from a recent summary review [2].

1.2.1 Physiological Effects

The literature is replete with evidence [2] of increased physiological strain with increasing soldier load mass (for summaries see Refs. [3], [5], [6], [7]. As carried mass increases, so too does the metabolic or energy cost to complete a task, as measured by oxygen consumption [8] – [21]. Other indicators of physiological strain that increase significantly with load mass include: heart rate [12], [14], [20], [22], [23], [24], [25], [26], [27], minute ventilation [8], [9], [12], [16], [25], [28], muscle activity [14], [22], [29], [30], [31], and blood lactate levels [27]. Muscle strength and endurance reduce with increasing load after extended marching or running [32], [33], [34] and carrying load on the torso will alter breathing mechanics, causing a reduction in pulmonary function that is characteristic of a restrictive ventilatory impairment[2] [9], [35], [36], [37], [38], [39], [40], [41], [42], [43].

An increase in physiological strain can lead to more rapid onset of fatigue, degradation of both physical and cognitive task performance [8], [10], [44], [45], [46], and increased risk of musculoskeletal injury, partially due to increased risk of slips and falls when fatigued [2]. There may also be increased risk of exertional illness and heat casualties, if soldiers are carrying loads under challenging conditions involving high heat and humidity, altitude, steep, uneven or soft terrain, or when operating at a fast pace [18], [47], particularly if soldiers are wearing encapsulating CPE [6], [7], [16], [48], [49].

1.2.2 Biomechanical Effects

Load carriage literature identifies a significant impact on biomechanics with increasing soldier load mass [2], [3], [50]. As load mass increases, so do a number of kinetic[3] measures. Ground reaction force measures have been shown to significantly increase during the gait cycle, including: maximum braking force[4] [21], [51]; maximal toe-off force[5]; [29], [52], [53] maximal heel strike force[6] [29], [53], [54]. Additionally, forces and moments acting on the ankle, knee or hip joints have been shown to significantly increase with increasing load mass [20], [21], [29], [55], [56], though not unequivocally at every joint across all studies [2]. A number of kinematic[7] measures are also affected by load mass. The most pronounced and consistent impact of load mass on joint angles occurs with trunk or hip angle; as backpack loads increase, hip flexion or trunk forward lean increase significantly [22], [26], [29], [50], [57], [58], [59], a strategy adopted by backpackers and soldiers to move the load over their body centre of mass and base of support. This postural change is often accompanied

[2] A restrictive ventilatory impairment is one where forced vital capacity (FVC) and forced expiratory volume in one second (FEV_1) are reduced, but the ratio of these values is normal or increased.

[3] Kinetics concerns the study of forces and torques that cause motion in a body. Typical load carriage kinetic measures include peak Ground Reaction Forces (GRF's), forces and moments acting on the joints.

[4] Maximum braking force is the maximum horizontal force generated when the foot contacts the ground at the beginning of the gait cycle.

[5] Maximal toe-off force is the vertical force generated when the toe of the foot pushes off from the ground.

[6] Maximal heel strike force is the vertical force generated when the heel of the foot makes contact with the ground.

[7] Kinematics concern the study of motion itself irrespective of the forces that caused it, and typical measures in studies on human load carriage include: torso lean, head position, peak flexion, or extension angles of joints.

by a more forward head position [57]. Increasing load weight of carried loads also has significant effects on the spatiotemporal aspects of gait, decreasing stride length [13], [57], [59], [60] and increasing stride frequency [13], [29], [59] and stride width variability [13], [61] references as cited by Bossi et al. [2]. Load mass also significantly increases double support time[8] [13], [21], [29], [59], [60]. These changes in gait may be attributed to a desire to maintain speed of movement while maintaining stability [59], [62], [63]. Any load-related changes to normal gait biomechanics may be important as they can lead to increased discomfort, blisters, potential for musculoskeletal injury (muscle strain, joint problems) [50], [57] as well as the longer-term risk of osteoarthritis [64], [65], [66], [67].

1.2.3 Cognitive Effects

Soldiering tasks require both physical and cognitive resources. Understanding the effect of load carriage on the physical aspects of soldier performance has been the primary focus of research over the years, whereas the effect of load carriage on cognition has received less attention. Military tasks that use cognitive resources are numerous; examples include maintaining vigilance, processing verbal communications, responding to threats and making go/no go decisions [68].

There is a complex relationship between exercise (irrespective of load) and cognition. Several reviews of the effects of acute bouts of exercise on cognitive task performance [68], [69], [70], [71], [72] reveal both positive and negative effects of exercise on cognition dependent on type of exercise, exercise intensity and duration, participant fitness, type of cognitive task and when that task is administered (during or after the exercise or delayed post-exercise).

Similarly, mixed results have been reported in studies that specifically explored the impact of load mass on soldier cognitive task performance. Some researchers found no impact on cognitive performance with strenuous load carriage of up to 61 kg across 20 km [73]. Others have found significant reductions in cognitive task performance during much lower load carriage demands [8], [10], [74]. Reviewed studies have shown improvements in some cognitive measures and decrements in others [75], [76], [77], [78].

1.2.4 Impact on Physical Task Performance

As reported in recent reviews [2], [3], [79], [80], [81], the scientific literature provides clear evidence of impairments to military-relevant physical task performance with increasing load mass. Decrements have been demonstrated across many tasks [2] including maintaining static [82], [83] or dynamic postural stability [84], range of motion or functional reach [85], [86], [87], [88], strength tasks such as number of pull-ups or hang-time [83], jump height or peak limb power [89], [90], and ammunition box or sandbag lift/move or place [53], climbing [82], [87], [91], crawling [87], [92], grappling [83], and simulated casualty drag or rescue [93], [94]. Effects on lethality tasks are less clear. Grenade throw [13], [53], [95]; and marksmanship metrics [87], [92] have been studied; while fatigue effects are often significant (difference in marksmanship performance between pre- and post- mobility task), very few studies demonstrate significant effects due to load mass (or equipment design) independent of physical fatigue [95], [96]. As summarized by Bossi et al. [2]. significant performance decrements with increasing load have been demonstrated for mobility tasks such as marching [19], [73], [82], [95], distance (i.e., aerobic) running [89] as well as high intensity explosive sprints, dashes or agility runs [10], [53], [82], [87], [89], [97], [98]. Many studies use obstacle courses or combat mobility courses to measure performance across a range of these high intensity mobility tasks [10], [53], [86], [91], [92], [97], [99]. Even more recently, performance for more tactically-relevant movements such as bounding rushes, manoeuvre under

[8] Double support time is the amount of time that both feet are in contact with the ground during the gait cycle.

fire or break contact drills has been shown to be significantly affected by load mass [79], [81], [90], [96], [98] and may effect soldier effectiveness including vulnerability to enemy action and overall integrated survivability [2], [79], [81].

There is a significant body of research that reports the effects of carrying load on soldier physiology, biomechanics, cognition, and soldier combat-relevant performance. This work is being undertaken to understand the nature of the burden, to measure it and then reduce it whilst assuring delivery of battle-winning operational capability. However, there is a need to take a comprehensive and holistic approach so that NATO can learn from and build upon this work in a more concerted and co-ordinated way.

1.3 OBJECTIVES

The aim of NATO Human Factors and Medicine (HFM) Research Task Group (RTG) 238 "Reducing the Burden on the Dismounted Soldier" was to establish a more coherent and co-ordinated approach to address the problem of soldier burden. The outputs of this RTG were designed to be used by the scientific community to ensure that Human Science research in this area is appropriately exploited and knowledge gaps are identified and filled. The specific objectives of this RTG were to:

- Scope the requirement;
- Define the burden;
- Identify those factors known to influence the size and nature of the burden; and
- Identify strategies to mitigate the threats in order to maintain operational effectiveness.

1.4 SCOPE

Given the broad scope of direction given to the RTG and the expertise, experience, and interests of the individual team members, it was necessary to limit the scope of the groups work to physical burden. However, recommendations were put forward to NATO Science and Technology Organisation to establish additional working groups to address the challenges to soldier performance which fall outside of physical performance (e.g., cognitive workload). Four work packages were designed to address the objectives of HFM-238. Three scenarios were also developed in collaboration with the Land Capability Group on Dismounted Soldier Systems – Soldier Capability Assessment Group (LCG DSS SCAG) to frame the scope of each work package.

1.4.1 Work Package 1: Load Definition

Using scenarios defined by the LCG DSS SCAG the panel surveyed representative national subject matter experts in order to define the loads that each nation would carry during the respective scenarios. Analyses of the differences and similarities between nations were conducted to identify lessons and inform the remaining work packages.

1.4.2 Work Package 2: Literature Review on Soldier Load

A review of the literature was undertaken to confirm current knowledge, and knowledge gaps. A systematic review process was used to identify the possible areas that offer capability to increase soldier performance

or mitigate the impact of soldier burden on the completion of load carriage and combat related tasks. The research questions were:

- Which soldier physical characteristics affect load carriage performance?
- What load characteristics affect combat task performance?
- To what extent do environmental conditions affect load carriage and combat task performance?

1.4.3 Work Package 3: Technology Watch

This task identified existing technology available to mitigate soldier burden. This task presents various types of technologies and discusses:

- The advantages/disadvantages of each technology type.
- The current leading technologies for each type.

1.4.4 Work Package 4: Aide to Decision Making

Information gleaned from the previous work packages was integrated and exploited into a practical decision making aide using the DOT MPLF framework. This aide is focused on strategic level, i.e., military planners who consider 'risks' associated with certain campaign strategies and options for mitigating probability and effect of occurrence.

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Chapter 2 – OPERATIONAL SCENARIOS

Aernout J.K. Oudenhuijzen
TNO
NETHERLANDS

2.1 SCENARIO SUMMARY

To address the problem of soldier burden, it is essential to understand the population of interest, the requirements of the soldiering task, the equipment used/worn and the operating environment. Thus, in order to define the scope and provide focus for the work of HFM-RTG-238, three scenarios were developed by TNO (the Netherlands) in collaboration with the Land Capability Group Dismounted Soldier Systems (LCG DSS). The scenarios were designed with the infantry soldier in mind and differed in environmental circumstances, threat level, type of mission, duration, exercise intensity and time of day. A summary of the main characteristics of each of the scenarios is provided in Table 2-1. Detailed scenario descriptions are provided in Section 2.2 and examples of the Dutch vehicles used is provided in Section 2.3.

Table 2-1: The Three Scenarios and Their Characteristics. POP = Possibility of Precipitation; RH = Relative Humidity; PRT = Provincial Reconstruction Team; IED = Improvised Explosive Device.

Scenario	1	2	3
Environmental Conditions	Hot (39°C day, 10°C night), 20% POP, 55% RH, wind 10 – 30 km/hr)	Mild (15°C, 60% POP, 65% RH, wind 10 km/hr)	Moderate (24°C, 0% POP, 12% RH, wind 18 km/hr)
Threat	Unknown. No incidents to date	High threat level	Low threat level (though IEDs used in past)
Type of Mission	Patrol (Secure a PRT during a patrol)	Attack (Raid to destroy IED factory, capture and eliminate insurgents)	Short Range Patrol
Duration	24 – 36 hours	24+ hours (4 – 6 hours for execution phase)	4 hours
Exercise Intensity	Low	High (during attack)	Medium
Overnight?	Yes	Not specified	No

2.2 DETAILED SCENARIO DESCRIPTIONS

2.2.1 Scenario 1

2.2.1.1 Situation

General: The Battlegroup is executing stabilization and reconstruction activities in the assigned areas (Figure 2-1).

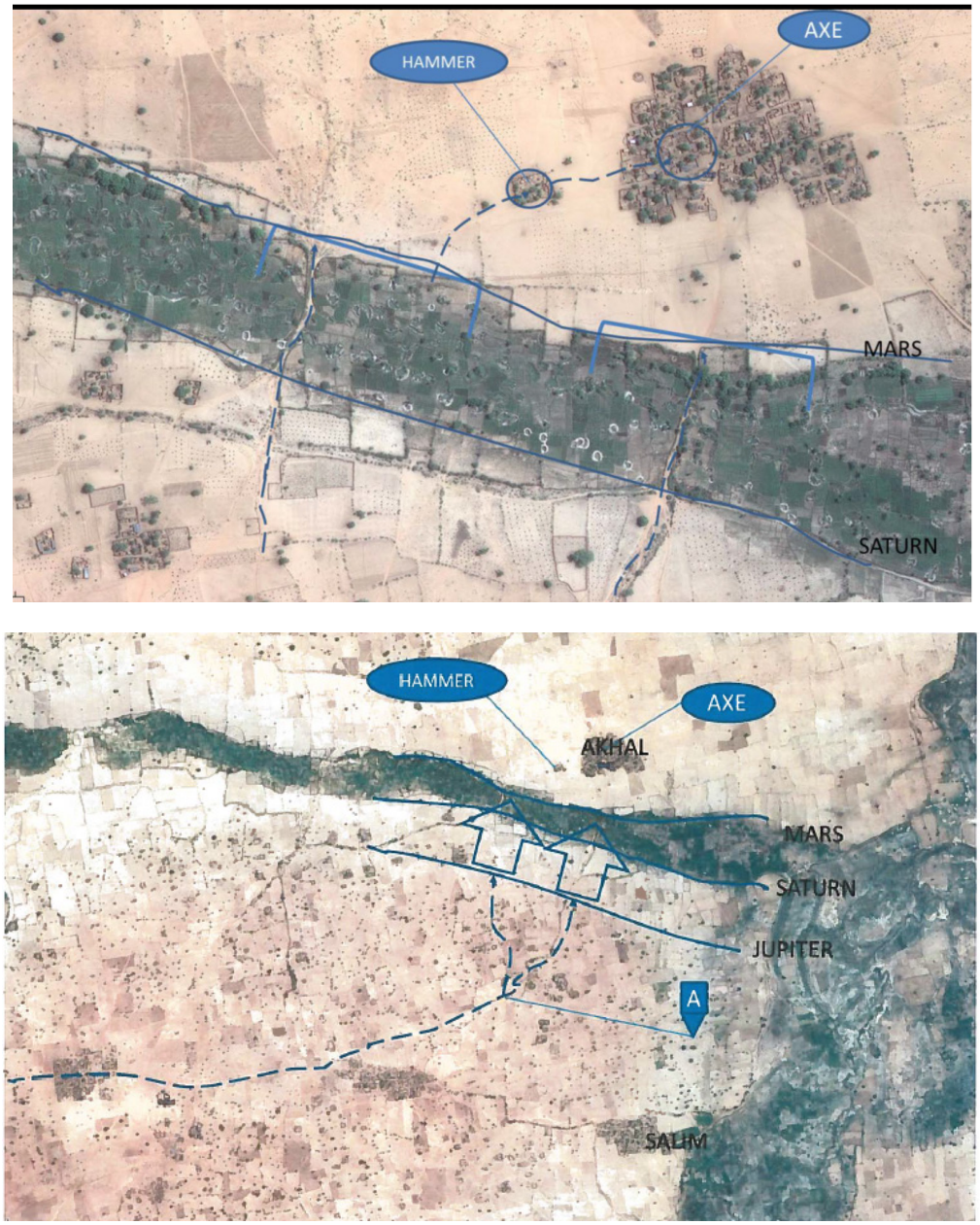


Figure 2-1: Scenario 1 Aerial Views. The overwatch is indicated by point A. Direction of travel is indicated by dashed lines.

The area is large, with complicated tribal distributions, resulting in a complex safety situation. The mission is to carry out an object raid in the area AKHAL to get rid of an Improvised Explosive Device (IED) factory and to capture or eliminate insurgents.

Environmental Conditions: Temperature: 15°C, possibility of precipitation 60%, relative humidity 65%, wind velocity 10 km/h.

Terrain: The road to the release point is paved and passable. After the release point, there is an increased risk to vehicles due to marshy terrain. Besides the two roads, the area between SATURN and MARS is not passable using vehicles. On the north side of MARS the terrain is open and flat with minimal options to cover.

Threat: There is a restless ambiance in the area. The insurgents are very aggressive. There is no local police or other local authorities in the area. The insurgents use small caliber weapons (AK-47, PKM, RPG-7) and use different types of IEDs (e.g., Victim Operated IED (VOIED) and Radio Controlled IED (RCIED)).

Battlegroup Organization: Note that the scenarios use Dutch vehicles as examples, further details of which are provided in Section 1.2.

- 1 infantry platoon comprised of three groups/sections. Vehicle support: 1 BUMA, 2 PATRIA, 2 MB G280.
- 1 engineering section/group. Vehicle support: 1 BUMA.
- Adjacent units: 1 infantry company using 1 BUMA vehicle, 1 fire support team using 1 Fennek, 2 patriaGWT (to transport of wounded soldiers) and 2 Fennek mr81mm vehicles.

2.2.1.2 Mission

Purpose: To carry out a raid on object AXE (Figure 2-1) in AKHAL.

Method: At sunrise, intruding the area of resistance by the second platoon, in order to attack and secure object AXE via HAMMER (Figure 2-1).

End State: Possessing AXE and captured or eliminated the insurgents.

2.2.1.3 Concept of Operations

Tasks:

- Move via vehicle from Base to release point
- Attack JUPITER
- Dismount through JUPITER to MARS
- Move into HAMMER
- Arrange fire base
- Move into AXE
- Secure AXE

2.2.1.4 Logistics

Personnel: In case of Wounded In Action (WIA), execute first aid. Medical support decides necessity of MEDEVAC or back to the overwatch (Marked A on Figure 2-1). Aerial MEDEVAC is available.

2.2.2 Scenario 2

2.2.2.1 Situation

General: The battle group is executing stabilization and reconstruction activities in the assigned areas. The area is large, with complex tribal distributions, resulting in a complex safety situation. The mission is to secure a Provincial Reconstruction Team (PRT) Mission Team (MT) during a patrol to TURA (Figure 2-2).

Environmental Conditions: Temperature: between 10°C at night and 39°C in the afternoon, possibility of precipitation 20%, relative humidity 55%, wind velocity 10 km/h, which can increase up to 30 km/h at night.

Terrain: The road to point B is paved and passable. After the junction, it is possible to approach with vehicles, but caution is required to minimize damage to vehicles and remain on the road surface. From the overwatch a broad river needs to be passed. It is not expected to be a deep river, but the edge is steep and not passable by vehicles. From the river onwards, the terrain is hilly.

Threat: There is a restless ambiance in the area. There are no local police or other local authorities in the area. It is highly likely that the local population does not trust their government. No incidents have occurred in this area. A reserved attitude in making contact is expected from the local population, as coalition forces have not had a permanent presence previously.

Battlegroup Organization: Note that the scenarios use Dutch vehicles as examples, further details of which are provided in Section 1.2.

- 1 infantry platoon consisting of 4 sections/groups. A group consists of 8 infantry, 1 BUMA, 2 PATRIA, 3 MB G280 vehicles.
- 1 Engineering group, 1 BUMA vehicle.
- 1PRT MT, 1 BUMA vehicle.
- 1 Forward Air Controller (FAC), 1 Fennek forward observer vehicle.
- 1 medical support group, 1 (ambulance) PATRIA vehicle.

2.2.2.2 Mission

Purpose: Ensure a safe and efficient transfer of the PRT MT movement and social patrol, in order to make a robust impression on the local population and create an opportunity for the PRT MT to make a solid village assessment.

Method: Secure PRT MTtha on patrol to TURA. Total distance will be between the 15 and 20 kilometers. Expected duration will be between 24 till 36 hours.

End State: The MT has a good impression of the location of TURA and the surrounding area. The unit has returned and can continue with the following mission without necessary extended recuperation time.

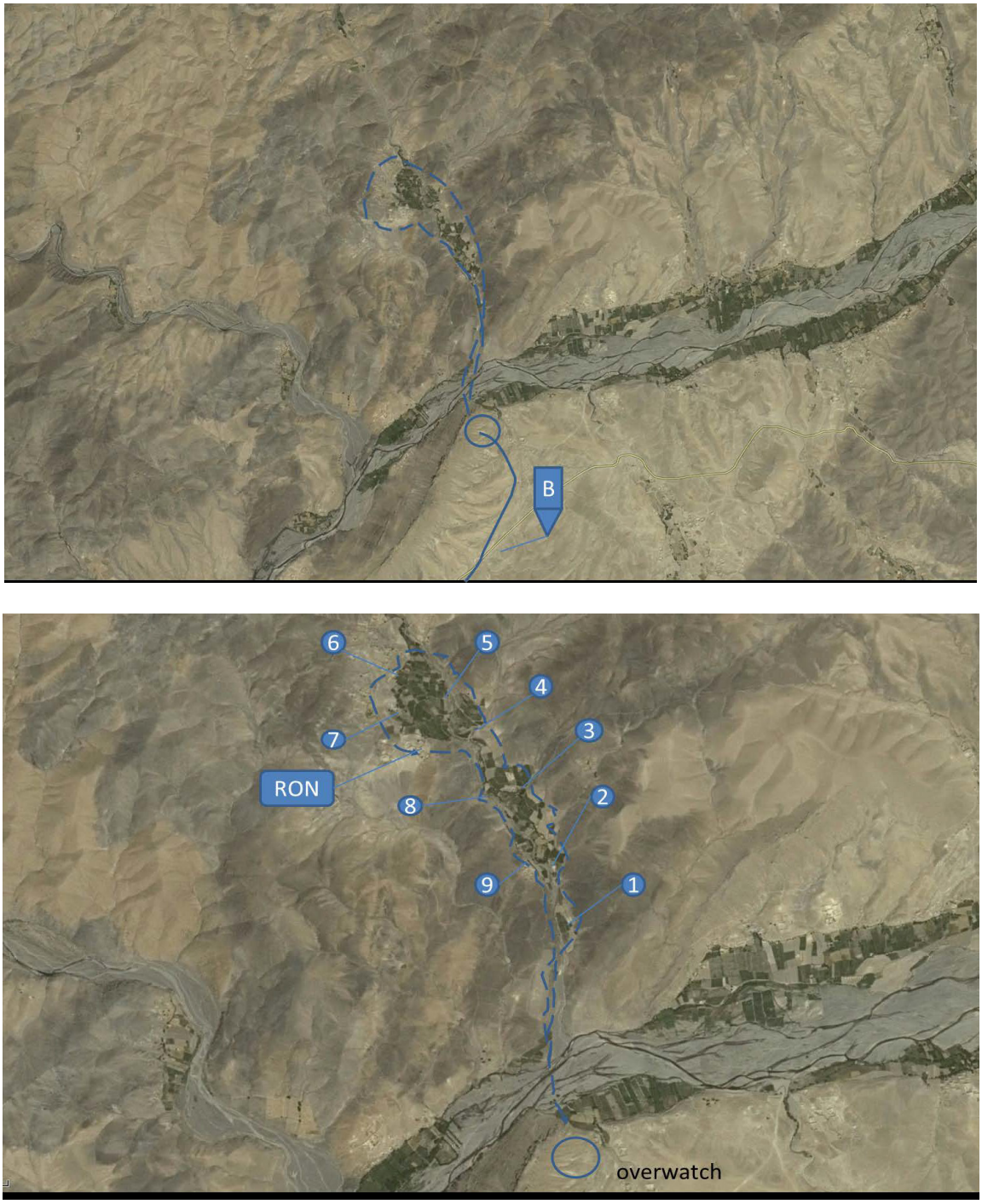


Figure 2-2: Scenario 2 Aerial Views. RON = Remain overnight. Direction of travel is indicated by dashed lines.

2.2.2.3 Concept of Operations

Tasks:

- Vehicle move from base to overwatch.
- Arrange overwatch.
- Start of patrol.
- Safe crossing of the riverbed.
- Execute village assessment.
- Remain Overnight (RON) at suitable location.
- Return by vehicle move.
- Move back to crossing.
- Safe crossing back to the overwatch.
- Hot debrief.
- Prepare for next mission.

2.2.2.4 Logistics

Personnel: In case of WIA, execute first aid. Medical support decides necessity of MEDEVAC. Aerial MEDEVAC is available.

2.2.3 Scenario 3

2.2.3.1 Situation

General: The Battlegroup is executing stabilization and reconstruction activities in the assigned areas. The area is large, with complex tribal distributions, resulting in a complex safety situation. The mission is to secure a PRT mission team during a patrol to WOTKAL (Figure 2-3).

Weather: Temperature: 24°C, rainfall chance 0%, relative humidity 12%, wind velocity 18 km/h.

Terrain: The road to point B is paved and passable. After the junction, it is possible to drive with vehicles, but caution is required to minimize damage to vehicles and remain on the road surface. From the overwatch, the village of WOTKAL is located in higher ground and a riverbed needs to be passed. The west edge is steep.

Threat: There is a quiet ambiance in the area. The presence of local police has created an environment where the citizens of the area are more trusting of their government. Incidents occur rarely, but are focused on local police, citizens working for the government or (S)IED attacks.

Battlegroup Organization: Note that the scenarios use Dutch vehicles as examples, further details of which are provided in Section 1.2.

- 1 infantry platoon, three sections/groups, 1 BUMA, 2 PATRIA, 3 MB G280 vehicles.
- 1 mechanic group (GNgp), 1 BUMA vehicle.
- 1 PRT MT, 1 BUMA vehicle.
- 1 Forward Air Controller (FAC), 1 Fennek vehicle. Medical support group, 1 PATRIA vehicle.

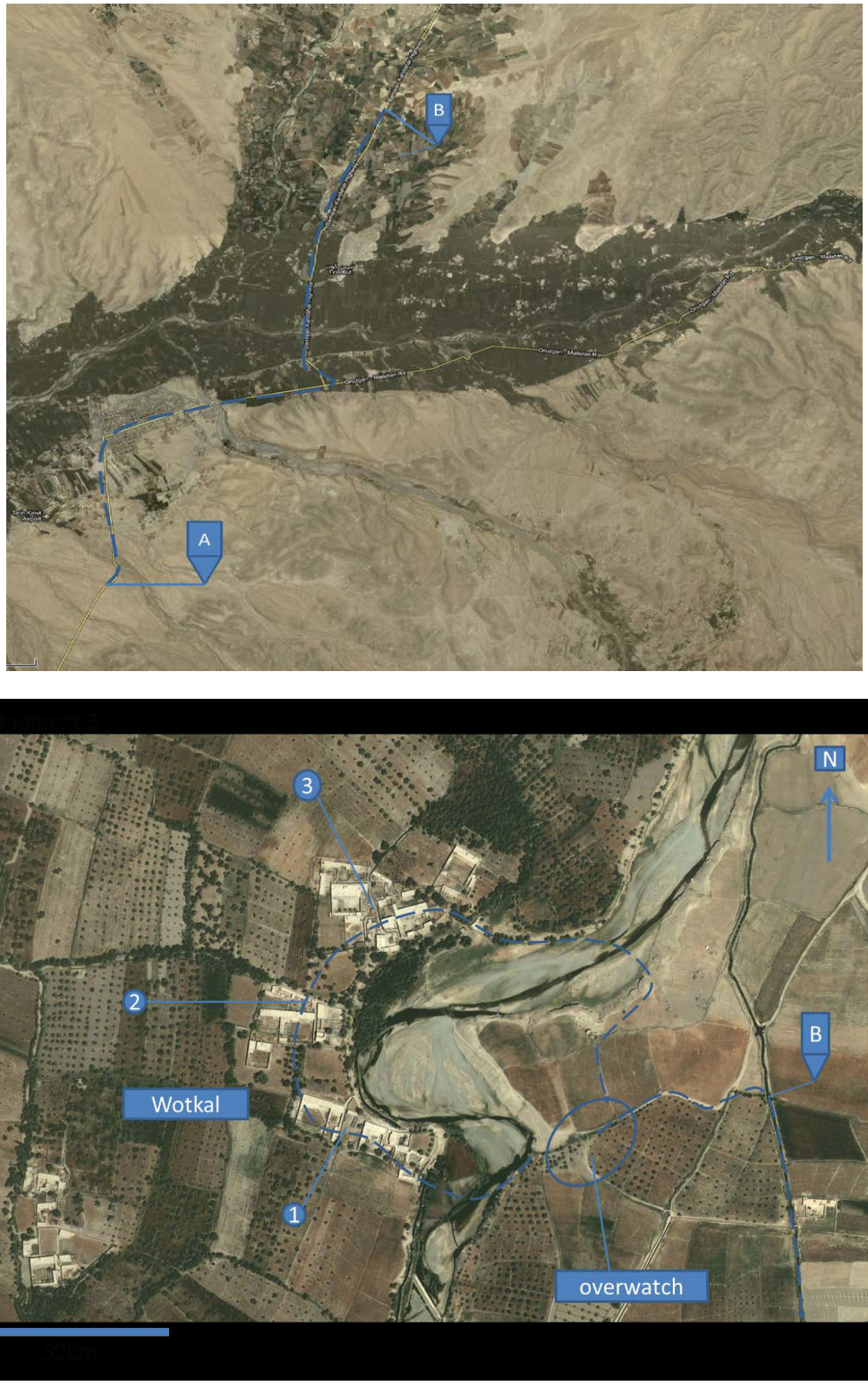


Figure 2-3: Scenario 3 Aerial Views.

2.2.3.2 Mission

Purpose: Providing security to the PRT MT during a short-range patrol.

Method: Secure PRT MT on patrol to WOTKAL. Total distance approximately 3 kilometers. Expected duration will be a maximum of 4 hours.

End State: The MT will be satisfied with the three installations and will have spoken with local representatives of the village. The MT will have returned safely to the overwatch to fulfill the next command.

2.2.3.3 Concept of Operations

Tasks:

- Move vehicle from base to overwatch.
- Arrange overwatch.
- Start patrol.
- Safe crossing of the riverbed.
- Safe reporting on point 1(see Figure 2-3).
- Representative of the village makes contact point 1 (see Figure 2-3).
- MT operates on point 1 (see Figure 2-3).
- Same on point 2 and point 3 (see Figure 2-3).
- Safe crossing back to the overwatch.
- Hot debrief.
- Prepare for next mission.

2.2.3.4 Logistics

Personnel: In case of WIA, execute first aid. Medical support decides necessity of MEDEVAC or back to the overwatch. Aerial MEDEVAC is restricted in this region.

2.3 VEHICLES INDENTIFIED IN EACH OF THE SCENARIOS

Various Dutch vehicles were referred to in the three scenarios. Details of these vehicles are provided so that each nation can substitute the equivalent vehicles.

2.3.1 Bushmaster (BUMA)

A light armored vehicle (often referred to as the Infantry Mobility Troop Vehicle). The BUMA has the following specifications (courtesy of the Dutch MOD) (Figure 2-4):

- Fuel: diesel.
- Turning radius: 18.60 meters.

- Maximum slope: 60%.
- Maximum driving range (road): 1,000 kilometers.
- Maximum speed (road, forward): 120 kilometers per hour.
- Engine/propulsion: Caterpillar 3126, 6-cylinder TD, 300 hp @ 2,400 rotations per minute.
- Tank volume: 340 liters.
- Number of tires: 4.
- Ground clearance (road): 0.40 meters.
- Width (body): 2.50 meters.
- Configuration: 4 x 4.
- Mass (combat-loaded): 15,000 kilograms.
- Mass (empty): 12,500 kilograms.
- Height (overall): 3,256 meters (top of wire cutters).
- Height: 2.65 meters (top of mount).
- Length (barrel forward): 7.183 meters (includes spare wheel).
- Length (hull): 7,087 meters.
- Power-to-weigh: ratio 20 hp/tons.
- Track width: 2.10 meters.
- Wheelbase: 3.90 meters.
- Weapon 7.62 mm or .50 machine gun and smoke canisters.



Figure 2-4: The Bushmaster (BUMA) Vehicle.

The hull of the Bushmaster is completely of welded steel construction. The bottom of the vehicle is made of V-shaped highly stretchable plates specifically designed to absorb the pressure of a mine explosion.

The Bushmaster has a pressure-safe reserve fuel tank that can hold approximately 19 liters of fuel. If the main tank is damaged, the vehicle can still drive on the reserve fuel for approximately 50 kilometers.

2.3.2 PATRIA

Two versions of this vehicle are in use:

- The PATRIA AV; and
- The PATRIA Ambulance.

The PATRIA AV is an armored vehicle for peacekeeping operations and used to carry personnel and their equipment in support of patrols. The PATRIA Ambulance has the same basic configuration as the PATRIA AV, but without weapon systems. The vehicle is intended for the safe and rapid extraction of casualties from crisis locations (Figure 2-5).



Figure 2-5: The PATRIA Vehicle.

The PATRIA Ambulance has room for 3 medical personnel and an extensive range of equipment for providing medical care. There is also room for a maximum of 7 casualties if seated and 3 casualties if lying down.

The PATRIA has the following specifications:

- Length: 7.52 meters.
- Width: 2.93 meters.
- Height: 3.08 meters (without wire-cutter).
- Mass: 23,000 kilograms (unloaded 20,000 kilograms).
- Crew: 2 – 9.
- Engine: valmet 6-cylinder turbo diesel; 202 kilowatts.
- Armament: 7.62 mm or .50 machine gun and smoke canisters.

In use with: Royal Netherlands Army, Royal Netherlands Navy, Netherlands Marine Corps.

The vehicle has a top speed of 95 kilometers per hour. It can negotiate grades up to 60 degrees and is extremely quiet. The PATRIA can drive over paved roads (75%), unpaved roads (15%) and cross-country (10%). It is deployable in arctic as well as tropical temperatures (operating range -46 °C to +49 °C). The PATRIA can drive through water up to 1.5 meters deep.

The crew can operate the weapon systems while under armor. The armor and the window shutters are able to withstand 14.5 mm AP ammunition. The vehicle can continue to drive on flat tires over a limited distance to bring itself to safety, for example after having been shot.

The vehicle has 2 x FM9000 radios, an HF Harris radio set, as well as GPS and SATCOM (communication via satellite) equipment.

2.3.3 Mercedes-Benz (MB) 280 GD



Figure 2-6: The Mercedes-Benz 280 GD Soft Top Vehicle (Top), Armored Vehicle (Bottom).

The MB 280 GD is an all-terrain vehicle in use since February 2009. The MB280 GD is a personnel carrier all-terrain 4-wheel drive vehicle.

It has the following specifications:

- Fuel: diesel.
- Turning radius: 13.2 meters.
- Maximum grade: 80%.
- Maximum driving range (without refueling): 1,280 kilometers (road).
- Maximum speed: 160 kilometers per hour (road), 120 kilometers per hour (with governor), 70 kilometers per hour (cross-country).
- Engine/propulsion: Mercedes-Benz OM 642 6-cylinder V turbocharged intercooled diesel CDI, Euro 4.
- Power: 185 hp (135 kilowatt) at 3,800 rotations per minute.
- Rollover angle: 25%.
- Tank volume: 147 liters including reserve tank.
- Wading depth: 0.60 meters.
- Tires: 4 + 2 reserve.
- Crew: 1 + 3 Width (body) 2.33 meters.
- Configuration: 4 x 4.
- Mass: (combat-ready) 4,500 kilograms; 4,800 kilograms including crew and load.
- Mass: (empty) 4.130 kilograms.
- Height: (overall) 2.20 meters.
- Length: (body) 5.42 meters.
- Track width: 1.57 meters.
- Wheelbase: 2.85 meters.

The new MB has many more options for installing communications equipment and antennas. Jammers and SatCom equipment can also be installed.

The vehicle has a Euro IV motor and is therefore compliant with environmental regulations. The intervals for maintenance are also longer.

The fully automatic transmission relieves the driver of some work. The vehicle always gives power and will not stall when changing gears in difficult terrain.

The winch can be removed and reinstalled on another vehicle of the same type without tools. That makes self-recovery possible.

The ring mount has been modified with improvements to the rotating mechanism of the brakes; an adjustable-height plate has been added under the mount so that gunners can assume a good position regardless of how tall they are.

The Mercedes-Benz G280 has 700 kilograms of integrated armor on the sides and underside. The vehicle also has removable mine protection.

2.3.4 Fennek



Figure 2-7: The Fennek Vehicle.

The Fennek light armored reconnaissance vehicle has good all-terrain capabilities. The Fennek has a laser distance meter, CCD camera (camera with a light-sensitive chip that converts images to digital information) and a thermal image viewer to give visibility in the dark.

The Fennek has the following specifications:

- Length: 5.58 meters.
- Width: 2.55 meters.
- Height: 2.29 meters.
- Mass: 10,400 kilograms (combat-ready).
- Engine: 6-cylinder diesel, 177 kilowatts.
- Crew: 3.
- Armament: 12.7 mm (.50 cal) heavy machine gun or 40 mm grenade launcher (both remote controlled).

There are various versions, used by the RnlA:

- Fennek Medium Range Anti Tank (MRAT);
- Fennek General Purpose (AD);
- Fennek Forward Observer (VWWRN);
- Fennek Tactical Air-Control Party (TACP);
- Fennek Mortar (MR); and
- Fennek Stinger Weapon Platform (SWP).

The version used by the FAC group is the Fennek Forward Observer (VWWRN). With multiple radios and hardware, the observers can call for fire support from the ground (ground-based fire support), the air (air support) or the sea (ships guns). The vehicle commander or fire-control officer uses additional C2 hardware to carry out fire support coordination tasks. There are also multiple command and control assets available. The vehicle has special observation equipment (BAA head with horizontal and vertical grid lines) built in. Units use forward observers as the eyes of the fire support to locate targets at long distances. Using the data provided by the Fennek, the artillery's howitzers engage targets quickly and accurately. The special observation equipment can also be used outside the vehicle (dismounted operations).

Chapter 3 – WORK PACKAGE 1: CHARACTERIZING DISMOUNTED SOLDIER BURDEN

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3.1 INTRODUCTION

NATO[1] repeatedly acknowledges that loads carried are too heavy and that this has negative consequences on the physical, mental, and cognitive burden of the combat soldier (much of which is supported by many research articles in the scientific literature, as highlighted in Chapter 1). Despite developments in lighter materials, improved integration, multi-functionality, and reduction in equipment size or bulk, carried load has in fact increased over the ages and continues to show this trend in modern times, as shown in Figure 3-1; [1], [2], [3].

Soldier overload has concerned military medicine and scientific researchers for some time. Studies to determine maximum soldier loading have been reported for more than a century [4], [5], [6], [7], [8], [9], and generally agree, based mostly on physiological strain, that the soldier should not carry loads of more than one-third of their body mass. Many militaries recommend slightly lower doctrinal fighting loads of 30% of body mass, recognizing that load carrying ability will be compromised by operational stressors, and allow for higher marching or administrative move loads at 45% of body mass for the average soldier [2], [10], [11].

The US Army Center for Lessons Learned assessed combat loads for groups of US Soldiers in Afghanistan 2002, during Operation Enduring Freedom III [12], [13] (data for which are reflected in Figure 3-1). The authors concluded in their summary:

> *The dismounted Infantryman continues to be over-burdened while conducting modern combat operations. The excessive weights that U.S. Army light Infantry forces are carrying on their backs in Afghanistan are neither the fault of poor unit discipline nor Soldiers taking too much gear into operations. The fault lies in the fact that these Soldiers are carrying mission-essential equipment that simply weighs too much. The excessive weights on the backs of these fit Soldiers, coupled with the harsh environments found in Afghanistan, prove detrimental to maximizing Soldier performance. Despite units going to great lengths to minimize the loads that their Soldiers are carrying while still ensuring that they could accomplish their assigned combat missions, the mass of the Infantryman's combat load is far too great and considerably exceeds the upper envelopes established by Army doctrin*e [12].

The United States Natick Soldier Research, Development and Engineering Center (NSRDEC) concluded from Iraq data that "significant advances must be made in reducing the mass of both Soldier borne technologies and logistic support, and significant steps must be made in reshaping Army doctrine so that the net result is that the Infantryman's combat load is drastically reduced" [14]. Overload due to too much equipment negatively influences soldier effectiveness and employability but will not be solved by simply reducing the mass of

[1] Particularly and specifically NATO Land Capability Group Dismounted Soldier System (LCG DSS).

the equipment (see Ref. [15], as cited in Ref. [3]). Furthermore, the unpredictable and flexible nature of military missions and tasks makes it difficult to be prescriptive on the type and amount of equipment to carry.

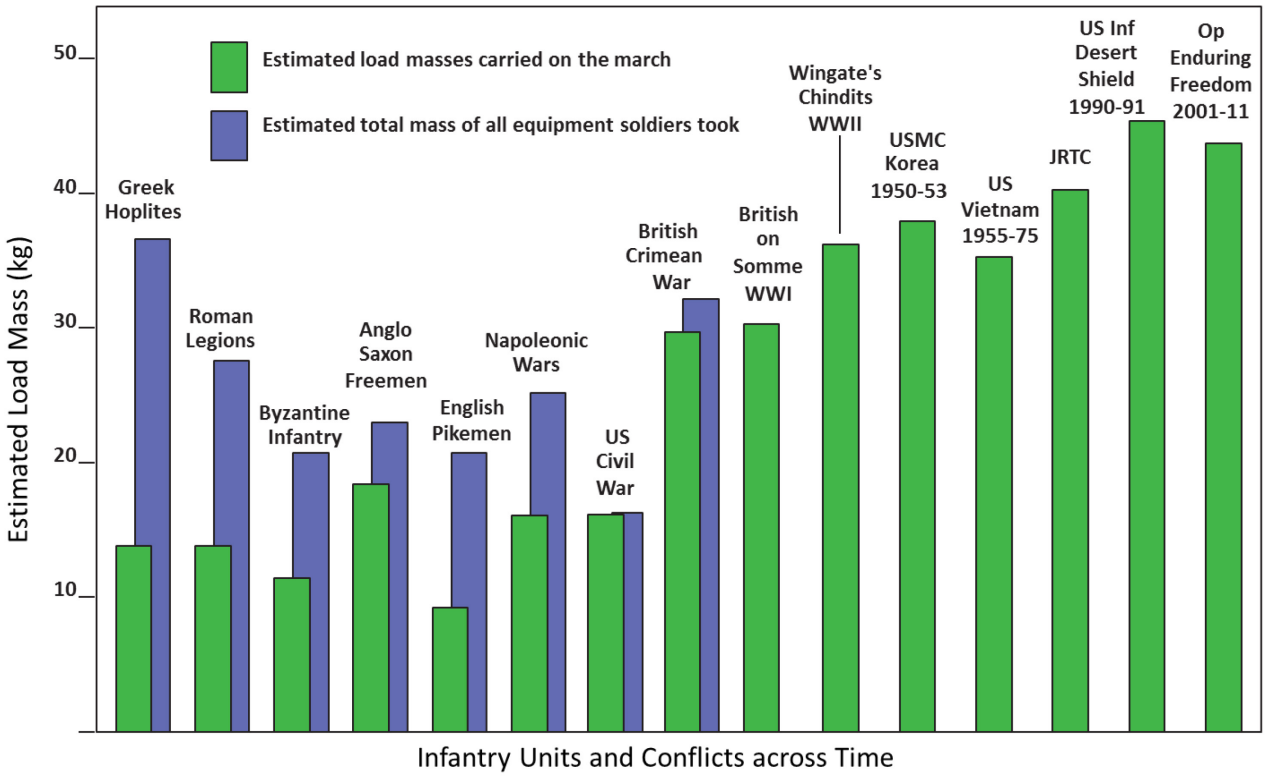


Figure 3-1: Loads Carried on the March by Various Infantry Units Throughout History. Data derived from Refs. [2], [12], [13].

RTG HFM-238 members recognize that multiple interventions, along many lines of capability development (from personnel selection and training, through research, education, support to decision-making, to equipment design), may be necessary to achieve the desired goal of burden mitigation, but first it is necessary to determine what NATO soldiers carry, try to understand why they carry these loads, and learn from commonalities or any differences amongst NATO nations in order to inform intervention strategies. Since most published load data are limited to US military, with few notable exceptions [16], NATO RTG HFM-238 decided that one of its first collaborative activities would be to quantify and characterize the loads of soldiers from a broader range of NATO nations.

In this chapter we describe RTG HFM-238's efforts to characterise the soldier load burden. A description of the methodology adopted is followed by presentation and comparison of scenario and nation-specific soldier loads with a view to identifying predominant sources of overload, lessons learned and best practices. Finally, we discuss the soldier loads identified against theoretical, doctrinal, and physiologically-derived load limits in order to characterise the extent of the problem.

3.1.1 Overview

Three different standardized scenarios were developed. Each participating nation was asked to complete a spreadsheet template providing typical dismounted soldier loads that would be carried during each of the three scenarios by members of a dismounted infantry Group/Squad/Section[2]. These nation-specific loads comprised named items of clothing or equipment, as well as quantities and the mass of each item. Nations consulted Subject Matter Experts (SMEs), Army doctrine, or conducted specific data collection activities (described below) in order to provide their nation-specific data[3]. Average load mass (across the soldiers in the Group/Squad/Section, and/or by dismounted role) were consolidated for the ensuing analysis.

3.1.2 Scenarios

Based on scenarios provided by NATO LCG DSS, three detailed scenario descriptions were developed by the Dutch Joint Soldier and Equipment Centre of Expertise, and subsequently endorsed by LCG DSS. These are described in detail in Chapter 2 and are summarized in Table 3-1. They intentionally represent a range of mission, task, threat, meteorological, workload, duration, and terrain conditions[4].

Table 3-1: Scenario Summary. POP = Possibility of Precipitation; RH = Relative Humidity; PRT = Provincial Reconstruction Team; IED = Improvised Explosive Device.

Scenario	1	2	3
Environmental Conditions	Hot (39°C day, 10°C night), 20% POP, 55% RH, wind 10 – 30 km/hr)	Mild, (15°C, 60% POP, 65% RH, wind 10 km/hr)	Moderate (24°C, 0% POP, 12% RH, wind 18 km/hr)
Threat	Unknown. No incidents to date.	High threat level.	Low threat level (though IEDs used in past)
Type of Mission	Patrol (Secure a PRT during a patrol)	Attack (Raid to destroy IED factory, capture and eliminate insurgents)	Short Range Patrol
Duration	24 – 36 hours	24+ hours (4 – 6 hours for execution phase)	4 hours
Exercise Intensity	Low	High (during attack)	Medium
Overnight?	Yes	Not specified	No

[2] Depending on nation, different terminology is used to name a dismounted group of 8 – 13 soldiers. NE uses Group. US uses Squad. AS/NZ/CA/UK use Section.

[3] Note that data collection approach methods varied across nations, so grouping and analysis of results were handled with some caution (descriptive summaries only, across nations who used a similar data collection approach: scenario-based or generic/doctrinal).

[4] In spite of the level of detail provided for Scenarios (see Chapter 2), note also that scenario assumptions and interpretation may well have differed across study staff (briefers/data collectors) as well as participant groups, warranting similar caution in analysis of results.

3.1.3 Data Collection

A spreadsheet was distributed to participating nations to record the required information about the clothing and individual equipment (hereafter referred to as gear) worn or carried by soldiers in a dismounted Group/Squad/Section, for each of the three scenarios. Participating nations were asked to distribute the spreadsheet (or collect data themselves) for various infantry groups in their nation. A detailed methodology was developed and executed first by the Netherlands and recommended to other participating nations.

Details of the recommended data collection activity are provided in Appendix 1 and are summarized as follows. Nations were to arrange for groups (minimum 5) of experienced Group Commanders (also known in other nations as Squad or Section Leaders), hereafter referred to as Soldier Subject Matter Experts (SMEs) to participate in a load allocation exercise or workshop. Prepared in advance of each workshop were gear cards, coloured according to equipment category, with names, mass, and images of each in-service equipment item. After being briefed on each of the three scenarios, the SMEs were asked to select gear cards depicting those items of equipment what they would choose to wear or carry for each scenario, and place those cards into either a green bin (indicating items that were doctrinally required to be carried), or a red bin (indicating items that they would choose to wear or carry in addition to or instead of the doctrinal items). SMEs arrived at loads using a consensus approach. They were asked to reflect upon choices made and these qualitative choices were recorded. Templated spreadsheets were thereafter completed by tallying the number of each item chosen and multiplying by the load mass of that item, and then summing the mass of all items to arrive at total load mass, overall and by equipment category. All nations reported average soldier loads across the group/squad/section. All but two nations (NL, SWE) also collected load data by group/squad/section role.

The types of infantry units consulted differed amongst participating nations. Australia (AS), Canada (CAN), Germany (DE), New Zealand (NZ), Sweden (SWE), United Kingdom (UK) and the United States (US Army) provided data on loads carried by generic dismounted infantry. France conducted the exercise with Mechanized (heavy) as well as Motorized (light) Infantry. The Netherlands conducted the load exercise with three groups: Marines, Air Maneuver Brigade and Mechanized Brigade.

3.1.4 Gear Categorization

Participating nations filled out the spreadsheets according to clothing and equipment categories specified in Appendix 1. Because of differences in interpretation of categories, and to facilitate identification of mitigation strategies, gear categories were redefined in more detail and national data were adjusted accordingly. These final gear categories are defined in Table 3-2.

Table 3-2: Clothing and Individual Gear Categories Used in this Study.

Gear Category	Sub-Category	Included Equipment	Excluded Equipment
Weapons	Weapon	• All carried small arms (rifles, MG, pistol, grenade launcher, etc.) • Carried mortars, anti-tank weapons, missiles	• Spare ammunition • Pouches used to carry ammunition (belongs in sustainment category)

Gear Category	Sub-Category	Included Equipment	Excluded Equipment
Weapons (cont'd)	Weapon	• Weapon ancillaries (foregrips, bipods, slings, cleaning kits, spare barrel, etc.) • Ammunition loaded on weapon (NOT spare ammo) • Bayonet, machetes for killing • Flare gun • Weapon slings, pistol holster and lanyard	• Utility knives
	Ammunition	• Spare ammunition of all types (NOT carried/loaded in weapon) • Pyrotechnics, flash-bangs • Grenades, HE and smoke	• Pouches to carry ammunition (this is in Sustainment)
	Weapon-Mounted Sights	• Weapon-mounted sights, sensors, electro-optics, laser aimers, flashlights to facilitate seeing / engaging targets	• NOT spare batteries (this is in sustainment) • Not rechargers for any of these items
Enhanced Vision	Head-Mounted	• Head-mounted sights, sensors, Night Vision Goggles (NVGs) to facilitate vision • That aid vision/sighting • Only batteries in the item (NOT spares)	• Weapon-mounted sights, sensors to facilitate seeing / engaging targets • Not spare batteries nor rechargers (these would be in sustainment)
	Hand-held	• Binoculars • Hand-held flashlights • Glow sticks • Para flares, pen flares • Marker panels	
C4I System		• Radio and communications gear • Displays (except sights which are in vision category) • Headsets (even if they include hearing protection)	• Spare batteries (goes in sustainment) • Recharging systems for any c4isr items

Gear Category	Sub-Category	Included Equipment	Excluded Equipment
C4I System (cont'd)		• Antennae • Batteries in system (not spares) • IFF/IR markers • Strobe • GPS • Laser Range Finders (LRF) • Compass, digital magnetic compass • Maps, map case, field message, writing utensil • Watch	
Protection	Non-ballistic	• All environmental protection (clothing, rainwear, insulation) • Hearing protection (unless integrated with c4i radio headsets) • Solar protection (i.e., sunglasses) unless integrated with ballistic protection • Insect repellent	• Excludes protection that is not worn (i.e., tent or shelter) which would be included in sustainment (overnight) category
	Ballistic	• Fragmentation protective soft armour • Hard armour ballistic plates • Ballistic protective eyewear • Ballistic protective helmet	
Subsistence	Power	• Spare batteries • Recharging equipment • Power generating equipment • Fuel (not batteries) for personal power generation equipment (e.g., e-lighter)	
	Non-Power related	• Water • Food and nutrition • Cooking / food heating	• Ammunition in/on the weapon

Gear Category	Sub-Category	Included Equipment	Excluded Equipment
Subsistence (cont'd)	Non-Power related (cont'd)	• Water carrier (bottle or camelback bladder, less harness) • Drinking / eating utensils	• Load carriage systems to carry supplies
Sustainment	Load Carriage	• Webbing, load carriage vests (if independent of ballistic protection) • Small packs, rucksacks • Pouches for storing any items on the load carrying system	• Body armour carrier (if that is where pouches are attached)
	Overnight Sustainment	• Any part of the sleeping system • Hygiene/toiletries (including foot powder) • Personal shelter items • Shelter lighting /heating items	• Clothing (this goes in protection category) • Food heating systems (this goes in sustainment category)
Miscellaneous	Theatre or Mission-Specific Equipment	• POW kit • Escape and Evasion kit • Rope, ladders • Entrenching kit • Breaching kit • Threat/ mine/ radiation/ chemical detection equipment • Electronic Countermeasures (ECM) • Demolition equipment • Axe/chain saws/ • Sandbag, barrier materials • Marker panels	
	Medical	• First aid kits, care under fire, advanced trauma life-saving kits, medical kits • Drugs, medicine, prophylaxes, and therapies • Medical equipment • Medevac equipment • Stretcher	

Gear Category	Sub-Category	Included Equipment	Excluded Equipment
Miscellaneous (cont'd)	Medical (cont'd)	• Casualty marker/identification tags • Physiological monitoring equipment	
	Personal	• Sewing kits • Personal items (smart phones, reading material, tobacco products, medication) • Id cards, identification tags, info • Insignia, wallet • Spectacles (eyeglasses)	• Notepad and pencil (should go in c4i)

3.1.5 National Deviations from Protocol

There were some deviations from the protocol, described in Appendix 2, and summarized as follows.

Not all nations used the three scenarios, either due to security concerns or for other reasons (e.g., lack of access to experienced soldier leaders for the data collection; unfamiliarity with scenarios, etc.). Data for AS, NZ, SWE and USA are therefore limited to a single generic or doctrinal scenario. Data for CA, FR, GE, NL and UK are available for each of the three scenarios. Note that the use of doctrinal loads has its limitations; the battle load more often differs from the doctrinal load.

Nations differed in how data were gathered. Deviations from protocol for AS, CA, and FR are detailed in Appendix 2 of this chapter; the following summarizes most of the deviations. Some distributed instructions and procedures to military SMEs while others conducted focus group discussions with SMEs to arrive at consensus loads. Not all nations prepared equipment cards in advance of the data collection. CA, for example, provided lists of all available in-service equipment from which participants could choose for their consensus scenario loads. They were also free to suggest non-service items (i.e., purchased gear that soldiers often take and use on operations). While most nations provided data on loads by dismounted soldier role, a few nations provided data only for a generic soldier role in the group/squad/section (NL, SWE). Concerning French data collection, the three different scenarios were not completed by the same SMEs; this may have introduced a bias related to the individual's experience and interpretation of scenario requirements. Nevertheless, efforts to control for this potential bias were implemented.

Data collected for France distinguish two types of infantry regiments characterised as "light infantry" (motorized, that is, those who possibly walk loaded for a longer distance, far from their vehicle) and "heavy" infantry (mechanized, that is, those who are always close to their vehicle and can leave part of their burden in it). This distinction is important to recognize when analyzing the different choices made by each group since "heavy infantry" tends to bring more on a mission, but much of that load is not actually carried by soldiers throughout the mission.

Note that the highlighted differences in methodology across participant nations, in terms of data collection approach (by scenario, generic, or doctrinal), personnel administering the data collection (leading to potential

differences in assumptions and scenario interpretation by different participant groups), and differences in the types of infantry units consulted, all pointed to the need to exercise caution in the grouping or analysis of data collected in this study. Only descriptive statistics were applied and scenario-based load data and generic/doctrinal load data were considered independently.

3.1.6 Data Analysis

For each contributing nation, the average load mass carried by a dismounted soldier (across the group/squad/section)[5] was calculated for each of the gear categories, and overall, for each scenario (for those nations who provided loads by scenario). Data were plotted in separate bar graphs for each scenario, to permit descriptive analysis of load mass and load composition according to mission context and across nations. Separate graphs were prepared for those nations who provided data for only one generic scenario or doctrinal load data.

Additional graphs were prepared for more in-depth analysis by gear category. This was done to identify where changes were made by group/squad/section commanders/leaders for the specific mission or task.

An analysis of proportion of load mass by gear category was also undertaken in order to target areas for possible mass reduction. Because the dismounted soldier's load mass can be higher or lower given the role of the specific dismounted soldier, further plots were produced, and analysis by infantry role was undertaken, where data were provided by role (all nations except NL and SWE).

Finally, average soldier load mass, as a proportion of body mass, was calculated for each nation, using average dismounted soldier body mass for each nation in order to relate to scientifically-recommended and doctrinal load limits (discussed previously in the Introduction to this chapter). This was done in order to normalize the data, since soldiers differ across nations in terms of their body size and mass, and since load carrying capacity, is in part driven by body size (see Chapter 4 for further details).

3.2 RESULTS

Appendix 3 provides summary data for each nation of average soldier load mass (total, and by gear category) for each scenario (or for a doctrinal or generic scenario as applicable).

3.2.1 Differences in Total Soldier Load Across Nations

Table 3-3 summarizes the main results of average soldier loads (by scenario a well as generic/doctrinal) for each nation as well as the mean load and range of loads across scenarios (if applicable) by nation.

Regardless of scenario, soldier loads varied between nations by almost as much as 30 kg, ranging from 41.03 kg (for NZ, generic scenario) to 70.17 kg (for AS, generic scenario). Examination of the mean of the average soldier loads by scenarios reveals that average loads were generally highest for NL and UK (and AS if generic loads are considered) and lowest for CA (and NZ, if generic loads are considered).

[5] Note that the average load mass corresponds to the total mass carried by a combat group/squad/section, divided by the number of members in that group/squad/section. Note also that group/squad/section size and composition differ amongst NATO nations.

Table 3-3: Average Soldier Loads Expressed by Scenario and Nation. NATO load was calculated as the mean of the national data available. Scenario 1: 24+ hours, long range patrol, hot day / cool night climate, unknown threat, low workload; Scenario 2: attack raid, mild temperature, high workload, high threat; Scenario 3: 4 hour patrol, moderate environmental conditions, low threat, and medium workload.

Nation	Average Soldier Load Mass by Scenario (kg)			Mean (kg)	Range (kg)
	1	2	3		
CA	49.05	47.40	49.38	48.61	1.98
GE	53.87	53.16	45.08	50.70	8.79
FR (mech)	59.45	56.02	56.02	57.16	3.43
FR (motor)	53.76	49.42	48.33	50.50	5.43
NL	58.35	62.30	59.13	59.93	3.95
UK	46.93	67.21	62.30	58.81	20.28
NATO load*	53.57	55.92	53.37	54.29	**n/a**
AS	Generic Scenario			70.17	n/a
NZ	Generic Scenario			41.03	n/a
SWE	Generic Scenario			51.92	n/a
USA	Generic Scenario			52.39	n/a
NATO load**				**54.12**	**n/a**

* NATO load average for five nations who reported load by scenario.

** NATO load average across all ten participating nations (generic or average across three scenarios).

For those nations who used scenarios for the load exercise, highest to lowest loads were recorded as follows. For Scenario 1 the heaviest loads were recorded for FR (mechanized) (at 59.45 kg), followed by NL (58.35 kg). Mid-range loads were recorded for GE (53.87 kg) and FR (motorized) (53.76 kg) with lightest loads reported for CA (49.05 kg) and the UK (46.93 kg). Ranking by load mass changed somewhat for Scenario 2 with the UK having the heaviest load (67.21 kg), followed by the NL (62.30 kg), FR (mechanized, 56.02 kg), then FR (motorized, 49.42 kg), GE (53.16 kg), and finally CA with the lowest average load (47.40 kg). For Scenario 3 average soldier loads were highest for the UK (62.30 kg), followed by NL (59.13 kg), FR (mechanized, 56.02 kg), CA (49.38 kg), FR (motorized, 48.33 kg), and finally GE with the lowest average load (45.08 kg).

Ranking of nations from highest to lowest mean load mass (across all scenarios) was as follows: NL had the highest mean load (59.93 kg), followed by UK (58.81 kg), FR (mechanized, at 57.16 kg), then GE (50.70 kg), FR (motorized, at 50.50 kg) with CA having the lowest mean soldier load mass across scenarios (48.61 kg).

For those nations who used generic scenarios or doctrinal loads only, average soldier loads were highest for AS (70.17 kg), next highest for US Army (52.39 kg) and SWE (51.92 kg), and lowest for

NZ (at 41.03 kg). With a range of 29.17 kg, this demonstrates significant variability amongst nations. The average soldier load across these four nations was 53.88 kg.

The degree to which each nation adjusted their average soldier load to suit the circumstances of each scenario is revealed by the right-most column in Table 3-3. Whereas the UK data reflect a large range of variability between scenarios (20.28 kg), most nations adjusted load mass by a much smaller amount (from 1.98 kg for CA to 8.79 kg for GE).

3.2.2 Differences in Average Soldier Load Due to Scenario

Referring once again to Table 3-3, one can see that mean soldier loads across nations were all quite similar regardless of scenario (see rows 7 and 12 of Table 3-2 which shows NATO mean loads to be within 2.55 kg of each other, regardless of scenario). Examination of individual nation data reveals inconsistent trends. For GE and FR, loads were highest for Scenario 1 (24+ hour, long range patrol, unknown threat, hot day, cool night) and lowest for Scenario 3 (4 hour, short range patrol, moderate conditions, low threat). UK and NL differed with average soldier load being highest for Scenario 2 and lowest for Scenario 1. Only CA SMEs chose highest soldier loads for Scenario 3 and lowest for Scenario 2.

Figure 3-2 shows main load results by nation for each Scenario. The difference in dismounted soldier loads across nations for Scenario 1 ranged by 12.52 kg (from 46.93 kg for UK to 59.45 kg for FR mechanized infantry). Mean load across all nations was 53.57 kg. The largest source of variability appeared to come from the Protection gear category, with CA having the least amount of protection (SMEs elected *not* to wear ballistic protection for this scenario due to high temperature and perceived low threat). CA and the UK selected the lowest amount of protection (respectively 8 and 11 kg), and GE had the heaviest protection system (23.47 kg).

The variability in soldier loads across nations for Scenario 2 was the greatest with a range of 19.81 kg (from 47.40 kg for CA to 67.21 kg for UK). Average load across nations for Scenario 2 was slightly higher than Scenario 1 at 55.92 kg. Again, the Protection gear category accounted for much of the difference, although all nations adopted ballistic protection for this high threat attack raid scenario. Also evident was an increase in load due to the weapon (which includes ammunition) and miscellaneous gear categories for this scenario.

For Scenario 3, variability amongst nations was 17.22 kg (ranging from 45.08 kg for GE to 62.30 kg for UK). The average soldier load across nations for Scenario 3 was 53.37 kg, which was marginally the lowest of the three scenarios. All nations had total loads approximating 45 – 59 kg, except the UK with significantly higher average soldier load mass of 62 kg. This is attributed to an increase in UK subsistence and miscellaneous equipment loads, including mission-specific jamming equipment, equipment not identified by the other countries. The Protection gear category showed similar variability between nations, though all countries opted to use ballistic protection for Scenario 3.

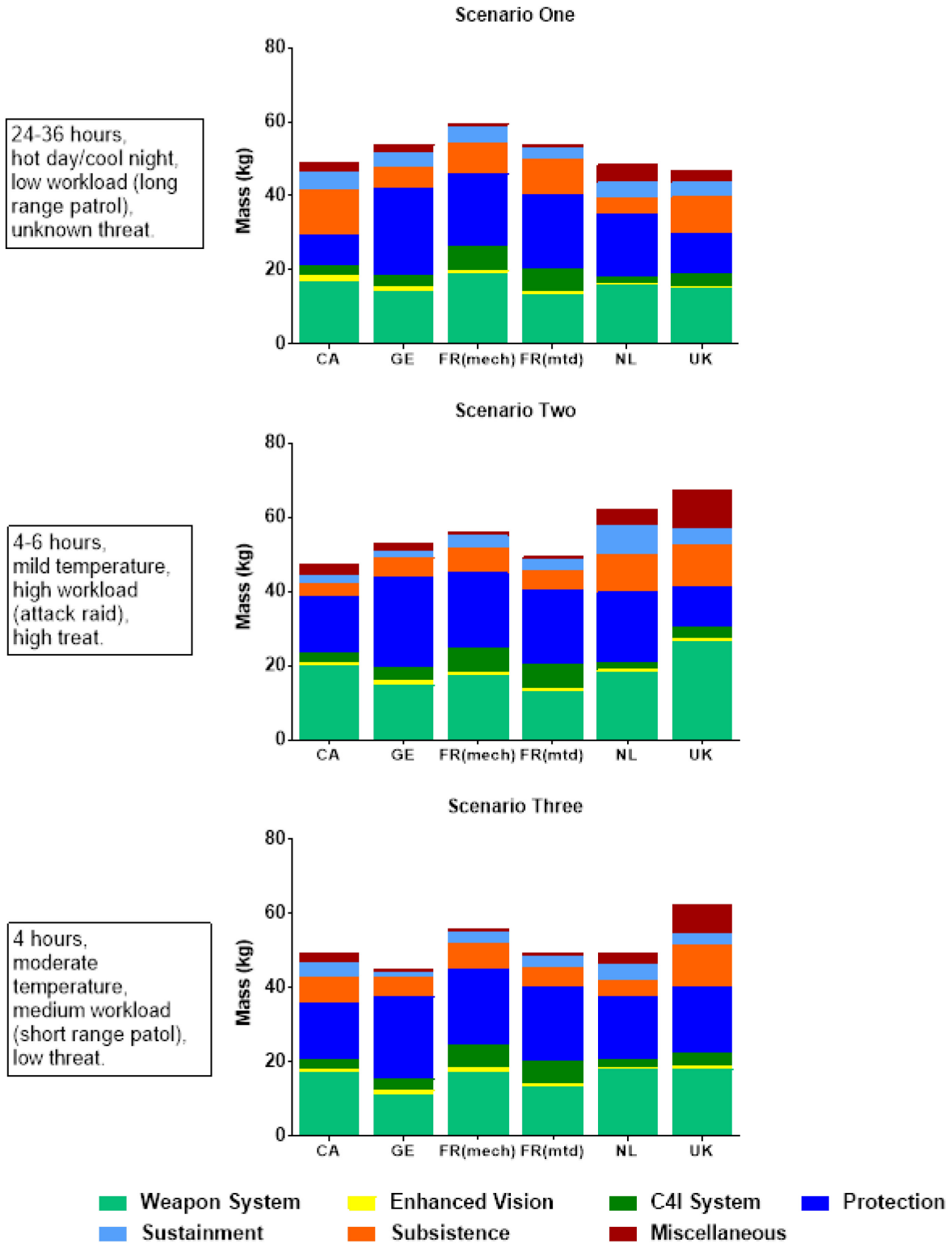


Figure 3-2: Dismounted Soldier Loads (kg) for CA, GE, FR (Mechanized and Motorized), NL and UK. Expressed according to scenario and gear category.

3.2.3 Differences in Doctrinal or Generic Loads

Figure 3-3 presents data for those nations who used a single doctrinal or generic scenario. The greatest load was reported by AS with a total of 70.17 kg. NZ reported the smallest load mass of 41.03 kg. The difference between nations appears to be due to the loads carried for sustainment and subsistence, and to a lesser extent, weapon, and protection sub-systems. SWE and the USA had similar loads approximating 52 kg

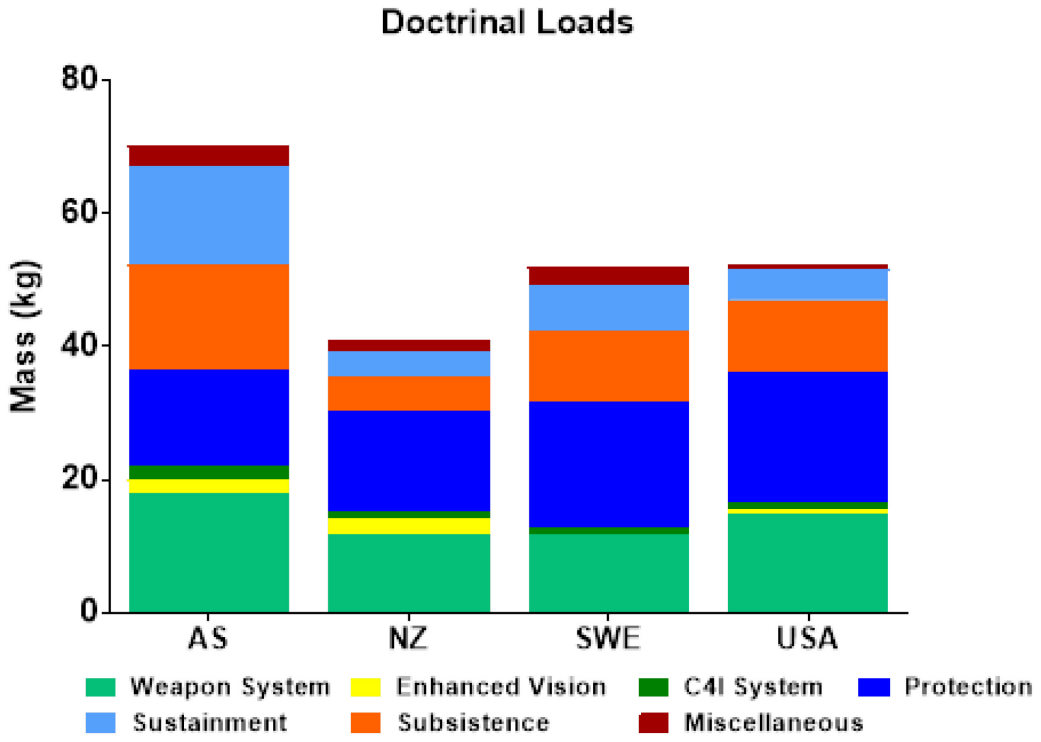


Figure 3-3: Dismounted Soldier Loads (kg) for AS, NZ, SWE and USA. Expressed according to gear category for a generic scenario.

3.2.4 Weapon System Gear Category Differences

Figure 3-4 shows the average weapon system loads by nation and scenario. The weapon system comprises weapon-mounted sights[6], ammunition, as well as the weapon itself, including ancillaries (such as sling, spare barrel, cleaning kit, etc.).

The largest source of variability between nations and scenarios was evident for the ammunition sub-category, with the heaviest ammunition load being 15.76 kg for the UK (in Scenario 2) and the lightest being 4.33 kg for FR (motorized) for all three scenarios. Significantly greater ammunition loads were evident for Scenario 2 (the attack raid on an IED factory) for CA, NL, and UK. Other nations (FR, GE) did not appear to adjust their ammunition loads to take into account the circumstances of each scenario.

[6] Note that weapon-mounted sights were considered intentionally in both the weapon gear category as well as the enhanced vision category, since they are strongly related to both.

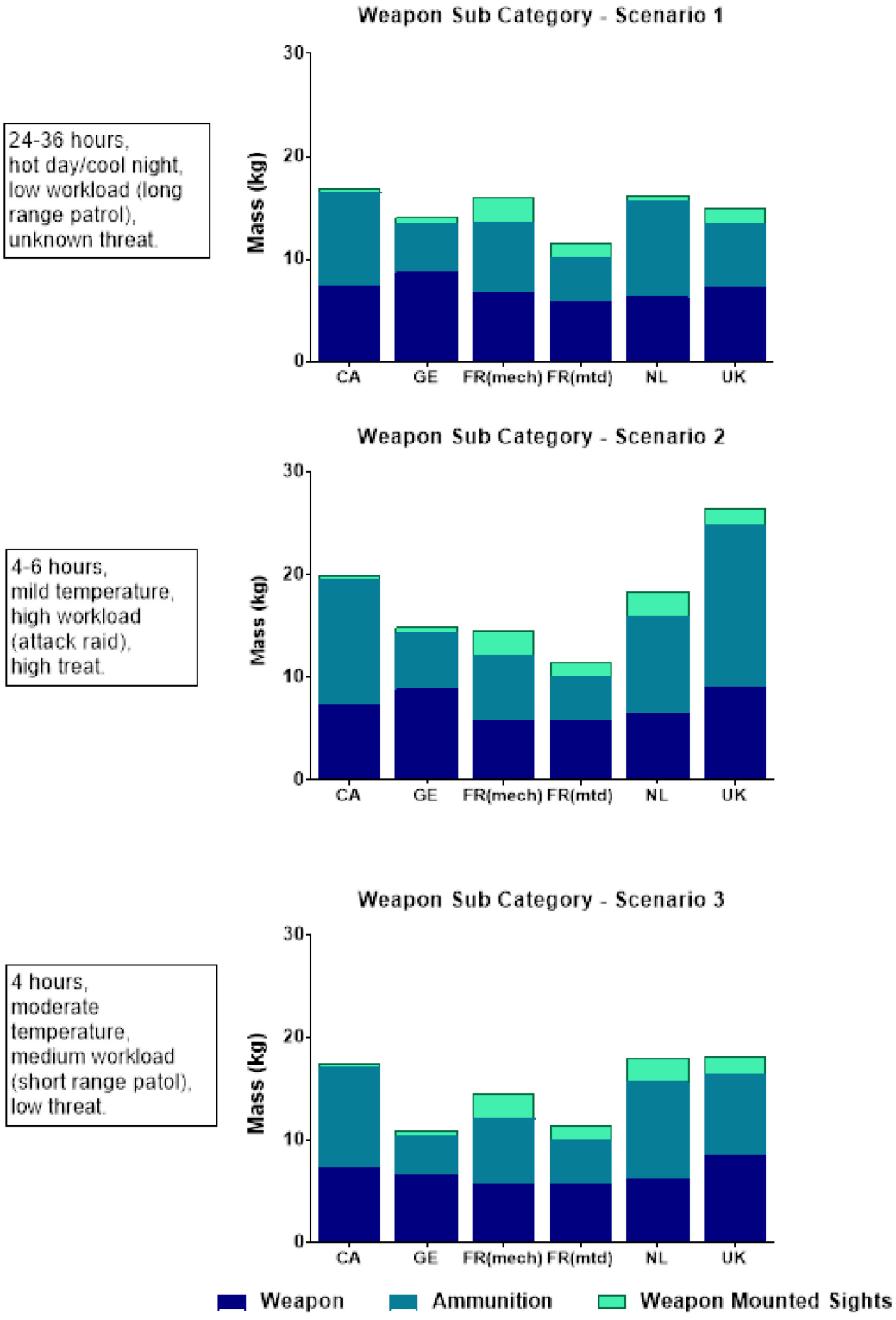


Figure 3-4: Weapon System Loads (kg) for CA, GE, FR, NL, and UK for Each Scenario. Note that weapon-mounted sights are also captured under enhanced vision system loads.

3.2.5 Enhanced Vision Gear Category Differences

Figure 3-5 shows the loads associated with the enhanced vision gear category by scenario for the six nations. Enhanced vision comprises weapon-mounted sights, head-mounted vision, and hand-held vision devices. There were almost no differences between nations or scenarios for this gear category with the exception of CA who opted not to bring head-mounted vision for Scenarios 2 and 3 (since overnight was not specified), and NL, which had a much lighter weapon-mounted sight for Scenario 1 (0.51 kg) than the sight used in Scenarios 2 and 3 (2.36 kg). FR and NL reported the highest enhanced vision loads for Scenarios 2 and 3, approximating 3 kg for this gear category.

3.2.6 Protection Gear Category Differences

Figure 3-6 shows the loads associated with the Protection gear category by scenario for the six nations. Protection is categorized into ballistic and non-ballistic protection. Across the nations, load due to protection systems ranged from 8.1 kg (for CA, Scenario 1) to 24.32 kg (for GE, Scenario 2). There were few or very minor changes in non-ballistic protection load between scenarios by countries, in spite of the wide range of environmental, threat and workload conditions. The only exception was for CA, who chose significantly more non-ballistic protection in Scenario 1 (due to overnight, cool nights and perceived low threat).

There were more obvious changes made in terms of ballistic protection. In scenario 1, CA SMEs opted not to use ballistic protection because the environmental conditions during the day were so hot, the ballistic threat was perceived to be low, and because the enemy was perceived to lack night fighting capability, they chose not to bring body armour for cooler night tasks either. The UK selected a lighter body armour for Scenario 1 because it would allow them to be more mobile and they perceived it to have a lower risk of heat injury. Interestingly, the UK assessed the threat to be the highest in Scenario 3 due to the risk of IED's. Therefore, they selected body armour that offered the highest level of protection (14.13 kg of ballistic protection for Scenario 3 versus only 6.42 kg for Scenarios 1 and 2). However, although the UK protection system includes groin protection the UK SMEs decided not to wear it because it degraded their mobility. One dismounted soldier reported "I'd rather risk my balls, than not be able to run". FR and NL reported that they would carry the same level of protection for all three scenarios despite the differences in threat level. One country opted to use ballistic side plates (FR) during Scenarios 1 and 3. The UK opted to use ballistic side plates in Scenario 3 only[7].

3.2.7 Subsistence Gear Category Differences

Figure 3-7 shows the loads associated with the Subsistence gear category by scenario for the six nations. This category is comprised of Power and Non-Power subsistence gear. Examples of non-power subsistence include: water and water containers, food or food preparation equipment, and utensils for eating.

The heaviest and lightest loads were reported by CA for scenario 1 (12.19 kg) and scenario 2 (3.8 kg). Subsistence loads selected by the UK were consistently one of the heaviest, largely because there was minimal change to food and water supplies between the scenarios despite differences in mission duration, and environmental conditions. A similar trend was observed for GE SMEs who did not modify the amount of food and water carried based on the scenario profile at all.

[7] Note that not all nations offer side plates as part of their soldier protection system.

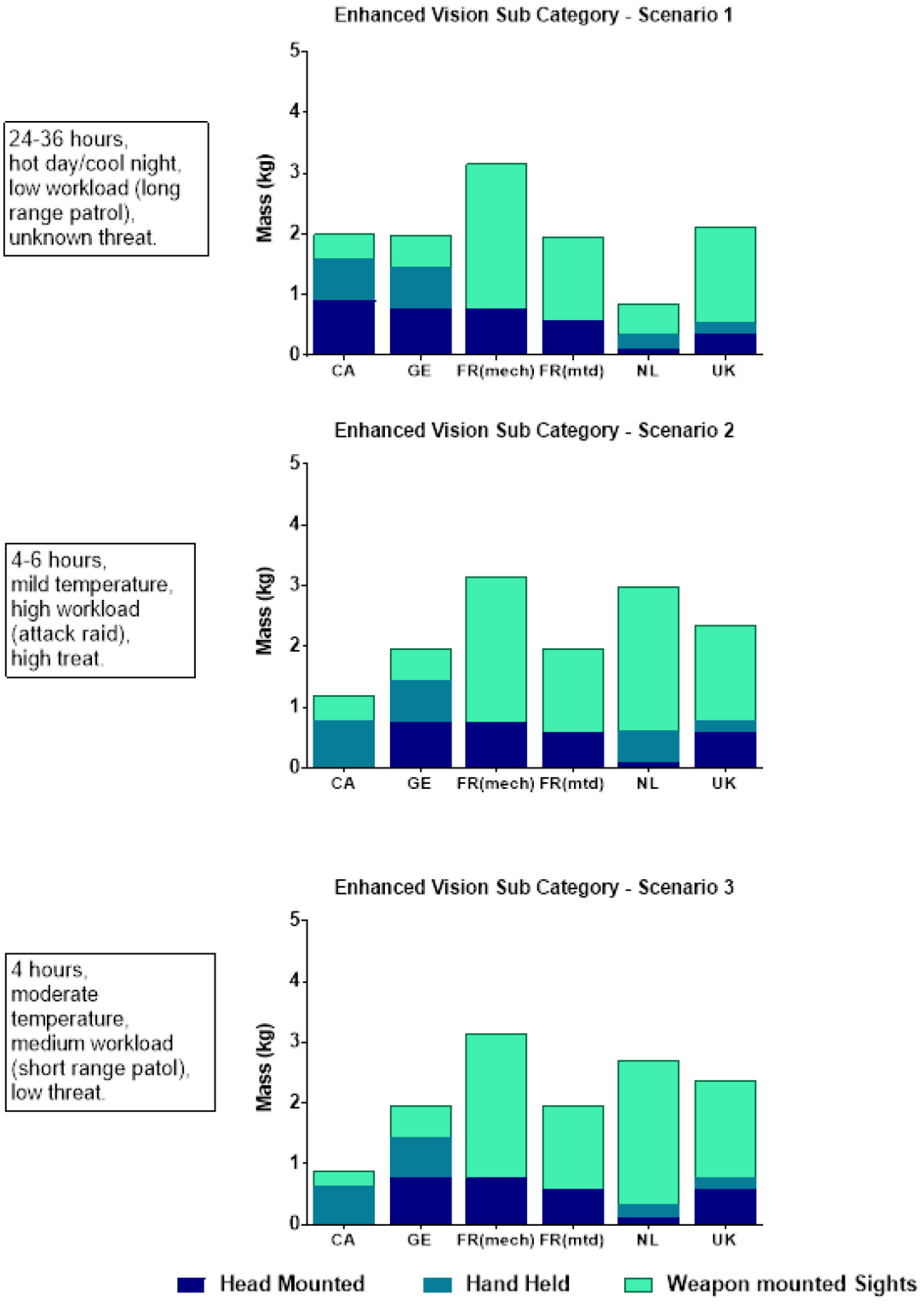


Figure 3-5: Enhanced Vision System Loads (kg) for CA, GE, FR, NL, and UK for Each Scenario. Note that weapon-mounted sights are also captured under weapon system loads.

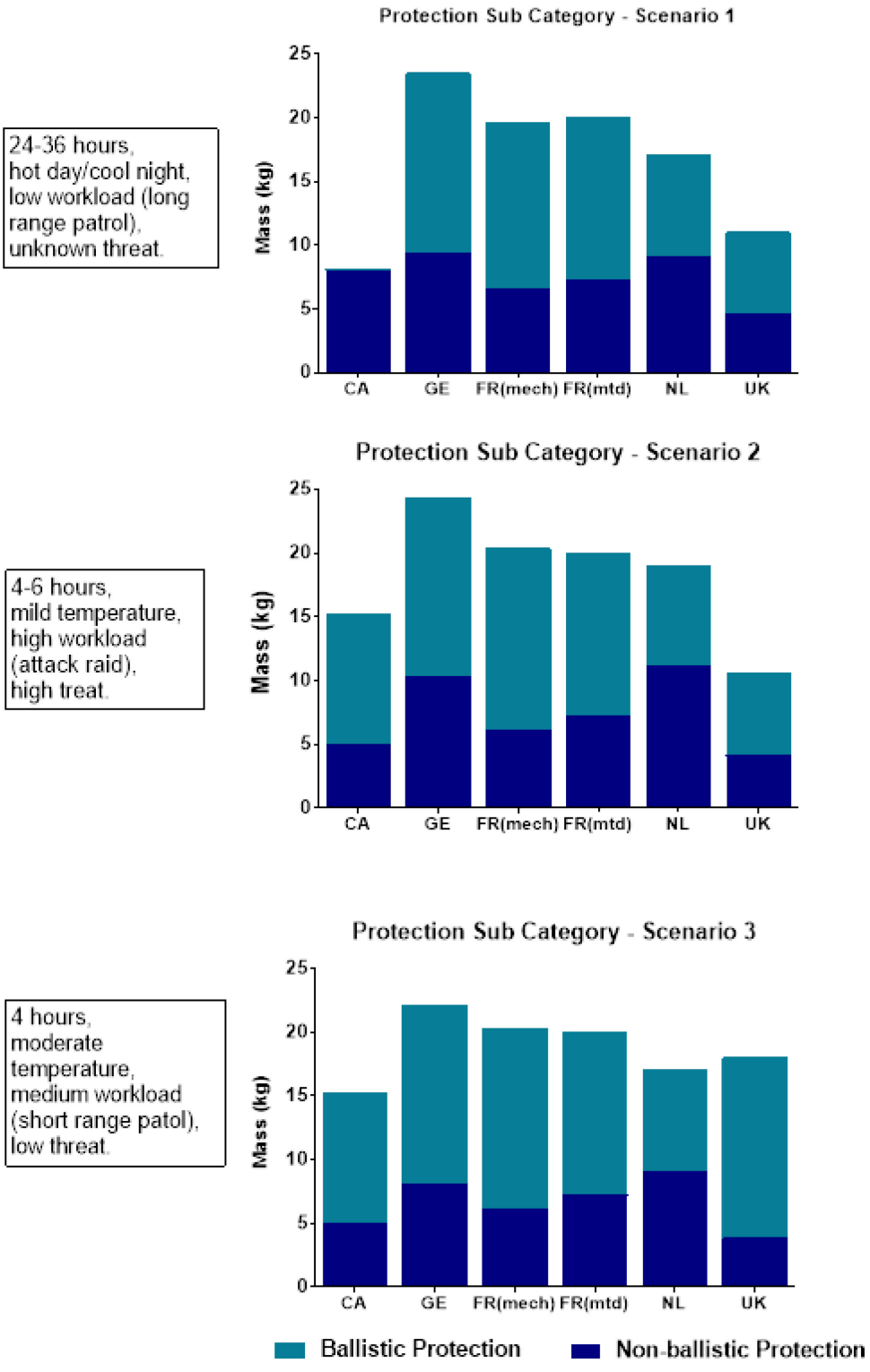


Figure 3-6: Protection Loads (kg) for CA, GE, FR, NL, and UK for Each Scenario.

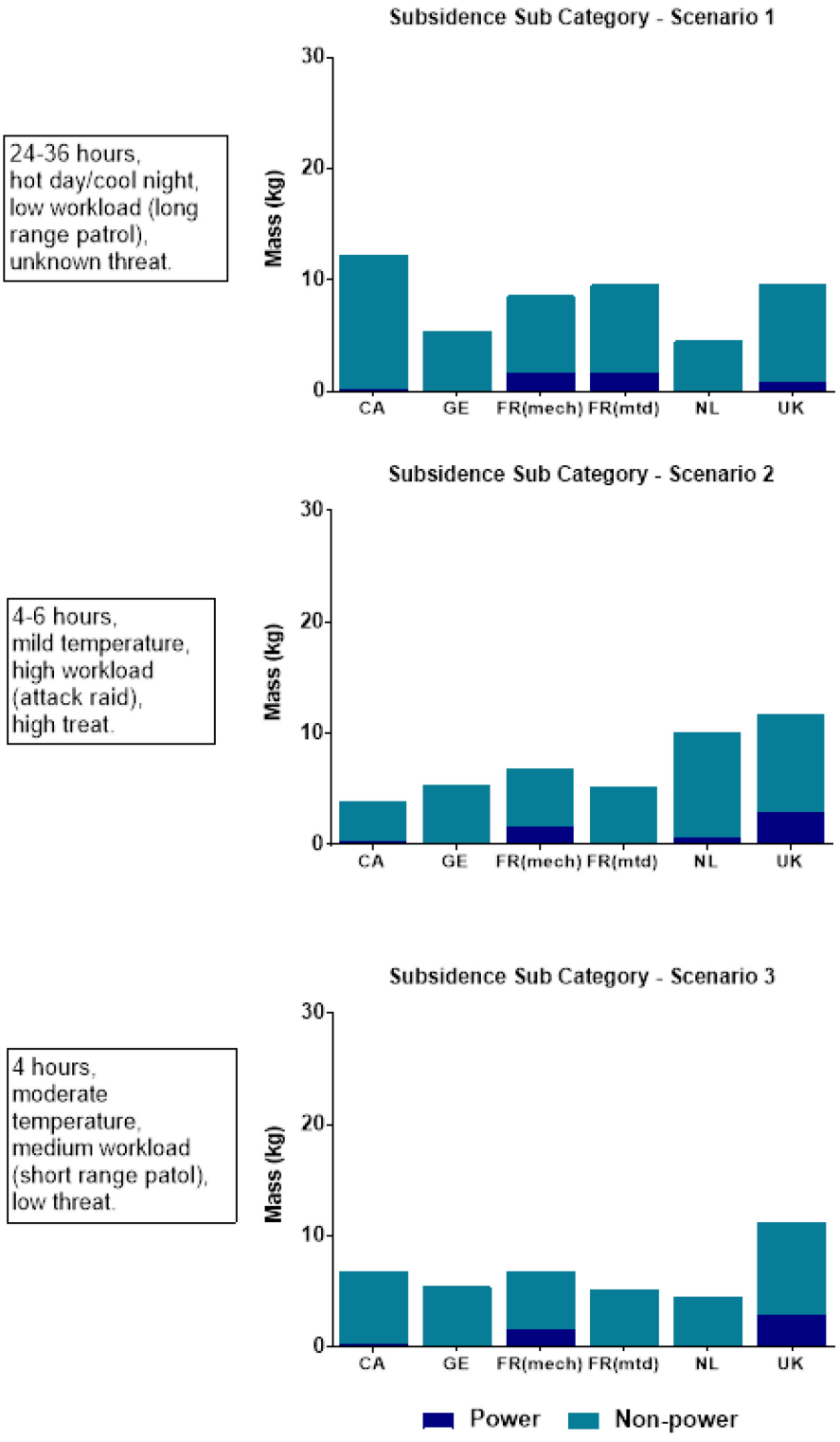


Figure 3-7: Subsistence Loads (kg) for CA, GE, FR, NL, and UK for the Three Scenarios.

3.2.8 Sustainment Gear Category Differences

Figure 3-8 shows the loads associated with the Sustainment gear category by scenario for the six nations. Sustainment is sub-divided into Overnight (i.e., sleeping/personal shelter equipment, personal hygiene/toiletries) and Load Carriage (i.e., vests, webbing, packs and associated empty pouches with attachment systems).

There was a fairly wide range of sustainment loads, the heaviest being 7.79 kg (NL, Scenario 2) while the lightest sustainment load was 1.3 kg (GE, Scenario 3). As expected, little to no overnight gear was chosen for Scenario 3 due to its brief 4 hour duration. Some overnight gear was selected for the longer duration Scenarios 1 and 2. In scenario 1, GE SMEs reported the highest overnight load of 2.78 kg. The heaviest overnight gear load (3.2 kg) for Scenario 2 is attributed to NL SMEs, whereas other nations chose little to no overnight gear for this scenario. The discrepancy may have been due to the lack of clarity on the duration of this scenario. In terms of load carriage equipment, there were few differences between scenarios with the exceptions of the UK SMEs, who reported a reduction in load carriage equipment for the shorter duration Scenario 3, and CA whose SMEs elected not to carry a small pack for Scenario 2 in order to enhance their mobility for the IED factory raid.

3.2.9 C4I Gear Category Differences

Figure 3-9 presents the C4I load gear category for the six nations. This includes communication equipment (radio's, antennae, headsets , etc.), GPS devices and navigation equipment (including maps and compass).

Minimal adjustments to the C4I equipment selected were made across the three scenarios. SMEs from FR (both mechanized and motorized) selected the heaviest C4I loads (6.34 kg), the lightest equipment was selected by NL SMEs (1.55 kg).

3.2.10 Miscellaneous Gear Category Differences

Figure 3-10 shows the loads associated with the Miscellaneous gear category by scenario for the six nations. This category is comprised of Theatre or Mission-specific gear, Medical or first aid equipment, and Personal equipment (such as tobacco, identification, reading material).

Miscellaneous gear loads ranged from 0.83 kg (for GE, Scenario 3) to 10.44 kg (for UK, Scenario 2). The major source of difference between nations or between scenarios is attributed to theatre or mission-specific equipment such as jammers, electronic warfare, and detection kits. This is very apparent for the UK in Scenarios 2 and 3 with 9.15 kg and 6.65 kg, respectively.

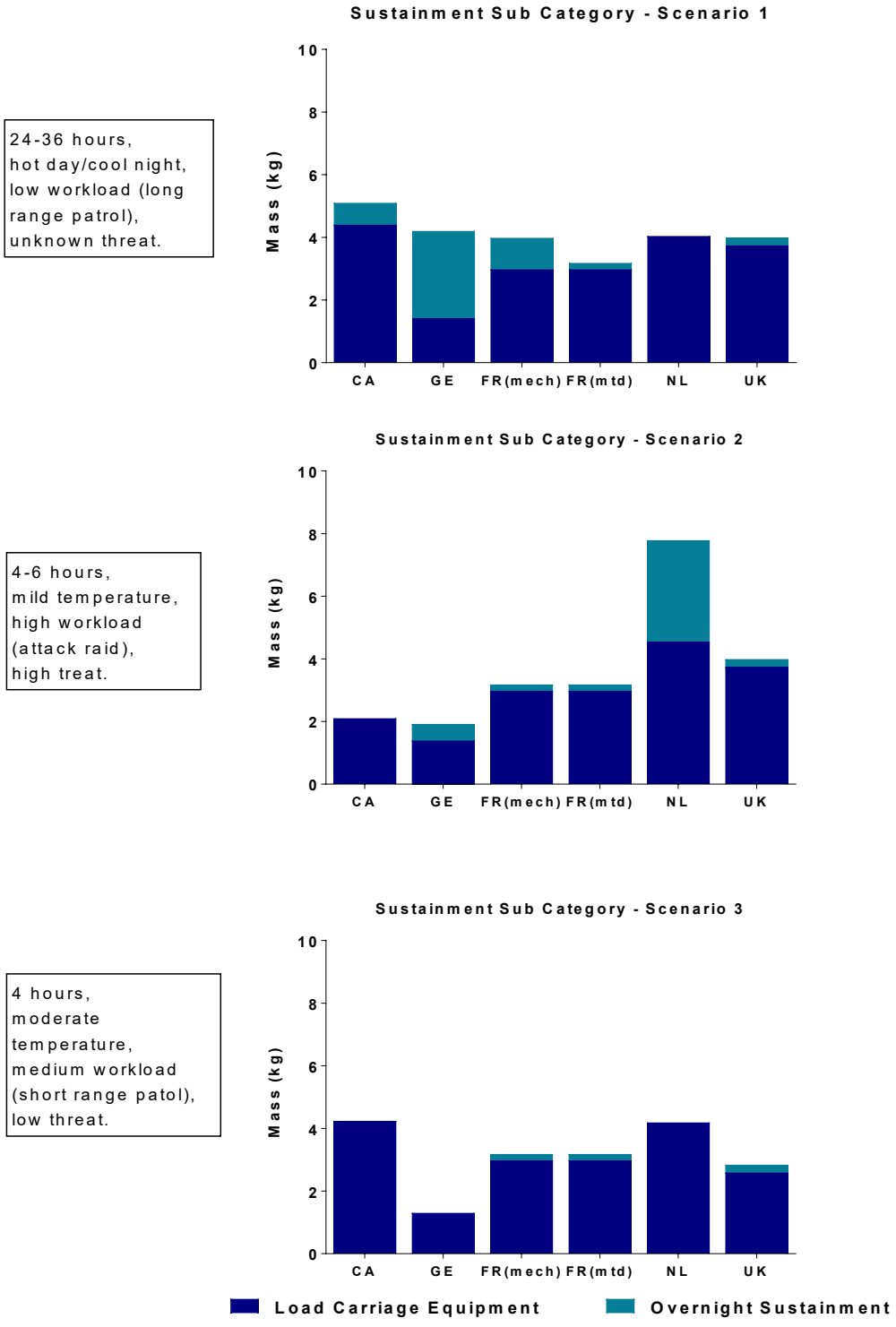
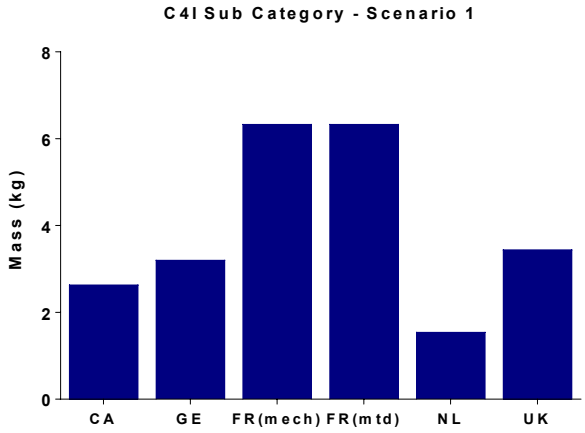
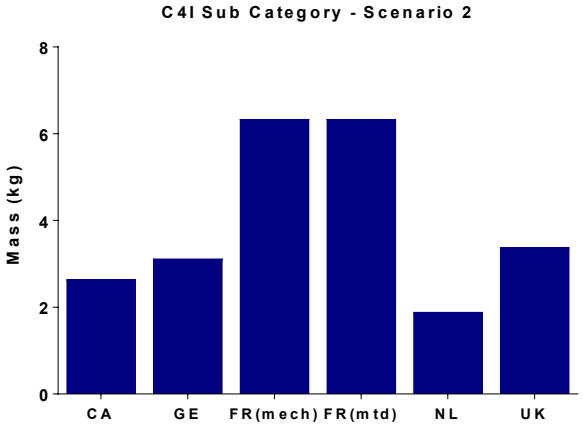


Figure 3-8: The Sustainment Loads (kg) for CA, GE, FR, NL, and UK for the Three Scenarios.

24-36 hours, hot day/cool night, low workload (long range patrol), unknown threat.



4-6 hours, mild temperature, high workload (attack raid), high treat.



4 hours, moderate temperature, medium workload (short range patol), low threat.

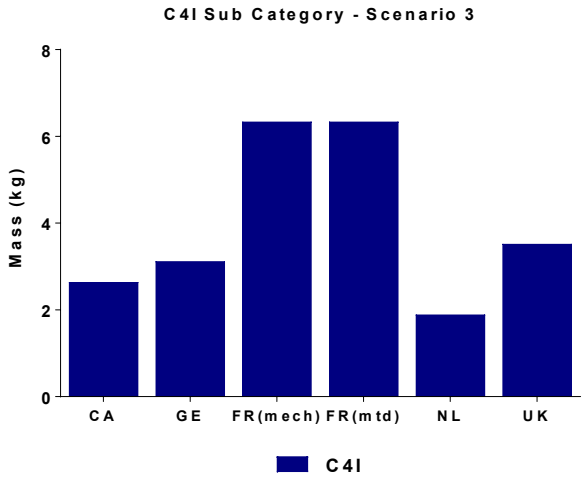


Figure 3-9: The C4I Loads (kg) for CA, GE, FR, NL, and UK for the Three Scenarios.

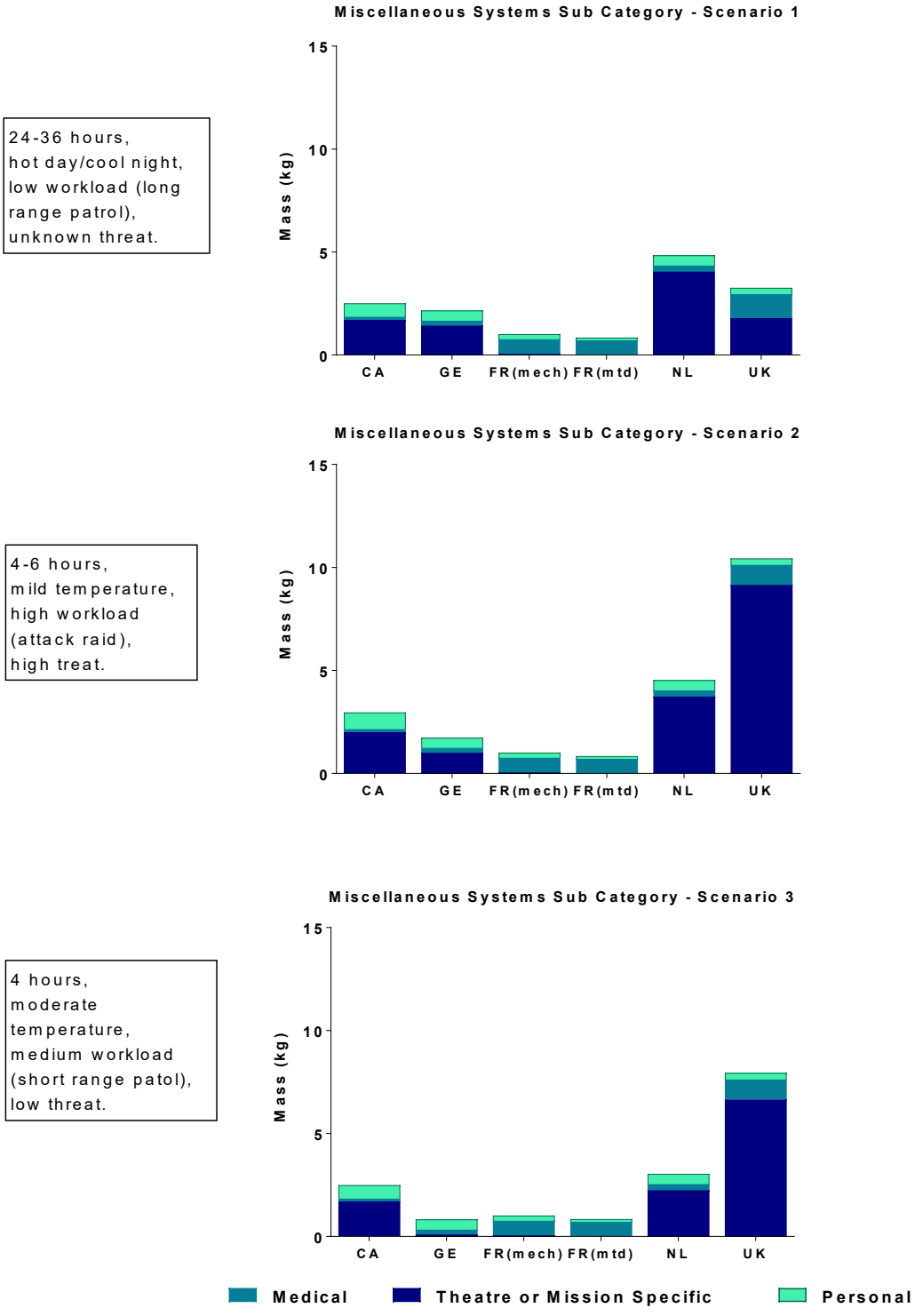


Figure 3-10: Miscellaneous Loads (kg) for CA, GE, FR, NL, and UK for the Three Scenarios.

3.2.11 Load Composition as a Proportion of Total Load Mass

As mentioned at the beginning of the results section, all summary data are provided in Appendix 3. These are presented in two summary tables. Table 3A3-1 (see Appendix 3) summarizes national load mass data (in kg) by gear category and sub-categories for each scenario (or for generic scenario/doctrinal load as applicable). Table 3A3-2 translates those data into percentages of load mass by gear category and sub-category so that data are normalized across nations. Figure 3-11 depicts the latter data to permit normalized analysis of load composition as a proportion of total load mass.

To highlight potential targets for mass reduction, each gear category was examined according to the percentage of total mass carried for each of the three scenarios (Figure 3-11). It is readily apparent that, regardless of scenario, the two gear categories that contribute most to total soldier load mass are Protection and Weapon System, with either Subsistence or Sustainment gear categories following next, depending on nation and scenario. The protection, category accounts for approximately (across all nations and scenarios) 33% of average total soldier load mass[8], followed by Weapon system, accounting for approximately 30% of total mass. The remaining gear categories contributed significantly less in terms of proportion of load; in decreasing order of contribution, these are as follows: Subsistence (14%), Sustainment (10%), C4I System (6%), Miscellaneous (5%), and Enhanced Vision (6%).

In order to pinpoint the actual source of these contributors Figure 3-12 and Figure 3-13 show the content breakdown of the two gear categories that contribute most to total load mass – Protection and Weapon System. Figure 3-12 shows that ballistic protection is by far the biggest contributor to protection load mass, accounting for 20% of total load mass (versus 13% for non-ballistic protective equipment). Figure 3-13 indicates that both ammunition and weapon system contribute equally to total load mass, with ammunition contributing 13% of total load mass and the weapon system contributing 12% of total load mass. Only the non-power subsistence sub-category (at 13% as indicated in Table 3A3-2) approaches these levels of contribution to total load mass.

[8] For actual percentage values (by sub-category and for each nation and scenario, refer to in Appendix 3 to this chapter.

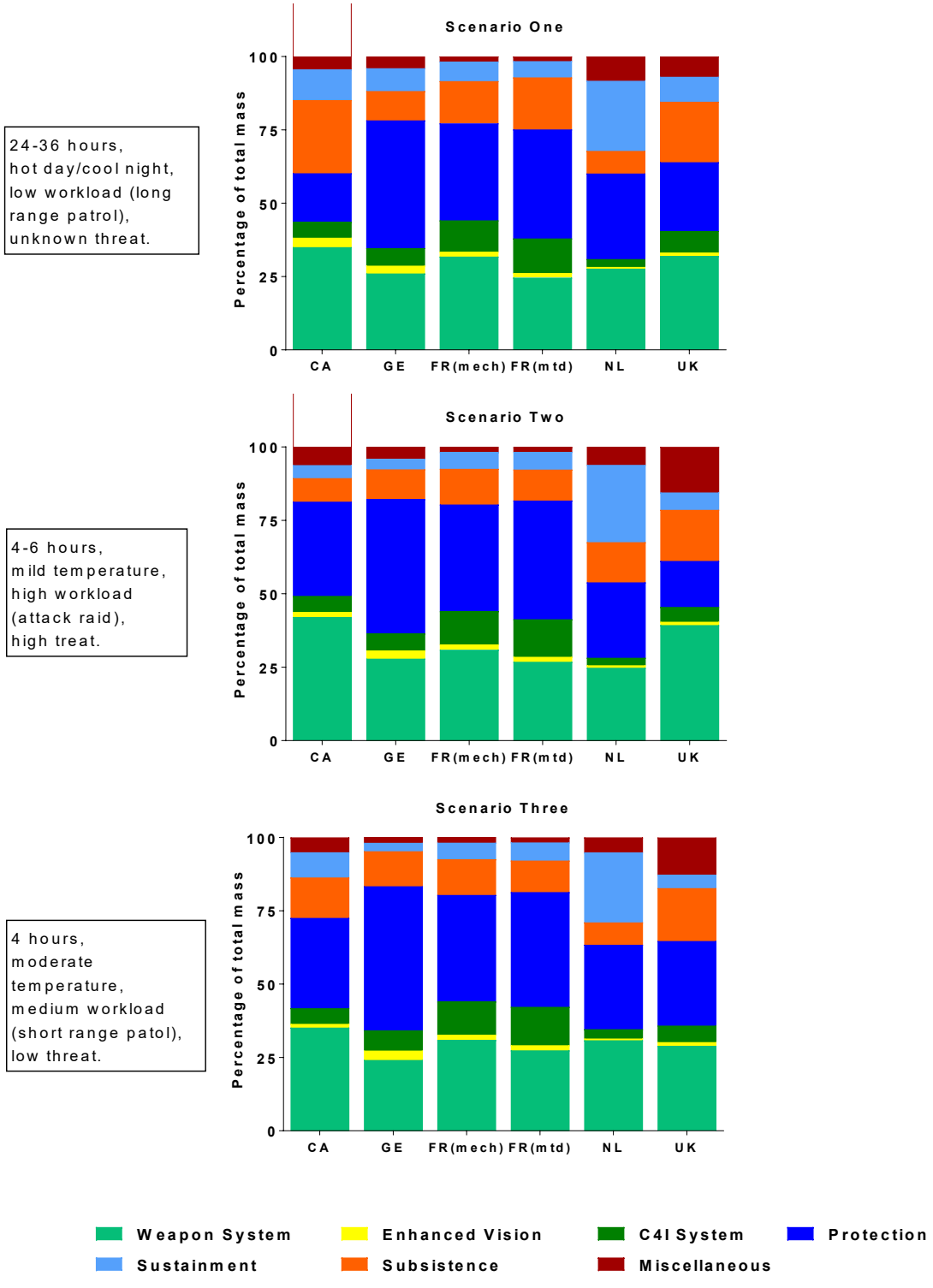
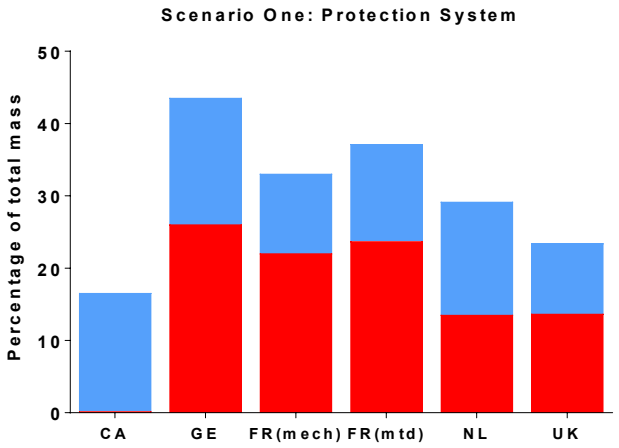
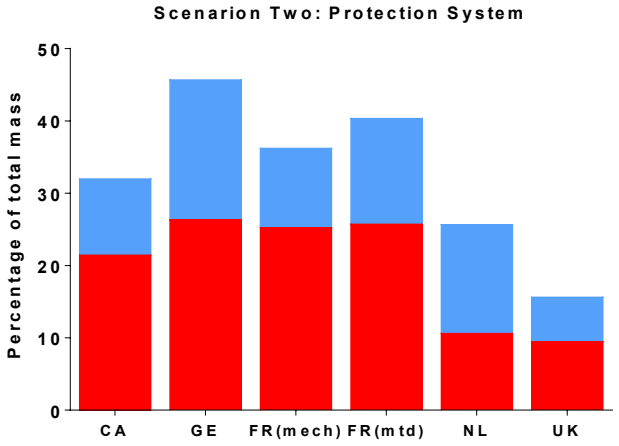


Figure 3-11: Load Categories Expressed as a Percentage of Total Load Mass.

24-36 hours, hot day/cool night, low workload (long range patrol), unknown threat.



4-6 hours, mild temperature, high workload (attack raid), high treat.



4 hours, moderate temperature, medium workload (short range patol), low threat.

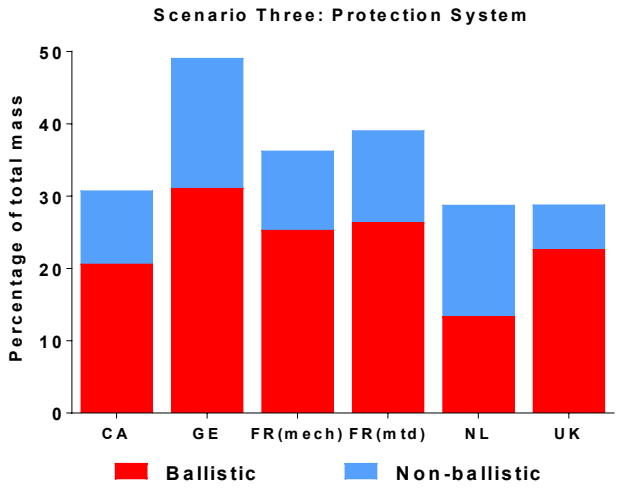
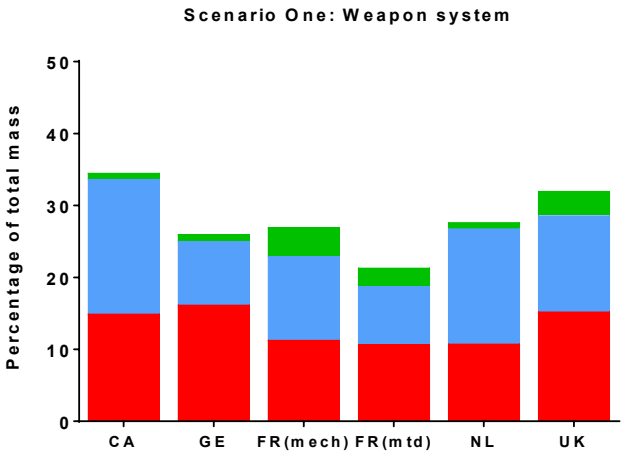
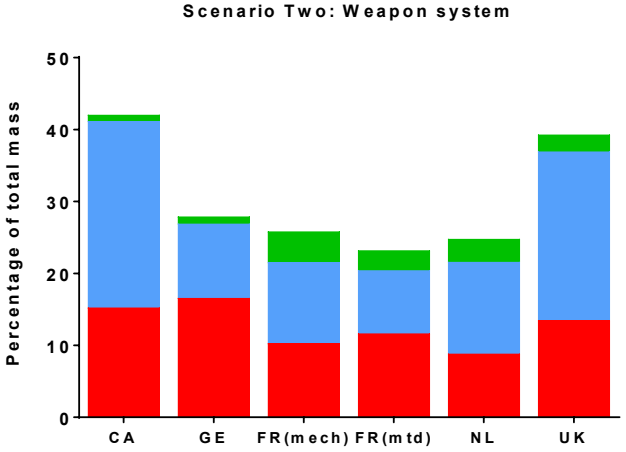


Figure 3-12: Proportion of Total Soldier Loads Due to Protection System.

24-36 hours, hot day/cool night, low workload (long range patrol), unknown threat.



4-6 hours, mild temperature, high workload (attack raid), high treat.



4 hours, moderate temperature, medium workload (short range patol), low threat.

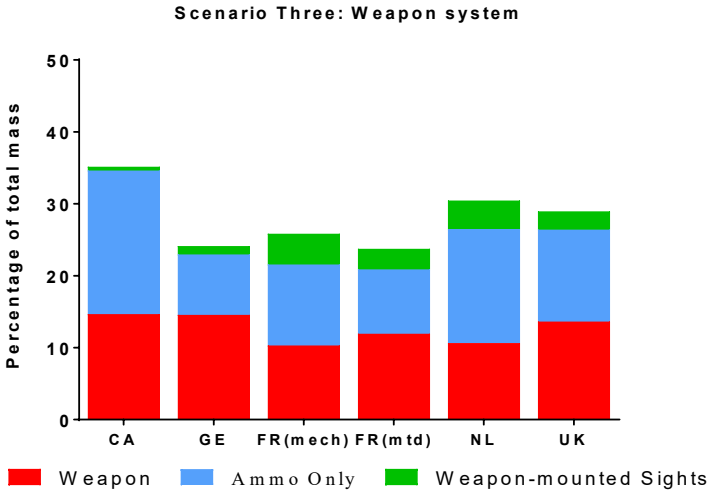


Figure 3-13: Proportion of Total Soldier Loads Due to Weapon System Sub-Categories.

3.2.12 Soldier Loads by Dismounted Squad/Group/Section Role

Seven participating nations gathered soldier load data by dismounted squad/group/section role; these nations included AS, CA, DE, FR, NZ, UK, and the US. Table 3-4 shows the contributions of each nation to the dataset considered in the following analysis. Figure 3-14 presents the mean soldier load mass, averaged across scenarios and contributing countries for each role.

Table 3-4: Contributions of Role-Specific Load Data by Nation.

Nation	Scenarios	Roles for Which Data were Provided							
		Squad Leader (Group Leader, Section Commander)	Section/Squad/Group Second in Command (2 I/C)	Rifleman	Grenadier	Light Machine Gunner	Marksman / Sharpshooter	Anti-Tank Specialist	Heavy/ General Purpose Machine Gunner
AS	Generic	✓	✓	✓	✓	✓			
CA	1,2, 3	✓	✓	✓	✓	✓			
DE	1,2, 3	✓	✓	✓	✓	✓	✓	✓	
FR	1,2, 3	✓	✓	✓		✓	✓	✓	
FR	1,2, 3	✓	✓	✓	✓	✓	✓	✓	✓
NZ	Generic	✓		✓	✓		✓		
UK	1,2, 3	✓	✓	✓	✓	✓	✓		✓
USA	Generic	✓	✓	✓	✓	✓			

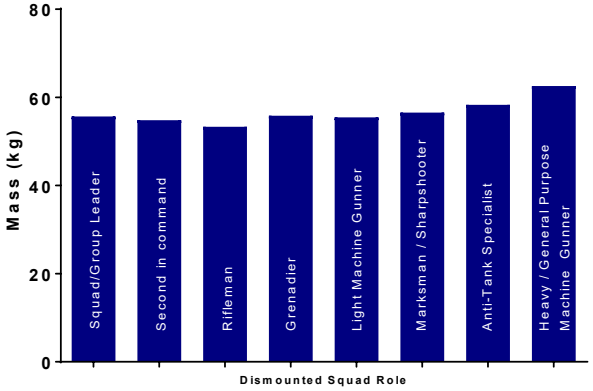


Figure 3-14: Average Absolute Soldier Load Mass (kg) by Role Across All Contributing Nations.

In general, (i.e., across all scenarios) the heaviest loads are typically carried by those in specialty/support weapon roles. For example, the heavy or general purpose machine gunner carries, on average, the heaviest load (62.56 g), followed by the anti-tank specialist (58.31 kg), sharpshooter (56.56 kg), grenadier (55.85 kg), and light machine gunner (55.46 kg). The squad leader, also known as the Section Commander (in AS, CA, UK) or Group Leader (in NL) carries the next heaviest load (55.67 kg), followed by the squad/section/group second in command (54.83 kg). The lightest loads are typically carried by the rifleman (53.32 kg). It should be noted that, in most nations, ammunition and associated equipment loads for these area and support weapons are typically distributed amongst the squad or section in order to mitigate any undue burden on a single role or individual. Loads are also routinely distributed to take into account the size, mass, or capacity of the individual members of the team.

Figure 3-15 shows the proportion of the squads load by nation, scenario, and dismounted infantry role. Again, it is quite evident, for those nations that provided data, that specialty support weapon roles like Machine Gunner, Marksman or Anti-tank specialist, carry heavier loads than other squad roles. Apart from those heavier support weapon loads, loads appear to be relatively evenly distributed across the squad in most nations and for all three scenarios.

Appendix 4 provides more detailed results for load composition by role for each nation and across scenarios.

3.2.13 Overall Equipment Overload

In order to determine the extent to which soldiers from participating nations are overloaded, it was decided to apply the generally accepted doctrinal guidance that soldier loads should not exceed 30% or 45% of body mass for fighting and marching loads respectively (the rationale for which was described in the introductory section of this chapter). The amount of overall equipment overload and how it was calculated is shown in Table 3-5 below. The average infantry soldier body mass presented in Table 3-5 was provided from each nation's most recent anthropometric survey. Percent soldier overload for Scenario 2 (or doctrinal/generic scenarios) was calculated for each nation by dividing the total load mass for the highlighted scenario by the recommended load limit of either 30% or 45% of body mass.

Soldier loads range from 48% (for NZ, generic scenario) to 85% of soldier body mass (for AS, generic scenario). For those nations who used the three scenarios, loads ranged from 55% to 83% of body mass. Every example significantly exceeds recommended load limits of 30% or 45% of body mass. The percentage overload ranged from 121% to 283% of the recommended maximum load limits.

3.3 DISCUSSION

3.3.1 Differences in Soldier Equipment Between Nations

There are several obvious differences between NATO nations in terms of the dismounted infantry section/squad/group that go beyond naming conventions or size. The dismounted soldier system design and its composite equipment differs significantly amongst the various countries, so one would reasonably expect variability in terms of soldier loads between nations. Examples of equipment differences include:

- Weapons carried by soldiers of different nations differ in mass, type, and distribution within the dismounted section/squad/group.
- Soft and hard armour coverage. Fragmentation and bullet protective gear varies in size, coverage, and placement. Not all nations have (or use) side plates or groin protection.
- Some nations separate ballistic protection from load carriage equipment (e.g., CA)[9], adding to load mass.
- Some nations are implementing significantly more C4I equipment (e.g., FR FELIN) than others. As nations continue to implement soldier modernization programmes, load mass due to enhanced vision, C4I equipment, and power sustainment gear is expected to rise.
- Some nations carry more electronic jamming equipment (e.g., UK) in the dismounted section than others.

[9] Separation of ballistic protection and load carriage capability allows soldiers to maintain protection while: reducing combat load for administrative or heavy work tasks such as moving sandbags or digging a trench; reducing bulk for vehicle occupants; and allowing armour to be worn under insulation (to retain loft) in arctic gear.

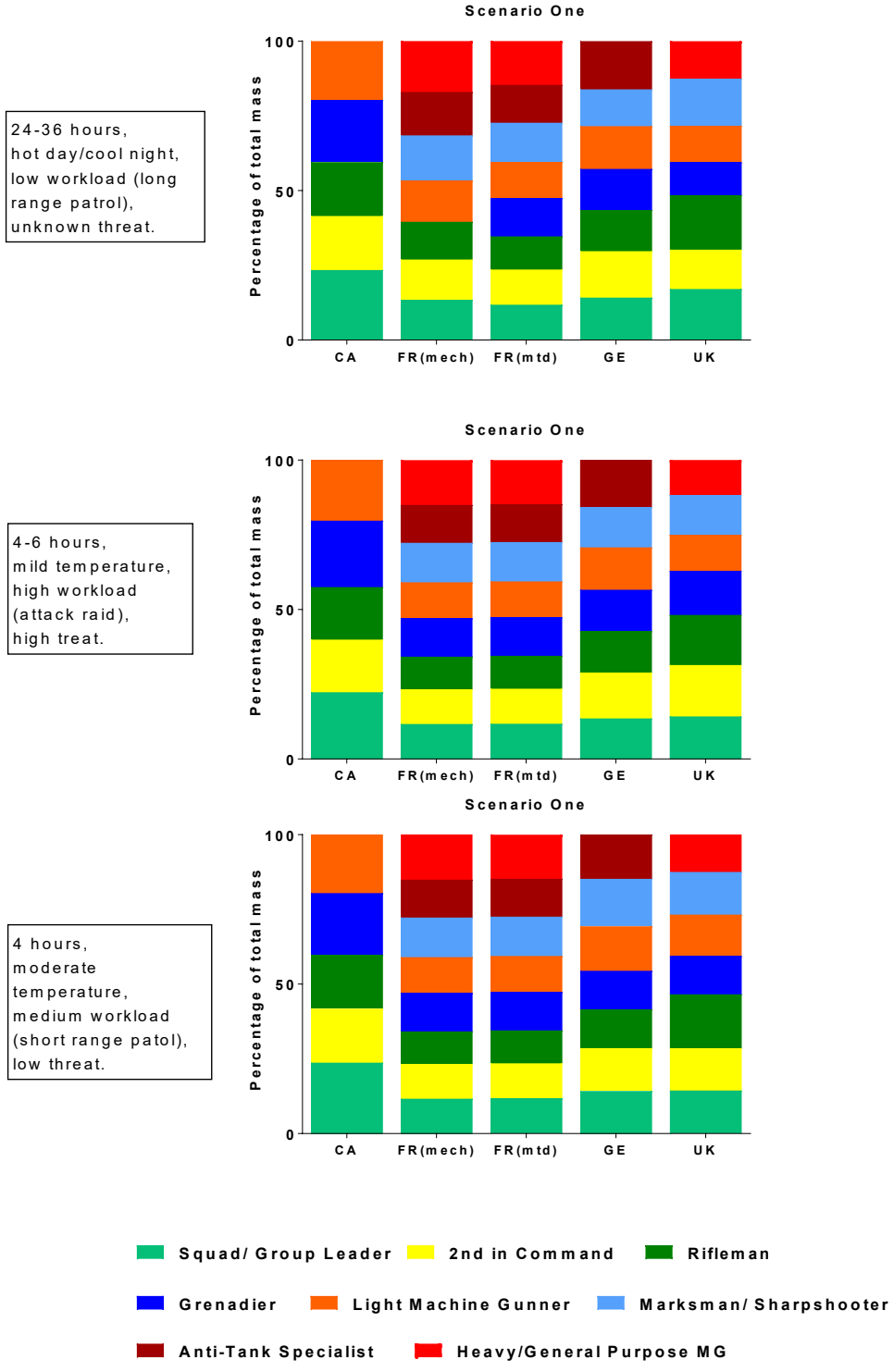


Figure 3-15: Proportion of Squad Total Mass by Role Across Nations and Scenarios (Percent).

Table 3-5: Dismounted Soldier Overload. Data are presented for each nation and are based on doctrinal recommendations for maximum loading (30% or 45% body mass). Dismounted infantry soldier mass was based on the average male weight from each nation's most recent anthropometric survey data. 2The rationale for using 30% and 45% of body mass is provided in Chapter 1 and Section 2 of this Chapter.

Nation	Infantry Soldier Body Mass (kg)[1]	Load by Scenario (kg)			Load by Scenario (% Body Mass)			% Overload for Highlighted Scenario (Scenario 2, Doctrinal or Generic Scenario)	
		1	2	3	1	2	3	(Using 30% body mass fighting load limit)[2]	(Using 45% body mass approach march load limit)[2]
CA	86.80	49.05	47.40	49.38	57	55	57	182	121
GE	79.80	53.87	53.16	45.08	68	67	56	222	148
FR(mech)	75.00	59.45	56.02	56.02	79	75	75	249	166
FR(mtd)	75.00	53.76	49.42	48.33	72	66	64	220	146
NL	82.10	58.35	62.30	59.13	71	76	72	253	169
UK	81.10	46.93	67.21	62.30	58	83	77	276	184
AUS	82.70	70.17			85			283	255
NZ	85.52	41.03			48			160	144
SWE	85.52	51.92			61			202	182
USA	85.49	52.39			61			204	184

3.3.2 Differences in Soldier Load Mass Between Nations

Some nations appear to consistently carry lighter loads than others, regardless of scenario. Examination of average national loads in Table 3-3 indicates that CA, GE, and NZ soldiers may carry lighter loads than their NL or UK counterparts. Whether this reflects reality or is merely a reflection of the circumstances and/or limitations of this study is difficult to ascertain. Data collection was conducted independently by each nation, using slightly different methods, different data collectors, and different stimulus materials (i.e., Dutch scenarios had to be translated into national language/vernacular. Not all nations used gear cards, etc.). Potentially different soldier SME demographics (which were not collected/ shared for analysis) may have contributed to differences in scenario interpretation and context assumptions. The extent to which non-issue or mission-specific gear were identified by soldier SME participants (which would naturally add to load mass) may also have been biased by the method employed by each nation.

3.3.3 Adaptation to Mission Scenarios and Context

Examination of average total loads by scenario reveals surprisingly little adaptation to meet specific mission or scenario requirements. One would expect that factors such as environmental conditions, threat, mission duration,

or workload, which varied substantially across the scenarios used in this exercise, would dramatically influence the loads carried. However, as shown in Table 3-3, mean load mass was surprisingly consistent across the three scenarios for most nations (UK being the notable exception with a difference in loads across scenarios of slightly over 20 kg).

Where adaptations to average total load mass were made by nations, these were inconsistent across scenarios. Two of the five participating nations (FR, GE) reported the heaviest loads for Scenario 1 (the longest duration mission with widest temperature variability), two (UK, NL) had the heaviest loads for Scenario 2 (unspecified duration but involving guaranteed combat with attack raid on an IED factory). Either of these outcomes were not surprising, considering the scenario circumstances. Contrary to all the others, however, one nation (CA) had their heaviest load associated with the short range patrol mission (Scenario 3), the mission that was associated with the lightest loads for all others (aside from the UK whose soldiers indicated a requirement for significant counter-IED protection and mission-specific jamming gear). While the data collection method employed by CA might have contributed to this seemingly surprising outcome[10], one should note that there was a mere 1.98 kg difference between CA loads across all scenarios. An alternative explanation may be that soldiers bring gear with the experience and in anticipation that mission circumstances such as duration could change at any time; if they want to be prepared for that, their loads will be similar, regardless of scenario.

Analysis of differences in load composition did reveal some degree of adaptation by some, but not all, nations. Analysis of load mass by gear category across nations revealed the following adaptations and national differences:

- **Weapon System –** the greatest variability in load mass for the weapon system came from ammunition loads, though this was not consistent across all participating nations. Not surprisingly, three of the five nations (CA, NL, UK) had significantly higher ammunition loads for Scenario 2, which involved an attack raid to destroy an IED factory. The other two nations (FR, GE) did not appear to adjust their ammunition load according to the task or threat circumstances.
- **Enhanced Vision –** For this gear category, only two nations appeared to alter their load mass noticeably. CA soldier SMEs opted not to bring head-mounted night vision gear for Scenarios 2 and 3. Neither mission mentioned night operations and CA soldier SMEs reported that they would be carrying weapon-mounted flashlights to deal with the possibility of dimly lit indoor tasks during the IED factory raid of Scenario 2. NL soldier SMEs chose a much lighter weapon-mounted sight for Scenario 1 than that chosen for the other two scenarios.
- **Non-ballistic Protection –** There were surprisingly few or very minor changes to non-ballistic protection in spite of the wide range of environmental, threat and workload conditions across scenarios. CA soldier SMEs elected to bring more environmental protection in Scenario 1 due to overnight, cool nights, and perceived low threat. Somewhat surprisingly, NL soldier SMEs chose slightly higher non-ballistic protection loads in Scenario 2. This might be explained by their interpretation of the scenario being an overnight one, given the lack of clarity about mission duration for Scenario 2.
- **Ballistic Protection –** More obvious changes were made to ballistic protection loads. CA soldier SMEs notably elected not to wear or bring body armour for Scenario 1. Their rationale was based on low perceived threat and concern about thermal casualties due to hot day-time conditions. While nights were cool, these soldier SMEs assumed that the enemy lacked night fighting capability as well. During

[10] CA soldier SMEs identified equipment items sequentially, first for Scenario 1, then 2, then 3. The consensus load list for each scenario was built upon the list arrived at for the preceding scenario. While every effort was made to revisit previous scenario load lists when new items of equipment were identified, this may not always have happened equally rigorously (due to data collection time constraints).

consensus discussion, CA SMEs pointed out that while they would choose *not* to bring body armour, their experience indicated that they would not be given such a choice in real operations and would likely have been ordered to wear armour in spite of the thermal and threat conditions. UK soldier SMEs elected to wear significantly more protection (more coverage and heavier armour) for Scenario 3, given the mention of previous IED incidents in the scenario context description.

- **Subsistence –** The amount of subsistence load identified by soldier SMEs varied dramatically across nations, and across scenarios for each nation. This variability was predominantly due to the mass of non-power subsistence (i.e., water, food, and equipment for storing, preparing, and/or consuming these). In spite of anecdotal reporting, load due to power sources was surprisingly low across most nations. As more and more NATO nations begin implementing their soldier modernization programmes, delivering networked capabilities with new soldier systems comprising more and more C4I gear, loads due to power are anticipated to rise. Many NATO nations are conducting (or monitoring) research in the areas of power generation, storage, and management, in anticipation of this future.
- **Sustainment –** Sustainment loads (load carriage and overnight gear requirements) also varied considerably between nations, particularly for Scenario 2 – this variability may be a reflection of the differences in interpretation of mission duration (which was not spelled out in stimulus materials). There was also variation in sustainment load between missions for most countries. Much of this variation appeared to relate to scenario duration, which is what one would expect.
- **Miscellaneous –** This category comprises mission-specific, medical, and personal gear. There was significant variability between nations in terms of miscellaneous load mass, ranging from less than 1 kg to over 10 kg. Some nations indicated little to no mass due to personal gear (such as tobacco products, identification, money, smart phone, reading material, etc.); this may be a reflection of the methodology adopted (i.e., they may have considered only issued items of equipment). Theatre or mission-specific gear accounted for the largest difference in loads between nations for this category. Only a few nations identified heavy gear (i.e., breaching kit, anti-jamming equipment) that perhaps other nations may have assumed were Platoon resources and therefore out of scope for the load of a dismounted rifle section.

Not apparent in the data reported, but evident to several data collectors, is the role of experience of soldier respondents with regards to the load choices made. French data (not shown here) collected from two motorized regiments demonstrated that the variability of load carried due to scenarios was larger when the responder had more experience and weaker when the responder was younger (and less experienced). Experience probably helps with decision-making regarding what is essential, useful, and not needed for a given scenario. Younger more inexperienced soldiers tend to demonstrate two trends, either taking too much or not taking enough, which may threaten mobility and self-sufficiency, respectively. Another strategy evident amongst experienced soldiers is the distribution of particularly heavy loads (e.g., area weapon ammunition and components) across several dismounted soldiers in the group when possible.

In general, there was surprisingly little adaptation to the circumstances of the scenario. It may well be that soldiers carry as much as they can, of whatever they feel is important to the particular mission, so in that sense, their loads may well be task-tailored. However, their tolerance limit for load is well beyond doctrine and what is recommended, whether one considers physiological strain, biomechanical perturbation, injury potential or operational performance penalty, suggesting the need for a number of interventions, including some suggested by other authors (including Refs. [17], [18], [19], [20]): leader intervention to limit loads, education of military leaders about the consequences of overload; unit and sub-unit collective training that requires mission-specific load planning by leaders and soldiers and that provides the necessary practical experience with the consequences of these loading decisions; exercises that include tactical resupply to improve soldier confidence in resupply

reliability; and an organizational culture that rewards leaders who monitor and correct soldier overloading due to ”worst case” load planning inclinations.

Research and development efforts should focus on filling knowledge gaps in the trade space of loads versus performance versus vulnerability (to injury, exertional or heat illness, or susceptibility to enemy fire) in order to inform the development of reliable load planning decision-support tools for military leaders. While we know that loads affect individual soldier task performance (such as mobility speed, postures and bounding behaviours[11]), the degree to which these load-induced changes impact soldier vulnerability, mission outcomes and ultimate force survivability are much less clear, may be very difficult to measure or derive, but will be important in the design of reliable decision-support tools (as well as to convince leadership and soldiers that overload is a survivability issue!). Appropriately designed physiological monitoring systems[12], integrated into soldier systems and employed effectively on exercises, would support training of soldiers to recognize the signs and symptoms of, and impact of loading choices on, exertional or heat illness. These same data, if appropriately contextualized, could be invaluable for developing trade-off models to feed improved load decision-support tools.

3.3.4 Load Mass by Soldier Role

Examination of role-specific loads confirms expectations that the heaviest loads are carried by those in specialty or support weapon roles (such as grenadier, machine gunner, marksmen or sharpshooters, and anti-tank specialists). Squad/section/group leader (and second in command) loads follow closely behind. Some nations (AS, CA, NZ, US) seem to do a better job than others in distributing those heavier loads amongst other dismounted section members. This may be partially attributable to the data collection methodology employed by nations. For example, if individual soldier SMEs were asked to report the loads they would carry in their individual role only, the averaged national data would be less likely to reflect a practice of distributing load amongst section members. On the other hand, where nations had soldier SMEs identify loads across the section roles in a group consensus manner (as described in Appendix 2 for Canada), the practice of load distribution amongst section members would be more apparent. It may also be a reflection of the experience levels of soldier SMEs consulted by those nations since experience seems to lead to greater adaptation of loads to mission circumstances. In any case, a take-away recommendation is that, where possible, the heavier loads of specialty/support weapon roles (i.e., spare ammo, barrels, etc.) should be distributed amongst section members to the extent practicable, in an effort to reduce the load burden on individual soldiers.

3.3.5 Load Composition Analysis

Analysis of load composition as a proportion of total average load mass (refer to Section 3.3.3) reveals several specific opportunities for load reduction. The two gear categories that account for the greatest proportion of soldier loads across nations and scenarios were the Protection and Weapon System categories.

Protective gear accounts for 33% of total average load (Table 3A3-2, in Appendix 3A3). Ballistic protection, in particular, makes up the largest proportion of total load at 20% (the highest proportion of load across all 15 gear sub-categories). How might the mass of ballistic protection (i.e., helmets, body armour) be reduced? Advances in material science can lead to reductions in the mass of armour, although these reductions may be quite modest, on the order about 6% to 10% [3], [15], [21]. There is potential to achieve significant burden mitigation (as much as 20 to 45 % mass reduction according to [21]) with the design and effective employment of modular, scalable

[11] See Chapter 1 for discussion and references supporting these performance decrements.

[12] As determined by currently ongoing NATO HFM Research Task Group 260, entitled “Enhanced War Fighter Effectiveness with Wearable Sensors and Physiological Monitoring”

armour systems that allow for alteration of the level and coverage of protection in order to adapt to the circumstances of the mission (type of unit, threat, environmental conditions, etc.). Several militaries have developed or are developing modular scalable armour systems, assessing the thermal, mobility and vulnerability implications for each tier, configuration or armour protection level, and developing decision-support tools or employment guidance for users [23], [24], [25]. However, the trade space, of protection versus mobility versus vulnerability (to exertional or heat illness, or susceptibility to enemy fire) and overall survivability, is not well researched or understood. Further research will be essential to fill this knowledge gap in order to develop reliable decision-support tools, essential for commanders who must make appropriate protection level decisions that balance risk between competing threats (of burden effects versus enemy action).

The extent to which military units who have modular scalable armour actually adapt their armour protection levels on operations is unknown, however, soldier SME engagements by several nations suggest a tendency to overprotect, at the risk of increasing heat casualties, or casualties due to burden-induced impaired performance (physical or cognitive). Doctrine that encourages adaptation of protection, development of science-based decision-support tools, education about the consequence of overload due to over-protection; education about the concept of integrated survivability[13], and training that reinforces and rewards sound evidence-based armour protection level decision-making, would all help with successful implementation of modular, scalable protective systems.

The Weapon System gear category accounted for the next highest proportion of loads (at 30% on average across nations and scenarios), with weapon mass and ammunition accounting for similar proportions of total load mass (at 12% and 13% respectively). Several interventions might be suggested here. Mass reductions may be achieved using new materials and technologies, perhaps more so for ammunition, magazines, or weapon ancillaries (e.g., sighting, aiming and illumination aids) than for weapons themselves (where a minimal mass may be needed to mitigate recoil effects). Better integration of weapon ancillaries may also contribute to reduced overall weapon system mass or improved mass properties with concomitant enhancement of performance [26], [27]. Lighter-mass plastics have replaced metal magazines in some nations. Several nations are pursuing the development and testing of caseless ammunition in order to reduce soldier load (or increase lethality for the same load). It has been suggested [28] (as cited in Ref. [2]) that improvements to marksmanship may also contribute to reduced ammunition loads (i.e., fewer rounds needed to hit intended targets, though the need to expend significant amounts of ammunition for suppression must also be recognized). Finally, consideration should be given to ammunition loads carried by soldiers. CA studies and user engagements [29], [30] indicate that dismounted CA soldiers typically carried 10 to 12 loaded magazines of 5.56 ammunition in Afghanistan, yet ammunition expended in firefights rarely exceeded two magazines, Amongst the hundreds of soldiers queried, few soldiers had, or knew of any soldier who had, expended their full ammunition load in a firefight, and there were no reports of failures in resupply. While there certainly had to be situations when soldiers ran out of ammunition, these findings reflect concern about ammunition or “fire” loads that has been repeatedly expressed by senior officers in the literature reviewed [17], [18], [19]. They attribute much of this to a leadership problem and insist that leaders need to do better load planning, give proper direction, and monitor compliance in order to balance the risks between burden and not having the supplies needed for every possible contingency.

3.3.6 Degree of Soldier Overload

It is clear from all results that soldier loads, regardless of nation or scenario, are alarmingly high (55 % to 83 % of average soldier body mass by nation), significantly exceeding recommended, doctrinal or generally accepted

[13] Integrated survivability considers that survivability depends on multiple layers of defence – not being there, not being seen, not being targeted, not being hit, not being penetrated, and not succumbing to the penetration. Personal protection should be considered amongst the last lines of defence – not the sole line of defence against ballistic threats.

load limits of either 30% or 45% body mass for fighting or approach march loads respectively. Overloads as calculated and presented in Table 3-5 range from 144 % to 276 % based on how much each nation exceeds those doctrinal load limits. As presented in Chapter 1, this degree of overload can have serious consequences in terms of soldier well-being and task performance, suggesting increased vulnerability to enemy fires, and impact on ultimate mission effectiveness.

Referring back to General Marshall's mention of soldiers as "beasts of burden" [18], it is worth noting that farmers (and some militaries) are very careful to limit loads for mules and horses to much less than even the soldier doctrinal load limits of 30% or 45% body mass [7], [18], [31]. This is paradoxical given that energy expenditure to carry loads is significantly less in equines than that of humans [32], and unlike soldiers, these "beasts of burden" are not required to go into battle once they have delivered their loads to their objective.

This maximum loading formula, upon which a century of doctrine has been based, relies solely on body mass as a predictor of load carrying capacity. This is quite unsuitable given the military context and the myriad of factors that contribute to load-bearing capacity (see Chapter 4 and [2], [5], [11], [33], for supporting references). While simple to employ, the percent body mass guideline is not practicable in the soldier setting, since body mass is so variable across the population, and since so many common items of soldier equipment (e.g., weapons, ammunition, radi*os, etc.) a*re not massed to the individual (protective gear being the exception since these are typically sized, thus massed, to the individual). The formula also does not account for the dismounted soldier's state – strength, physical fitness, how well-rested, how physically fatigued, mental state, motivation, prior injury, to name only a few soldier factors that even intuitively might influence load carrying capacity. Tolerance of loads also depends on multiple soldier system factors not limited to the soldier's own capabilities, including: the clothing and equipment worn and carried, workload associated with their missions and tasks, and the environment in which they must operate (refer to Chapter 4 for a full review of these factors). Finally, a simple percent body mass calculation fails to predict the short or long term effects of loads on the dismounted soldier's health and well-being. It is widely appreciated that infantry soldiers who have been exposed to only a few years of training or combat operations are likely to have suffered hearing loss, foot, knee, lower back and other injuries and there is little doubt that overloading has contributed to the very high incidence of musculoskeletal injuries amongst soldiers [2], [34], [35], [36].

So the question of how much mass a soldier can, or should, carry or how long a soldier can carry a given load, is a complex one to answer and requires further research [33]. Our knowledge is limited in terms of what parameters to look for when recruiting or training for load-bearing capability (see Chapter 4), performance under load (see Chapter 1), or resilience to repeated loading in training and on operations. There are a few instruments from the field of occupational safety and health, to help determine maximal permissible loads, including those listed below:

- The National Institute for Occupational Safety and Health (NIOSH) formula for Recommended Mass Limit (RWL)[14] [37] is mostly used for lifting and carrying tasks in industry and construction settings, and is referred to by various occupational health and safety standards/regulations;

[14] RWL = LC x HM x VM x DM x AM x FM x CM
where LC is the load constant (23 kg) and other factors in the equation are:

- HM, a Horizontal Multiplier factor
- VM, a Vertical Multiplier factor
- DM, a Distance Multiplier factor
- FM, a Frequency Multiplier factor
- AM, an Asymmetric Multiplier factor
- CM, a Coupling Multiplier factor

- The Rapid Upper Limb Assessment (RULA) tool [38] was developed to consider biomechanical and postural load requirements of job tasks/demands on the neck, trunk and upper extremities.

However, these tools are not valid in the military dismounted soldier situation for many reasons, including: the nature of load carriage tasks; work week duration is not limited to eight hours, five days per week; the population is younger and more fit than the general civilian working population; and mission success trumps occupational health and safety considerations on operations. So, there is a strong recommendation to develop a better standard for dismounted soldier loading that considers the unique circumstances of the military domain, while considering physical (and cognitive) task performance requirements.

The vast majority of load carriage research has focussed on males, though there is a growing body of load carriage literature applicable to women (see Chapter 4). With increasing numbers of women entering combat arms and other military occupations that require carriage of heavy loads and exposure to combat, it is essential that sex differences are considered when developing load carriage capability (across the domains of personnel selection, equipment development, training, doctrine, *etc*.) as well as standards.

3.3.7 Study Limitations

Several study limitations have been mentioned throughout this chapter and there are others that should be considered before drawing conclusions about NATO soldier loads. Firstly, not all NATO nations participated, so the extent to which the data reported here reflect NATO soldier loads is not clear. Secondly, data collection methodology was not consistent across nations or soldier participant groups, as has been highlighted in the methods section. Additionally, the scenarios used in this study were developed hypothetically and the loads associated with them may not accurately represent the loads actually carried by soldiers on operations. Soldier SMEs consulted in this study were not required to pack and bear the loads they proposed for each scenario; in other words, they would not have had the physical load feedback that an actual load would provide. So, it is not unreasonable to think that the loads reported here may be exaggerated.

France reports that, for a tactical patrol mission with a succession of mounted and dismounted periods (between seven to eight hours) in Central Africa, the total load dismounted soldiers carried was 40 kg with 10 kg in the backpack. Since the backpack can be left behind in the vehicle, one can conclude that actual load carried by a basic rifleman was about 30 kg, significantly lower than the 53.6 kg load chosen by FR for hypothetical scenario 1. The apparent discrepancy was determined to be related to the lack of C4I and vision enhancement equipment during this particular Central African deployment (which did not employ the FELIN soldier system). Other studies from the UK [39] showed that the dismounted soldier load was even higher in theatre.

Ideally, actual soldier loads and load composition should be measured on reasonably large samples of representative soldiers in actual theatres of operation, with detailed data collected about soldier demographics and characteristics (age, rank, role, training, experience, size, fitness, etc.), environmental conditions, mission/task and workload associated with those missions and tasks, and the outcomes of those loads carried (physiological, discomfort, injury, performance, casualties taken) while wearing the gear to truly gain a picture of the extent of the problem. This is rarely feasible for most nations. The authors believe that the hypothetical loads reported here are likely representative of typical combat mission loads of soldiers in any modern military, but efforts should be made to validate these data with data from operations (such as those collected by [40]).

3.4 CONCLUSIONS

The mass carried by soldiers from participating nations is well above doctrinal or reasonable limits, with potentially serious consequences in terms of soldier health, well-being, performance, and effectiveness. The impact on unit and mission outcomes is unclear but may be equally grave. Adaptation of load to account for mission circumstances such as heat, humidity, workload, threat, and mission duration does not appear to be universally or even widely practiced. Load composition analysis points to a need to address protective gear and weapon system loads as a priority. Multiple intervention strategies, across multiple capability areas, are likely needed to reduce load or mitigate the consequences of overloading. Included amongst these strategies are: education of leaders and soldiers, improved collective training, doctrine that requires mission-specific load planning and adaptation; technology solutions, as well as research to fill knowledge gaps in our understanding of the trade-offs between loads (particularly protection and ammunition loads), performance and vulnerability. This research is needed to inform the development of decision-support tools that will enable military leaders to make evidence-based decisions on operations that balance risk and ultimately enhance survivability and effectiveness.

3.5 ACKNOWLEDGEMENTS

The following persons are acknowledged by the authors for their invaluable contribution to this chapter in defining the scenarios, executing the load exercises/workshops, and/or assisting with data collection and analysis. These persons are:

- Alexandra Malgoyre (France);
- Dan Billing (Australia);
- Nicky Armstrong (United Kingdom);
- Garry Simpson (United Kingdom);
- Luke Hawkins (United Kingdom);
- Graham Fordy (New Zealand);
- Leif Hasselquist (United States);
- Ola Eiken (Sweden);
- Ulrich Rohde (Germany);
- Brittany Sinclair (Canada); and
- Warrant Officer Mariangeles Najlis (Canada).

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Appendix 1: GUIDANCE FOR THE LOAD EXERCISE / DATA COLLECTION

3A1.1 Introduction

This section describes the method, to be used by the NATO RTG HFM-238 members, to collect the data and how to report the collected data using the dismounted soldier load spreadsheet (distributed to members separately).

3A1.1.1 Military Target Population

The military target population consists of experienced group commanders (a group consists of a varying amount dismounted soldiers in the Netherlands, see below). Experience is defined in having an operational experience, as group commander, for a period of at least three years.

The study will focus on three different parts within the Army. The Dutch study used group commanders from: the infantry, mechanic brigade and the airmobile brigade. It is recommended for the study to involve three group commanders from similar military groups. At least five group commanders, for each group, will complete the dismounted soldier load spreadsheets.

3A1.1.2 Workshop Preparation

Three items have to be prepared for before the workshop can take place:

- The three military groups have to be chosen (see Section A3.1.3). The groups chosen for the Dutch study are specified below. Corresponding groups have to be chosen for each specific nation.
- The spreadsheet specifies Dutch military gear in various categories. The corresponding military gear, for each nation, has to be specified and categorized.
- The scenarios include support vehicles used by the Royal Netherlands Army. The corresponding vehicles, for each nation, have to be specified and clarified to the three groups.

3A1.1.3 Workshop

The military target population consists of experienced group commanders (a group consists of eight dismounted soldiers in the Netherlands). Experience is defined in having an operational experience, as group commander, for a period of at least three years. The study will focus on three different parts within the Army, the groups involved in the Dutch study are the:

- Dutch Air Maneuver Brigade (group has 11 combat dismounted soldiers);
- Dutch Marines (group has eight combat dismounted soldiers); and
- Dutch Mechanized Brigade (group has ten combat dismounted soldiers).

It is recommended for the study to involve, at least five group commanders, from three similar military groups. The core activity of the workshop is an exercise in which the participants pretend to go on a mission, and to select the military gear, given the above mention goals.

The participants in the workshop will be split into three groups, based on their function.

Each of the three groups will be presented with the three scenarios. The scenarios as presented to the groups are included in the scenario section of this document (Chapter 2). For each scenario, the groups will classify military gear items into two categories:

- At first to obtain the doctrinal equipment loads for such military personnel to conduct the three scenario(s): For instance: *'ask dismounted soldiers what their official procedures state they should carry to conduct the scenario(s)'*. The group commanders will put these cue cards (Figure 3A1-1) into the green bin.
- Secondly to identify those items of equipment that dismounted soldiers choose to carry in order to conduct the scenario(s). This list may deviate from the doctrinal load list. The group commanders will put these cue cards into the red bin (Figure 3A1-2).
- Third to explain the reasons why they choose not to carry the items.



Figure 3A1-1: Equipment Cards as Used During the Workshop.



Figure 3A1-2: Workshop Participants Categorizing the Cue Cards into the Red/Green Bins.

The military gear items, i.e., personal protection equipment, dismounted soldier systems (C4I, weapons, ammo), food and water, will be represented in using small cue cards (1/12th of A4 paper), showing the name and a picture of the item, its mass and in some cases its volume (see Figure 3A1-1). The items are colour-coded into the following categories:

- Sight (magenta);
- Overnight (gray);
- Food and water (brown);
- Weapons (yellow);
- Ammunition (black);
- C4i (red);
- Protection (blue);
- Vest (green); and
- Extra (orange).

During and after the process the groups will be asked to explain and reflect on their choices.

3A1.1.4 Data Processing

The results of the workshop will be used to complete the spreadsheet. The average results of all group commanders in a military group will be completed in the various tabs of the spreadsheet for each contributing nation. The reasons why group commanders chose to deviate from the doctrinal loading list will be documented qualitatively.

Appendix 2: NATIONAL DEVIATIONS FROM THE RECOMMENDED PROTOCOL

3A2.1 CANADA

The Canadian approach to data collection differed only slightly. Participants were drawn from the Combat Training Center Infantry School (Canada's Infantry Centre of Excellence) in Gagetown New Brunswick. Participants comprised five combat-experienced Senior NCOs (Warrant Officers), all instructors, and one deployment experienced Captain who was the Technical Adjutant for the school. The three scenarios were translated into Canadian Army vernacular (with adjustments to vehicles, nomenclature, weapon systems, *etc*. in order to facilitate their understanding) by a Canadian Army Infantry Warrant Officer reservist with multiple tour experience. The scenarios were presented via PowerPoint presentation by DRDC scientific staff (who also had military background and experience, albeit non-infantry). Data were collected by DRDC scientific staff. Instead of preparing gear cards, an in-service doctrinal load list was the starting point for identifying, by focus group discussion and consensus-building which items, in-service or commercial (personally-acquired), and how many of each item of clothing and equipment, would be carried by each member of a dismounted rifle section for each scenario. Roughly one day was spent reviewing and discussing each scenario and compiling a consolidated load list for each scenario by role. Following data collection, the mass of each item was determined (either measured directly or obtained via internet or NATO Stock Number catalogue consultation) and recorded on the data collection spreadsheet in order to calculate individual soldier mass (average across section and by role) and total load for the dismounted section. As much as possible, given time constraints, as new items of equipment were identified, earlier scenario load lists were revisited to ensure the same items were considered for those scenarios as well.

3A2.2 FRANCE

Spreadsheets for the three different scenarios were not necessarily completed by the same person across scenarios. This may have introduced a response bias that makes direct comparison of loads by scenario problematic. Nevertheless, efforts to control for this bias were made through the use of a training course dedicated for captains and commanders in which the scenarios were proposed and completed.

Note that at the time this exercise was conducted, the FELIN system had not been fully introduced into service. As such the soldiers will not have been as experienced using this system, therefore the mass of the FELIN system may not be a true representation of the system. FELIN equips soldiers with C4ISR and sighting devices whereas the currently fielded system, for which French soldiers have much experience, does not employ these capabilities. The C4ISR and sighting devices increase the soldier load mass in the FELIN system by approximately 8 kg and are integrated into the jacket.

Data collected for France distinguish two types of infantry regiments characterised as "light infantry" (motorized, that is those who possibly walk loaded for a longer distance, far from their vehicle) and as "heavy" infantry (mechanized - those who are always a close to their vehicle and can leave part of their burden in it). Hence, the commanders for these two types of regiments make different equipment choices.

Appendix 3: SUMMARY OF NATIONAL DATA – AVERAGE LOAD MASS

Table 3A3-1 summarizes national data of average soldier load mass (kg) for each scenario (or for generic/doctrinal scenario) by gear category. Table 3A3-2 summarizes the same data as percent of total load mass.

Table 3A3-1: Summary of National Data for Average Soldier Load Mass (kg) by Scenario and Gear Category.

NATION	SCENARIO	WEIGHT BY GEAR CATEGORY (kg)																				
		Weapon System				Enhanced Vision			C4I System	Protection			Subsistence			Sustainment			Miscellaneous				TOTAL
		Sub-Total	Weapon	Ammo Only	Wpn-mounted Sights	Sub-Total	Head-mounted Vision	Hand-held Vision	Sub-Total	Sub-Total	Non-ballistic	Ballistic	Sub-Total	Power	Non-power	Sub-total	Load Carriage Eqpt	Overnight	Sub-Total	Theatre or Mission Specific	Medical	Personal	All Categories
CA	1	16.94	7.34	9.19	0.41	1.58	0.90	0.68	2.64	8.10	8.00	0.10	12.19	0.20	11.99	5.10	4.40	0.70	2.51	1.70	0.15	0.66	**49.05**
CA	2	19.94	7.24	12.29	0.41	0.78	0.00	0.78	2.64	15.20	5.00	10.20	3.80	0.20	3.60	2.10	2.10	0.00	2.96	2.00	0.15	0.81	**47.40**
CA	3	17.36	7.24	9.86	0.26	0.63	0.00	0.63	2.64	15.20	5.00	10.20	6.81	0.20	6.61	4.24	4.24	0.00	2.51	1.70	0.13	0.66	**49.38**
GE	1	14.02	8.73	4.77	0.53	1.44	0.76	0.68	3.21	23.47	9.44	14.03	5.38	0.00	5.38	4.19	1.42	2.78	2.16	1.42	0.24	0.50	**53.87**
DE	2	14.83	8.82	5.49	0.53	1.44	0.76	0.68	3.12	24.32	10.29	14.03	5.38	0.00	5.38	1.91	1.39	0.53	2.16	1.00	0.24	0.50	**53.16**
DE	3	10.87	6.56	3.78	0.53	1.44	0.76	0.68	3.12	22.15	8.12	14.03	5.38	0.00	5.38	1.30	1.30	0.00	0.83	0.09	0.24	0.50	**45.08**
FR(mech)	1	18.89	6.72	6.92	2.39	1.02	0.76	0.00	6.34	19.66	6.55	13.11	8.56	1.62	6.94	3.98	2.98	1.00	1.01	0.05	0.71	0.25	**59.45**
FR(mech)	2	17.33	5.76	6.32	2.39	1.02	0.76	0.00	6.34	20.34	6.15	14.19	6.82	1.62	5.20	3.18	2.98	0.20	1.01	0.05	0.71	0.25	**56.02**
FR(mech)	3	17.33	5.76	6.32	2.39	1.02	0.76	0.00	6.34	20.34	6.15	14.19	6.82	1.62	5.20	3.18	2.98	0.20	1.01	0.05	0.71	0.25	**56.02**
FR(mtd)	1	13.24	5.76	4.33	1.38	0.84	0.58	0.00	6.34	19.98	7.24	12.75	9.54	1.62	7.92	2.98	2.98	0.20	0.84	0.00	0.71	0.13	**53.76**
FR(mtd)	2	13.24	5.76	4.33	1.38	0.84	0.58	0.00	6.34	19.98	7.24	12.75	5.20	0.00	5.20	2.98	2.98	0.20	0.84	0.00	0.71	0.13	**49.42**
FR(mtd)	3	13.24	5.76	4.33	1.38	0.84	0.58	0.00	6.34	18.90	6.15	12.75	5.20	0.00	5.20	2.98	2.98	0.20	0.84	0.00	0.71	0.13	**48.33**
NL	1	16.15	6.29	9.35	0.51	0.34	0.10	0.24	1.55	17.03	9.13	7.90	4.50	0.00	4.50	4.04	4.04	0.00	4.84	4.04	0.30	0.50	**58.35**
NL	2	18.35	6.54	9.45	2.36	0.61	0.10	0.51	1.89	19.03	11.13	7.90	10.10	0.60	9.50	7.79	4.54	3.25	4.53	3.73	0.30	0.50	**62.30**
NL	3	18.24	6.29	9.35	2.36	0.34	0.10	0.24	1.89	17.03	9.13	7.90	4.50	0.00	4.50	4.19	4.19	0.00	3.04	2.24	0.30	0.50	**59.13**
UK	1	15.02	7.16	6.28	1.59	0.53	0.35	0.18	3.45	11.00	4.58	6.42	9.69	0.86	8.83	3.99	3.74	0.25	3.25	1.79	1.15	0.32	**46.93**
UK	2	26.41	9.06	15.76	1.59	0.77	0.59	0.18	3.38	10.55	4.13	6.42	11.67	2.84	8.83	3.99	3.74	0.25	10.44	9.15	0.97	0.32	**67.21**
UK	3	18.04	8.49	7.97	1.59	0.77	0.59	0.18	3.52	17.97	3.84	14.13	11.24	2.84	8.39	2.84	2.59	0.25	7.93	6.65	0.97	0.32	**62.30**
AS	n/a	17.74	8.54	7.90	1.30	2.22	1.40	0.82	1.92	14.55	7.64	6.92	15.86	2.30	13.56	14.84	10.73	4.11	3.04	1.65	0.59	0.81	**70.17**
NZ	n/a	11.60	6.14	5.01	0.46	2.54	1.50	1.04	1.00	15.15	4.57	10.58	5.01	0.44	4.57	4.02	4.02	0.00	1.71	0.00	1.67	0.00	**41.03**
SWE	n/a	11.55	5.24	5.35	0.96	0.24	0.18	0.06	0.78	19.18	7.83	11.35	10.46	0.00	10.46	6.82	3.65	3.17	2.89	2.48	0.41	0.00	**51.92**
USA	n/a	14.89	6.06	7.75	1.08	0.71	0.62	0.10	0.80	19.86	10.05	9.81	10.67	1.28	9.39	4.62	3.77	0.85	0.84	0.00	0.83	0.01	**52.39**
	MEAN	**16.15**	**6.88**	**7.37**	**1.26**	**1.00**	**0.58**	**0.35**	**3.43**	**17.68**	**7.15**	**10.53**	**7.94**	**0.83**	**7.11**	**4.33**	**3.53**	**0.82**	**2.78**	**1.81**	**0.59**	**0.36**	**54.21**

Table 3A3-2: Summary of National Data – Percent of Average Soldier Load Mass by Scenario and Gear Category.

		PERCENT OF LOAD BY GEAR CATEGORY (%)																			
NATION	SCENARIO	Weapon System				Enhanced Vision			C4I System	Protection			Subsistence			Sustainment			Miscellaneous			
		Sub-Total	Weapon	Ammo Only	Wpn-mounted Sights	Sub-Total	Head-mounted Vision	Hand-held Vision	Sub-Total	Sub-Total	Non-ballistic	Ballistic	Sub-Total	Power	Non-power	Sub-total	Load Carriage Eqpt	Overnight	Sub-Total	Theatre or Mission Specific	Medical	Personal
CA	1	34.54	14.96	18.73	0.84	3.21	1.83	1.38	5.38	16.51	16.31	0.20	24.85	0.41	24.44	10.40	8.97	1.43	5.11	3.47	0.31	1.34
CA	2	42.06	15.26	25.93	0.86	1.64	0.00	1.64	5.56	32.07	10.55	21.52	8.02	0.42	7.59	4.43	4.43	0.00	6.23	4.22	0.32	1.70
CA	3	35.15	14.65	19.98	0.53	1.27	0.00	1.27	5.34	30.78	10.13	20.66	13.80	0.41	13.39	8.59	8.59	0.00	5.07	3.44	0.27	1.33
GE	1	26.03	16.20	8.85	0.98	2.67	1.41	1.26	5.96	43.57	17.52	26.04	9.99	0.00	9.99	7.78	2.64	5.15	4.01	2.64	0.44	0.93
DE	2	27.90	16.58	10.33	1.00	2.71	1.43	1.28	5.87	45.75	19.36	26.39	10.12	0.00	10.12	3.59	2.61	1.00	4.06	1.88	0.45	0.94
DE	3	24.11	14.56	8.39	1.18	3.20	1.69	1.51	6.92	49.13	18.01	31.12	11.93	0.00	11.93	2.88	2.88	0.00	1.84	0.20	0.53	1.11
FR(mech)	1	31.77	11.31	11.64	4.01	1.71	1.27	0.00	10.66	33.06	11.02	22.04	14.40	2.72	11.68	6.69	5.01	1.68	1.71	0.08	1.19	0.43
FR(mech)	2	30.93	10.29	11.28	4.26	1.82	1.35	0.00	11.31	36.30	10.98	25.32	12.17	2.89	9.27	5.67	5.32	0.35	1.81	0.09	1.27	0.45
FR(mech)	3	30.93	10.29	11.28	4.26	1.82	1.35	0.00	11.31	36.30	10.98	25.32	12.17	2.89	9.27	5.67	5.32	0.35	1.81	0.09	1.27	0.45
FR(mtd)	1	24.63	10.72	8.06	2.56	1.56	1.08	0.00	11.78	37.16	13.46	23.71	17.74	3.01	14.73	5.54	5.54	0.36	1.56	0.00	1.32	0.24
FR(mtd)	2	26.80	11.66	8.77	2.79	1.70	1.18	0.00	12.82	40.43	14.64	25.79	10.51	0.00	10.51	6.03	6.03	0.39	1.69	0.00	1.44	0.26
FR(mtd)	3	27.40	11.93	8.96	2.85	1.74	1.20	0.00	13.11	39.10	12.73	26.37	10.75	0.00	10.75	6.17	6.17	0.40	1.73	0.00	1.47	0.26
NL	1	27.68	10.78	16.03	0.87	0.58	0.17	0.41	2.66	29.19	15.65	13.54	7.71	0.00	7.71	23.89	23.89	0.00	8.29	6.92	0.51	0.86
NL	2	24.80	8.84	12.77	3.19	0.82	0.14	0.69	2.55	25.72	15.04	10.68	13.65	0.81	12.84	26.34	21.95	4.39	6.12	5.04	0.41	0.68
NL	3	30.85	10.64	15.82	3.99	0.57	0.17	0.41	3.20	28.80	15.44	13.36	7.61	0.00	7.61	23.83	23.83	0.00	5.14	3.79	0.51	0.85
UK	1	32.00	15.25	13.38	3.38	1.13	0.74	0.39	7.35	23.45	9.76	13.68	20.65	1.84	18.81	8.49	7.96	0.53	6.93	3.81	2.44	0.67
UK	2	39.29	13.49	23.45	2.36	1.15	0.88	0.27	5.03	15.70	6.15	9.55	17.37	4.23	13.14	5.93	5.56	0.37	15.53	13.62	1.44	0.47
UK	3	28.95	13.62	12.78	2.55	1.24	0.95	0.30	5.65	28.84	6.17	22.67	18.03	4.56	13.47	4.55	4.15	0.40	12.73	10.67	1.55	0.51
AS	n/a	25.27	12.17	11.25	1.85	3.16	1.99	1.17	2.74	20.74	10.88	9.85	22.60	3.28	19.32	21.15	15.29	5.86	4.34	2.35	0.84	1.15
NZ	n/a	28.28	14.97	12.20	1.11	6.19	3.66	2.53	2.44	36.93	11.14	25.80	12.22	1.08	11.13	9.79	9.79	0.00	4.16	0.00	4.06	0.00
SWE	n/a	22.25	10.09	10.30	1.85	0.46	0.34	0.12	1.51	36.94	15.08	21.86	20.15	0.00	20.15	13.14	7.03	6.11	5.56	4.77	0.79	0.00
USA	n/a	28.43	11.57	14.80	2.07	1.36	1.18	0.18	1.53	37.90	19.18	18.72	20.36	2.43	17.93	8.81	7.19	1.63	1.61	0.00	1.58	0.02
		MEAN	**29.55**	**12.72**	**13.41**	**2.24**	**1.90**	**1.09**	**0.67**	**6.39**	**32.93**	**13.19**	**19.74**	**14.40**	**1.41**	**12.99**	**9.97**	**8.64**	**1.38**	**4.87**	**3.05**	**1.11**

Appendix 4: RESULTS FOR LOAD COMPOSITION BY ROLE

Squad Leader loads (Figure 3A4-1) range from 42.64 kg (for NZ) to 67.46 kg (for AS). On average, the highest proportion of their load is comprised of Protection (34%), followed by Weapon System (25%), C4I System (14%), Subsistence (14%), Sustainment (7%), Enhanced Vision (4%), and Miscellaneous (2%). CA and UK squad leaders tend to choose the highest proportion of their load as C4I equipment (18 – 26 %, compared to 4 – 15 % for all other nations). UK squad leaders chose the heaviest proportion in the Weapon System sub-category (31 – 41 %). AS, CA and UK Squad Leaders tended to choose the least amount of protection in terms of proportion of total load (14 – 25 % versus 36 – 56 % for other nations).

Squad Second in Command loads (Figure 3A4-2) range from 43.01 kg (UK, Scenario 1) to 78.45 (for UK, Scenario 2). Results for Squad Second in Command load composition are similar to those for Squad Leader, with the highest proportion of their loads, on average, comprised of Protection (35%) and Weapon System (25%), followed by Subsistence (16%), C4I System (10%), Sustainment (7%), Miscellaneous (4%) and Enhanced Vision (3%). In this role, French, British and German tend to carry the highest proportion of C4I equipment (9 – 15 %, versus only 2 – 5 % for other nations). British and Canadian 2 I/C's tend to carry the highest proportion in the Weapon System category (30 – 35 %, versus 17 – 27 % for other nations, with a notable exception of 46% for British 2 I/Cs for Scenario 2, due to their carrying Anti-Structures Materiel in that scenario).

Rifleman loads (Figure 3A4-3) range from 39.42 kg (NZ) to 77.75 kg (for UK, Scenario 3). Results for Rifleman load composition are similar to those for the previously discussed roles, with the highest proportion of their loads, on average, comprised of Protection (37%) and Weapon System (28%), followed by Subsistence (15%) and the remaining categories of Sustainment (7%), Miscellaneous (7%), C4I System (5%) and Enhanced Vision (3%). French riflemen carry significantly more C4I equipment (11 – 13 % of their load vice 0 – 2 % for all other nations), reflecting the fielding of the FELIN system. German riflemen tend to wear the most protection (50 – 62% of their load versus other nations who are all below 42%, and overall average of 37%). Like other roles British and Canadian riflemen tend to carry the highest proportion in the Weapon System category (30 – 39 %, versus others who are all below 30% of their load).

Grenadier loads (Figure 3A4-4) range from 35.96 kg (UK, Scenario 1) to 67.73 kg (UK, Scenario 2) with an average across nations and scenarios of 55.85 kg. Similar to other roles, the highest proportion of the Grenadier's load is attributed to Protection (34%). As one would expect, the proportion of their load attributed to the Weapon System is higher than for roles previously discussed (at 33% of their load on average). Proportions for remaining categories are similar to those presented for other roles, with 15% for Subsistence, 7% for Sustainment, 5% for C4I System and Miscellaneous, and 2% for Enhanced Vision.

Light Machine Gunner loads (Figure 3A4-5) range from 39.82 kg (UK, Scenario 1) to 81.19 kg (AS) with an average across nations and scenarios of 55.46 kg. Similar to all other roles, the highest proportion of their load is attributed to Protection (34%) very closely followed by the Weapon System (33%), as for the Grenadier. Proportions for remaining categories are similar to those presented for other roles, and identical to those for the Grenadier, with 14% for Subsistence, 7% for Sustainment, 5% for C4I System and Miscellaneous, and 2% for Enhanced Vision. Australian, Canadian, and American Light Machine Gunners have the highest proportion of their load due to Weapon System (over the average of 33%, ranging from 35 to 43 %).

Marksman or sharpshooter loads (Figure 3A4-6) range from 41.02 kg (NZ, generic scenario) to 66.26 kg (FR mechanized, Scenario 1) with an average across nations and scenarios of 56.56 kg. Like other roles, the

highest proportion of the marksman's load is attributed to Protection (36%), closely followed by the Weapon system (35%). Proportions for remaining categories are similar to those presented for other roles, with 13% for Subsistence, 6% for each of Sustainment and C4I System, 3% for Miscellaneous, and 1% for Enhanced Vision.

Anti-tank specialist loads (Figure 3A4-7) range from 49.67 kg (GE, Scenario 3) to 63.72 kg (FR Mechanized, Scenario 1) with an average across nations and scenarios of 58.31 kg. Like other roles, the highest proportion of the marksman's load is attributed to Protection (38%), closely followed by the Weapon system (35%). Proportions for remaining categories are similar to those presented for other roles, with 11% for Subsistence, 7% for C4I System, closely followed by 5% for Sustainment and 2% for each of Enhanced Vision and Miscellaneous.

Heavy/General Purpose Machine Gunner loads (Figure 3A4-8) range from 41.19 kg (UK, Scenario 1) to 74.12 kg (FR Mechanized, Scenario 1) with an average across nations and scenarios of 62.56 kg. Unlike other roles, and as one would expect, the highest proportion of the marksman's load is attributed to the Weapon category (40% on average across nations) followed by Protection (27%). Proportions for remaining categories are similar to those presented for other roles, with 13% for Subsistence, 7% for C4I System, closely followed by 6% for each of Sustainment and Miscellaneous, and only 1% for Enhanced Vision.

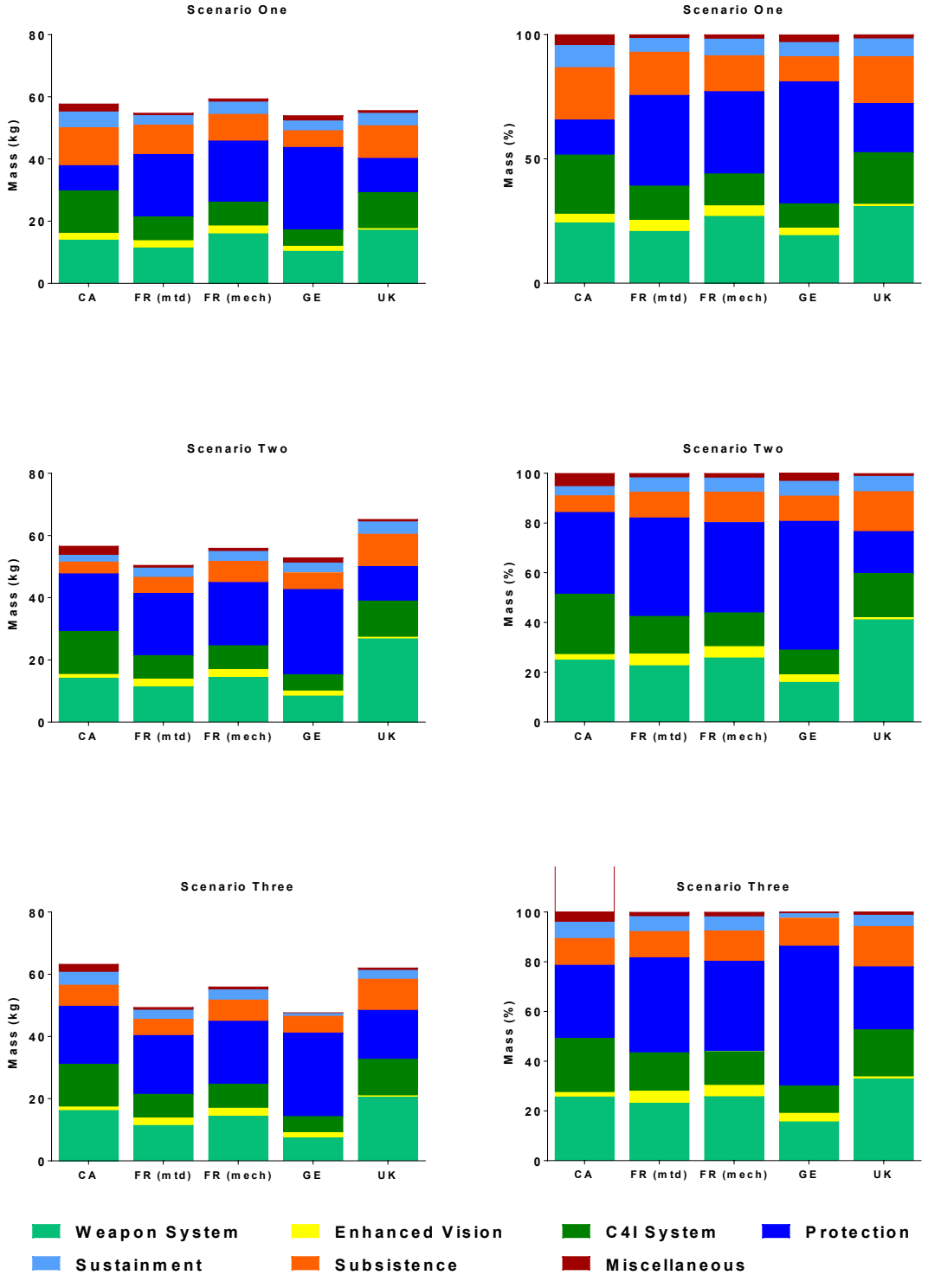


Figure 3A4-1: Loads Borne by Squad Leaders / Section Commanders Group Commanders by Nation and Across Scenarios.

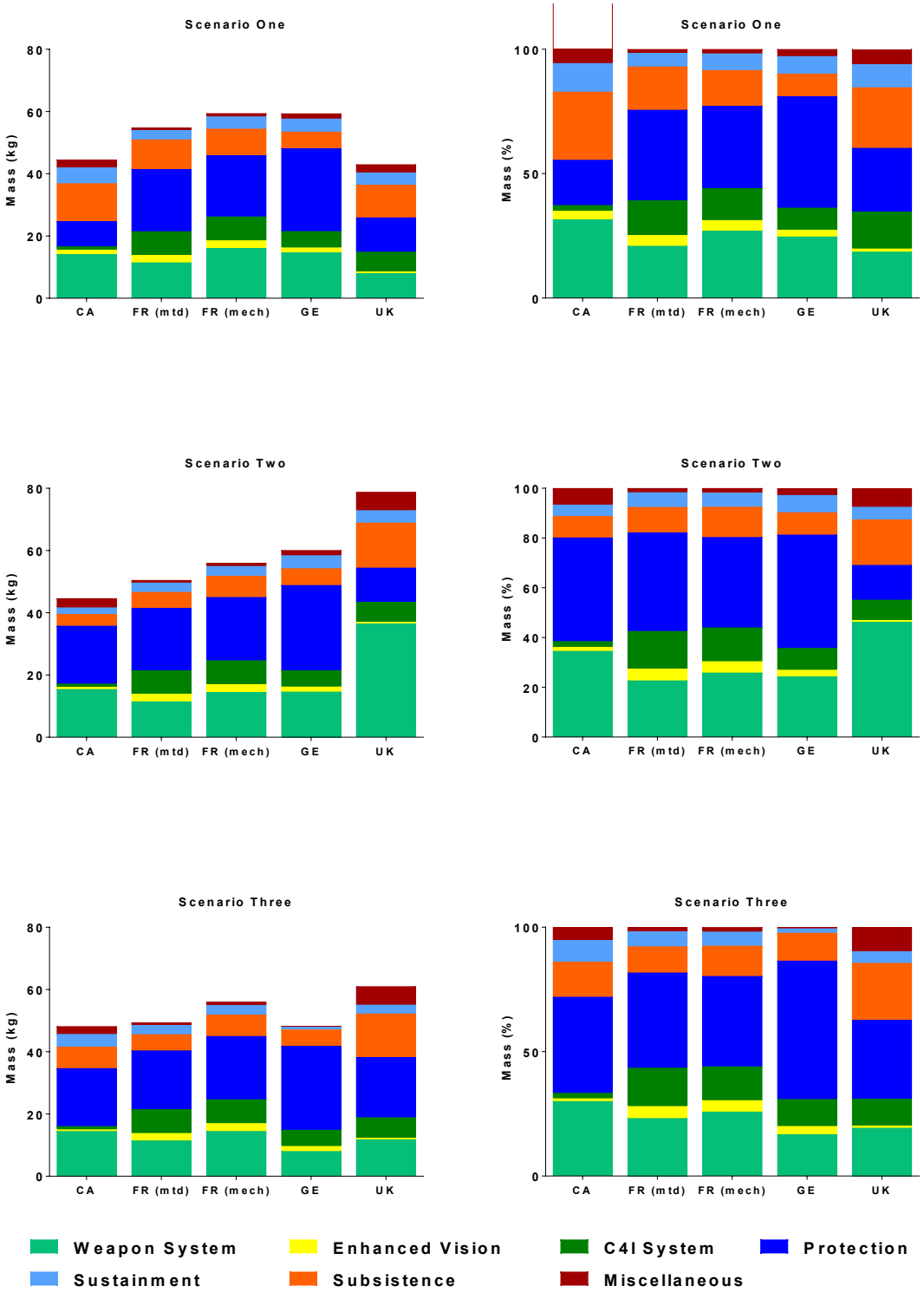


Figure 3A4-2: Loads Borne by Squad / Section / Group Second in Command (2 I/C) Across Nations and Scenarios.

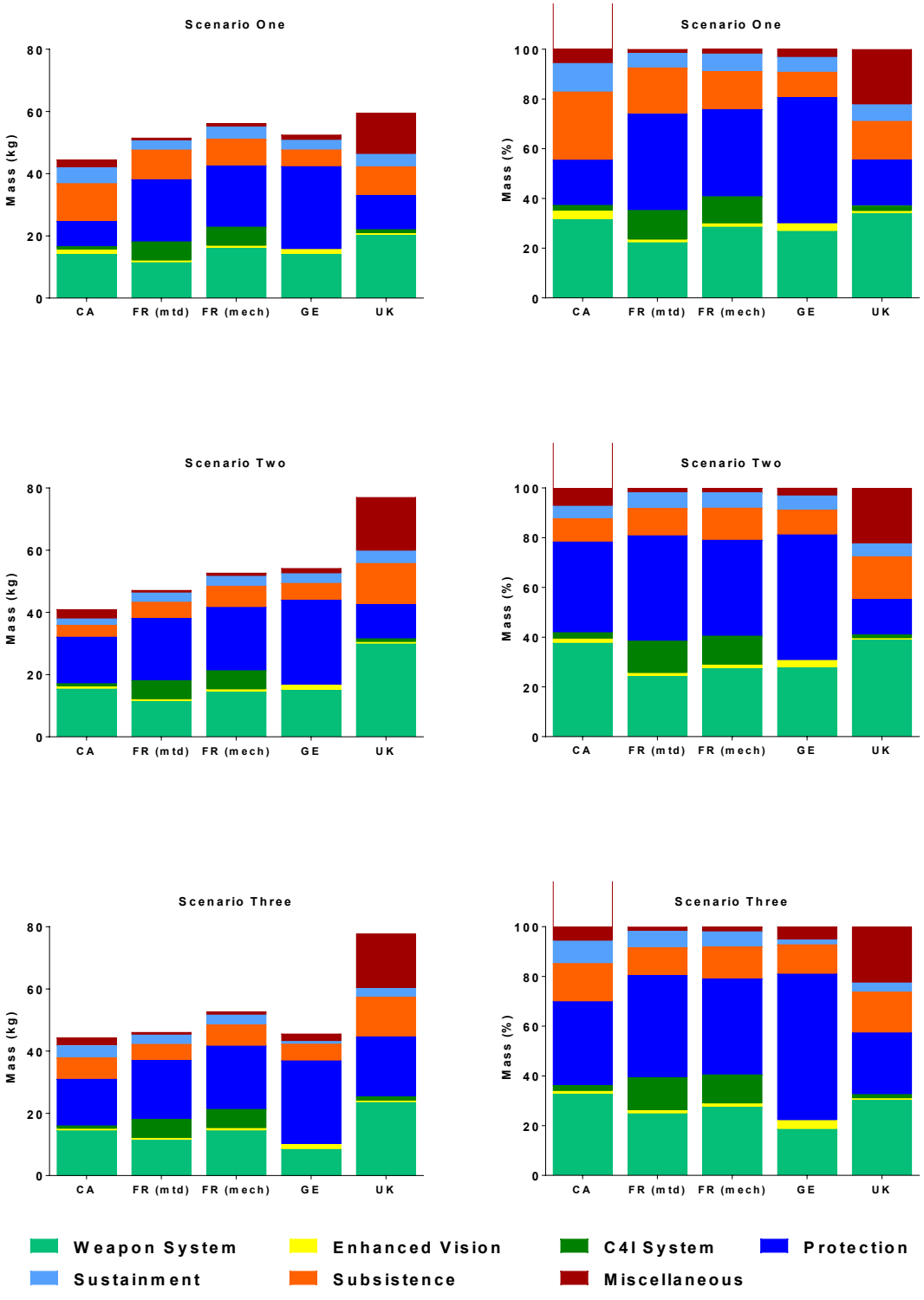


Figure 3A4-3: Loads Borne by Riflemen Across Nations and Scenarios.

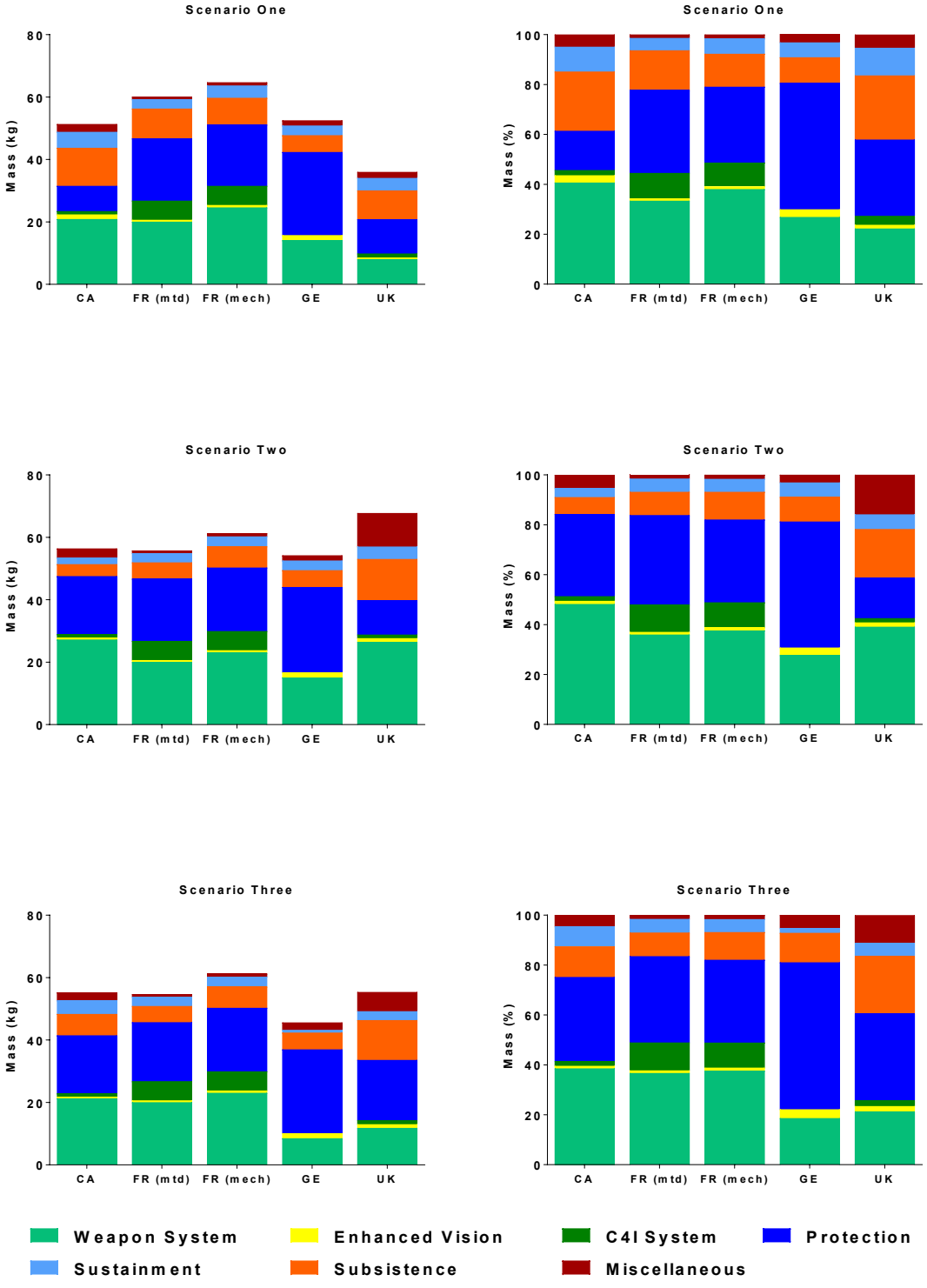


Figure 3A4-4: Loads Borne by Grenadiers Across Nations and Scenarios.

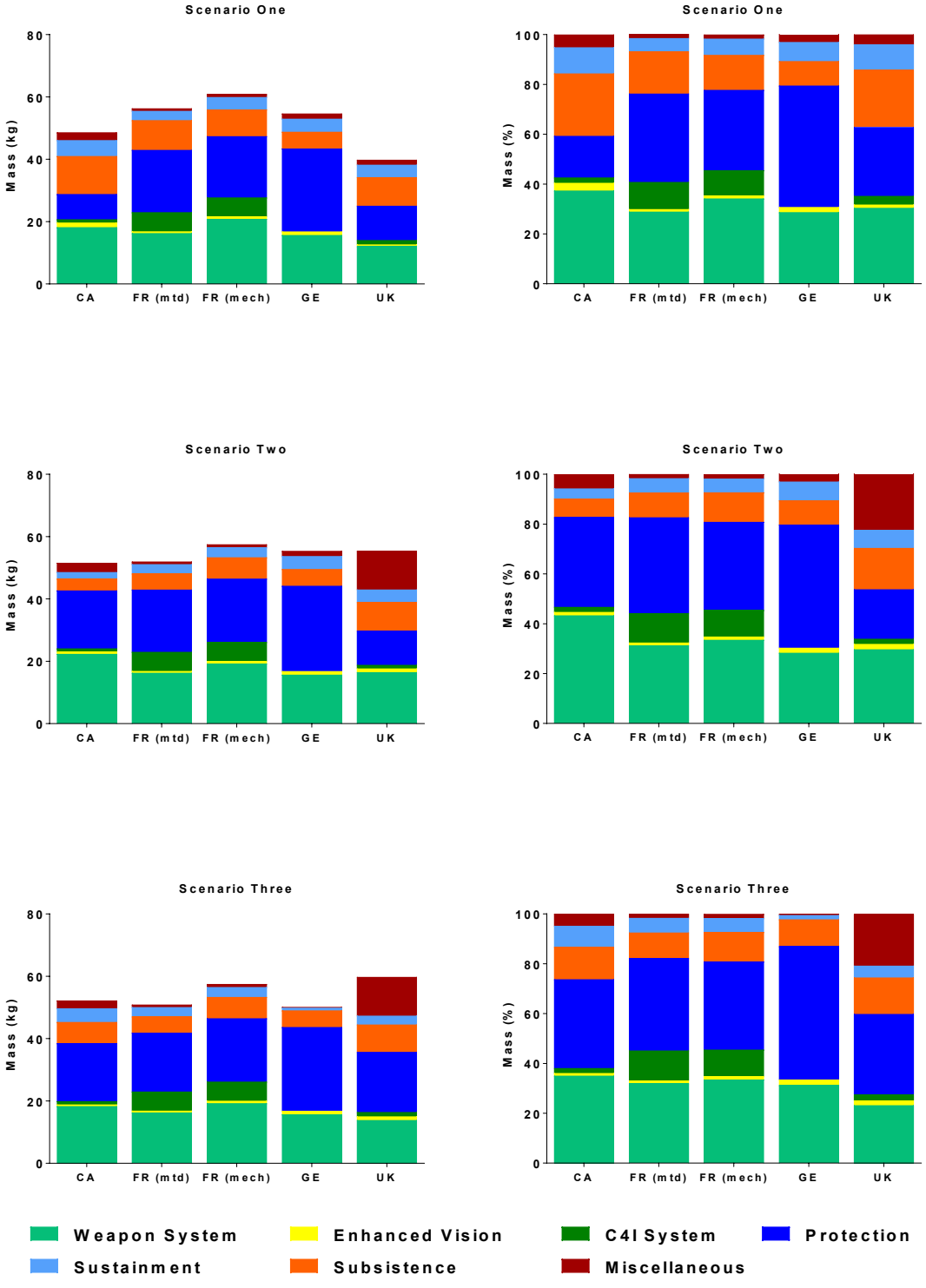


Figure 3A4-5: Loads Borne by Light Machine Gunners Across Nations and Scenarios.

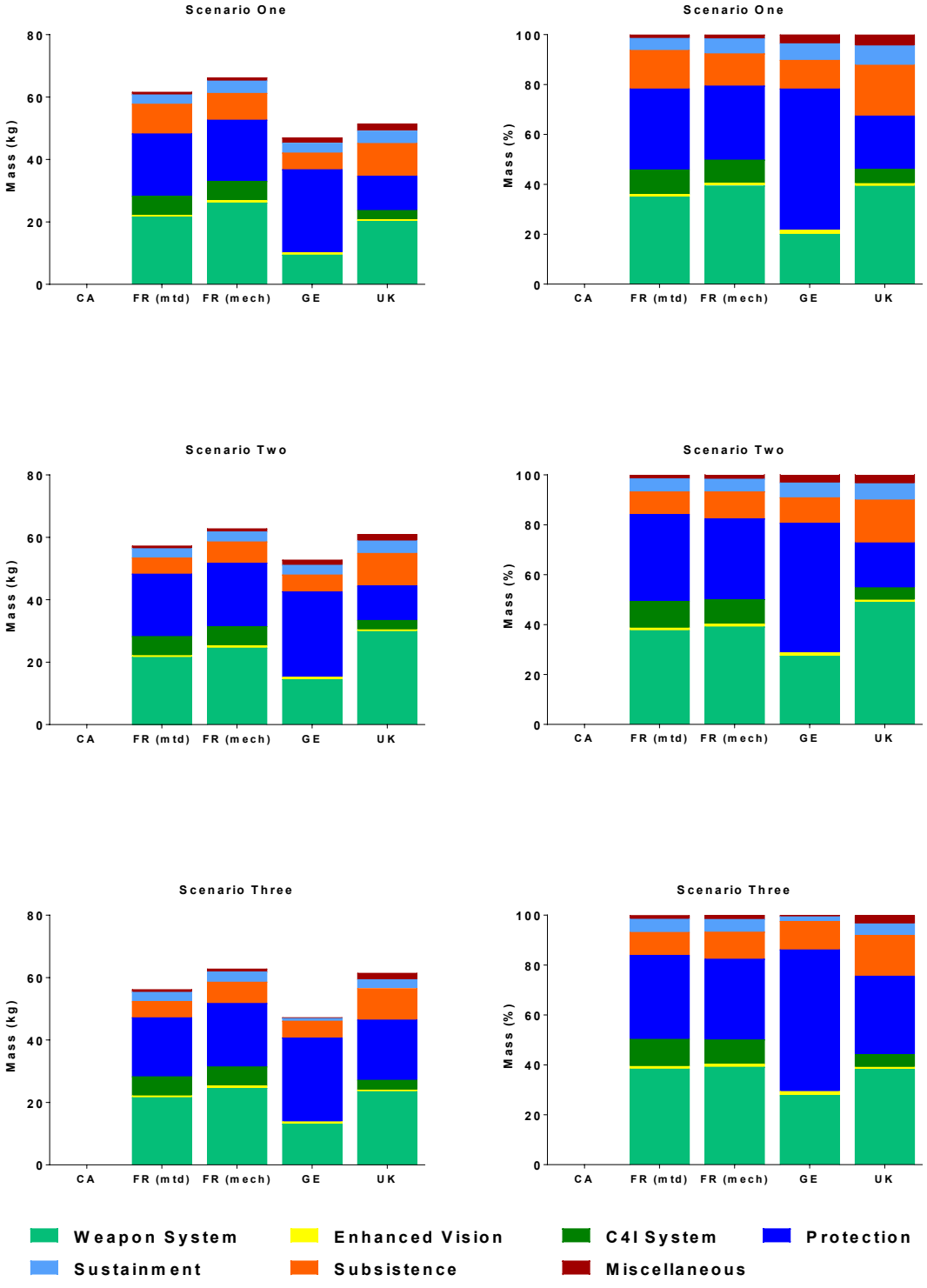


Figure 3A4-6: Loads Borne by Marksmen / Sharpshooters Across Nations and Scenarios.

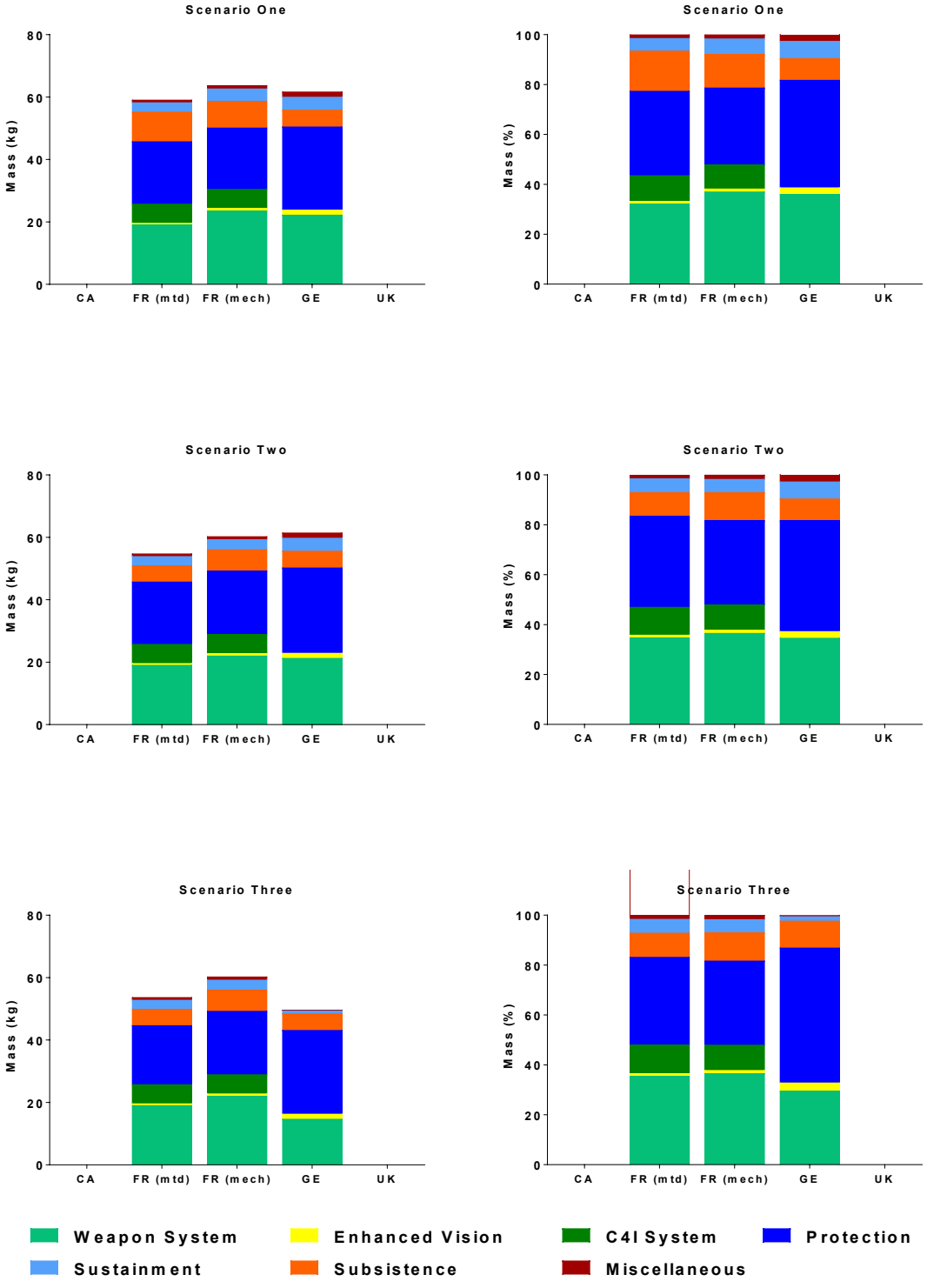


Figure 3A4-7: Loads Borne by Anti-Tank Specialists Across Nations and Scenarios.

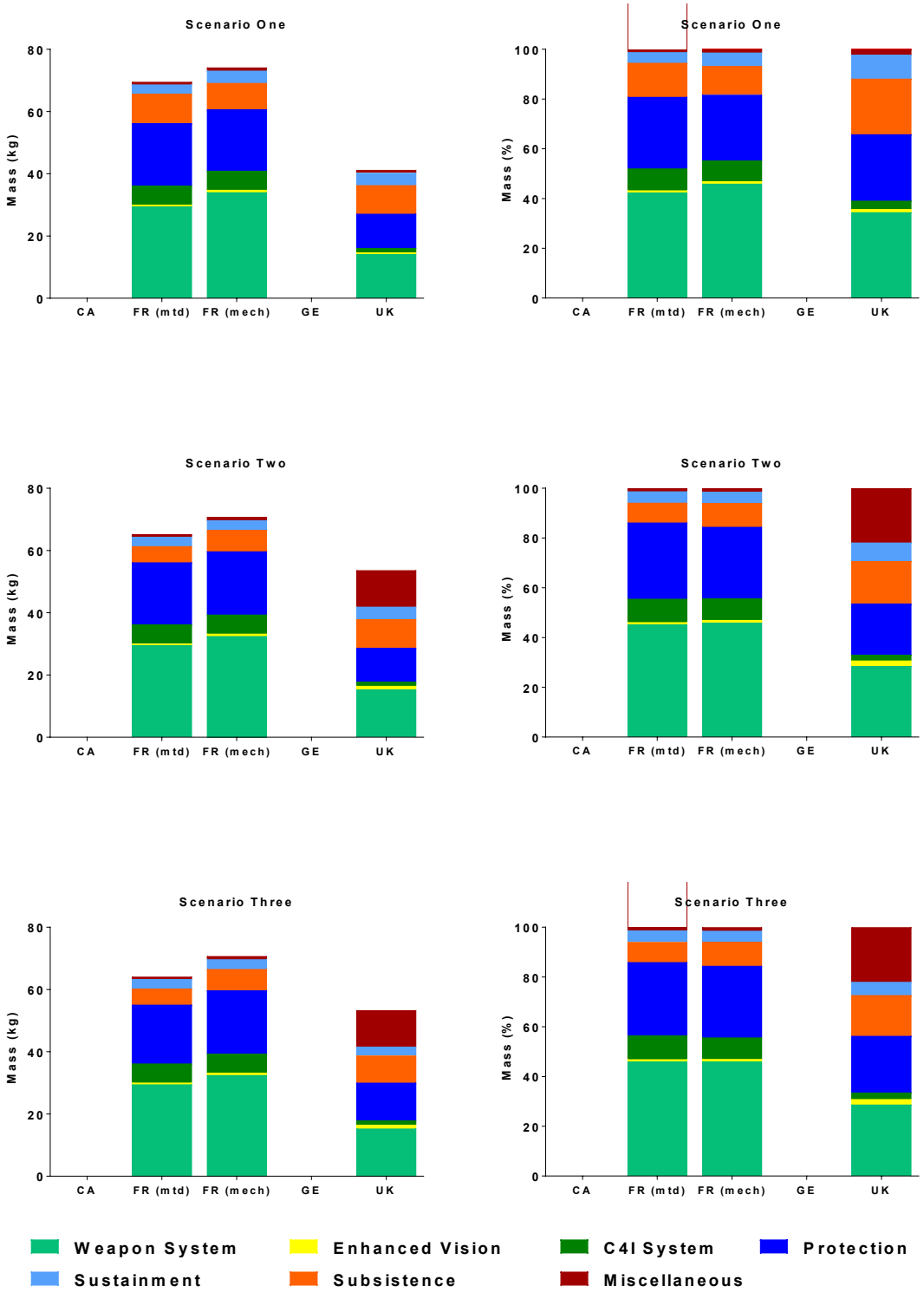


Figure 3A4-8: Loads Borne by Heavy or General Purpose Machine Gunners Across Nations and Scenarios.



Chapter 4 – WORK PACKAGE 2: LITERATURE REVIEW ON SOLDIER LOAD

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4.1 INTRODUCTION

Load carriage is a vital requirement for many military personnel and thus is of central importance for individual and collective military capability [1]. Whether the requirement is in support of trade, logistic or battlefield tasks, the physiological characteristics linked to load carriage performance can influence strategic and tactical decision making and can also affect soldier lethality and survivability [2], [3].

The load carriage systems utilized across the member nations of NATO will be discussed in greater detail in a following chapter. However, suffice to say that actual load (weight, stiffness and bulk), will have profound effects on load carriage performance [2]. Moreover, the composition of the actual combat task (administrative or dynamic) and the setting (training, tactical or mission critical) will all affect load carriage performance and therefore mission success.

The aim of this chapter is to investigate the personal, load and tasks characteristics (particularly environmental heat) that affect load carriage performance. These areas of focus are allied to the scenarios identified in Chapter 2.

4.1.1 The Influences on Military Load Carriage

"An individual's load carriage capacity is influenced by a multitude of factors that can broadly be categorised into three groups:

1) Personnel characteristics (e.g., fitness, body mass, anthropometry, sex, age, injury profile, load carriage experience),
2) Task characteristics depending or not on the load (e.g., the characteristics of the load, total external load, distribution of load, load carriage equipment design and the characteristics of speed, march duration, work to rest ratio) and
3) Environment (e.g., terrain, heat, humidity, altitude) in which the task is performed" [2].

Please see Figure 4-1.

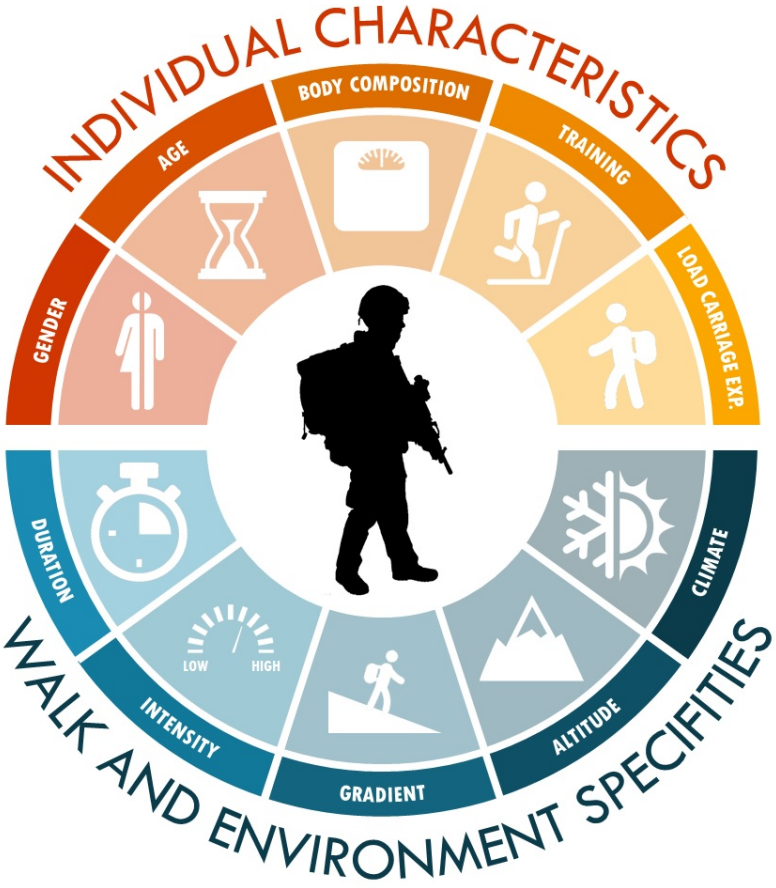


Figure 4-1: Individual Characteristics of Load Carriage (Adapted from Ref. [2]).

Load Carriage is synonymous with many military tasks and some of these tasks are very different in their execution and range from long slow 'adaptive' tasks and short dynamic 'reactive' tasks. Although both activities conform to the influences of load carriage as described by Drain et al. [2], there are clear differences in personal requirement. It would be remiss of any meaningful review not to acknowledge these differences. Moreover, these different tasks of load carriage are not isolated but combined during combat. Thus, fatigue induced by 'administrative advance' could also alter efficiency in dynamic war-fighting tasks. So, an understanding of the consequences of long loaded walk on neuromuscular function i.e., maximal strength generating capacity, muscle endurance and fatigability, is important.

To fully investigate these aspects Section 4.2 will focus on the personal characteristics for performance in long slow 'adaptive' tasks whereas Section 4.3 will review the characteristics of load (mass, stiffness and bulk). Section 4.4 will focus on soldier physical and physiological capability to complete short dynamic 'reactive' tasks' after a long slow advance. Cognisant of the scenarios identified in Chapter 2, Section 4.5 will be focused on the implications of environmental heat for load carriage and combat task performance. Section 4.6 will identify the main gaps in research identified from systematic and literature review. Finally, and where possible, Section 4.7 will highlight the ideal soldier characteristics for load carriage tasks. This narrative will focus on what is modifiable and the critical path to change.

4.2 SYSTEMATIC REVIEW: WHICH PERSONAL CHARACTERISTICS AFFECT LOAD CARRIAGE (ADMINISTRATIVE ADVANCE – SLOW ADAPTIVE) PERFORMANCE

4.2.1 Introduction

This chapter will focus on the adaptive administrative advance. Through the investigative pathway, the initial aim of answering the research question through traditional systematic review leading to a meta-analysis suffered through a lack of available data. Specifically, regarding the influence of physical characteristics, insufficient evidence existed to afford an evidence base to undertake a meta-analysis. It was therefore agreed to conduct a systematic review and include other forms of investigative research as this would better reflect the body of research. A systematic review will form part of this chapter; however, the review will only include data specific to the traditional load carriage activity allied to an 'administrative advance' and not the dynamic war-fighting tasks, where performance and military outcome are paramount.

The aim of this systematic review is to report the findings in relation to the research question '*which personal characteristics affect an administrative advance load carriage performance*?' To meet this aim, this chapter will introduce the research specific to military load carriage undertaken by NATO military personnel and to offer evidence-based strategies to enhance soldier performance in respect of load carriage. Additionally, this chapter will also highlight the research base and suggest where evidence gaps appear. This review will only include data based on military populations (as the output of the review will inform strategic and tactical decision making), it was thought the inclusion of non-military populations would lack context and add too much variability. In addition, the influence of some physical characteristics may not appear in this report due to reporting and contextual issues. However, and where tacit and explicit data exist these areas have been identified as gaps in current evidence.

4.2.2 Methods

4.2.2.1 Search Terms

Based on the determination of scope and preliminary review of military load carriage, a short list of key terms was identified for a literature search. While specific search term approaches were adapted to address different database systems, combinations and variations of the following terms were used:

("**load carriage performance**" or "**load carriage capability**") AND

("military" OR "armed services", OR "army" or "navy" OR "air-force" OR "marines").

The following personnel characteristics were the selected key component terms:

"physical conditioning," or "physical fitness" or "sex" or "age" or "fatigue" or "nutritional status" or "nutrition" or "skill" or "experience" or "discomfort" or "pain" were used.

4.2.2.2 Inclusion and Exclusion Criteria Used in Literature Review

Inclusion:

- Document type:
  - Published Journals;

    - Military and non-military sources; and
    - UK and non-UK sources.
- Dates:
    - >1980 – present (Dec 2015).
- Language:
    - English.
- Population type:
    - Human.
- Population characteristics:
    - Age: Adults (> 18 years but < 55 years), and
    - Reported as healthy (i.e., not injured).

Exclusion:

- Document type:
    - Books;
    - Editorials;
    - Presentations/abstracts; and
    - Drafts or work-in-progress documents.
- Dates:
    - <1980.
- Language:
    - Non-English.
- Population type:
    - Animal studies;
    - *In vivo* / toxicology / pathology; and
    - Engineering theory.
- Population characteristics:
    - <18 years (Children/infants) and >55 years (elderly); and
    - Disabled/health-compromised persons.

4.2.2.3 Data Sources

The goal of the literature search was to use data search sources that were broad reaching yet available at no cost to the author's host institution. These sources are described below:

Searchable Databases: The databases used included PubMed, EBSCO (MEDLINE, Biomedical Reference Collection, Academic Search Premier, Nursing and Allied Health Collection: Comprehensive; Cochrane Methodology Register, CINAHL and CINAHL Full Text; partial use of SportDiscus and SportDiscus Full text before access was closed), and EMBASE. The Defense Technical Information Centre (DTIC) provided an online search of military reports and documents.

Grey Sources: Internally available documents (e.g., government reports) were identified during both the preliminary review and by Subject Matter Expert (SME) recommendations.

4.2.2.4 Full Text Review and Data Extraction

Returned articles were extracted and then pooled using the online referencing software Endnote (Thompson Reuters, New York, USA). An automatic duplication sequence was completed in addition to a manual search to ensure only original articles proceeded to the next stage. Systematic review software (Covidence, Melbourne, Australia) was utilized to screen articles through two stages; title and abstract, and full text with articles were excluded from the process due to meeting one or more of a pre-set exclusion criteria. Reports and manuscripts selected for full text review were reviewed and key data elements were recorded into a master Excel spreadsheet (Microsoft Corporation, Washington, USA). Key elements included:

- Document information: name, author(s), year, type (technical report, journal article).
- Population information: size (n), sex, age, nationality, military type.
- Load carriage information: weight, and performance measure (distance / time).
- Physical characteristic outcome measures: e.g., body composition, strength, experience, stature, sex).
- Statistical results: e.g., Pearson correlation (r) values and statistical significance. 95% confidence intervals).

4.2.2.5 Quality Scoring

All studies were assessed using the Downs and Black Tool for methodological quality [4]. Saunders et al. (2003) compared 18 instruments which assessed the quality of randomised and non-randomised trials [5]. The authors suggested the Downs and Black Tool was foremost, due to its development using psychometric methods and positive outcomes in relation to reliability and validity [5]. The tool consists of 27 questions in the following sub-sections: Reporting, External Validity, Internal Validity (bias) and Internal Validity (confounding). The original tool quality scoring ranged from 0 to 32. However, the wording for the last question was ambiguous and difficult to score. Therefore, it was modified from a scale of 0 to 5 to a scale of 0 to 1 where 1 was scored if a power calculation or sample size calculation was present while 0 was scored if there was no power calculation/sample size calculation (or explanation whether the number of subjects was appropriate). Consequentially, the modified version ranged from 0 to 28, with a higher score indicating higher methodological quality.

4.2.2.6 Statistics

Although the reviewed literature did not permit the development of a meta-analysis, summary statistics (where appropriate) were calculated using comprehensive Meta-Analysis software (CMA version 3, Biostat, New Jersey, USA).

4.2.3 Results

4.2.3.1 Study Selection

The systematic review followed the process outlined in Figure 4-2 and as indicated, 13 papers were included in the review.

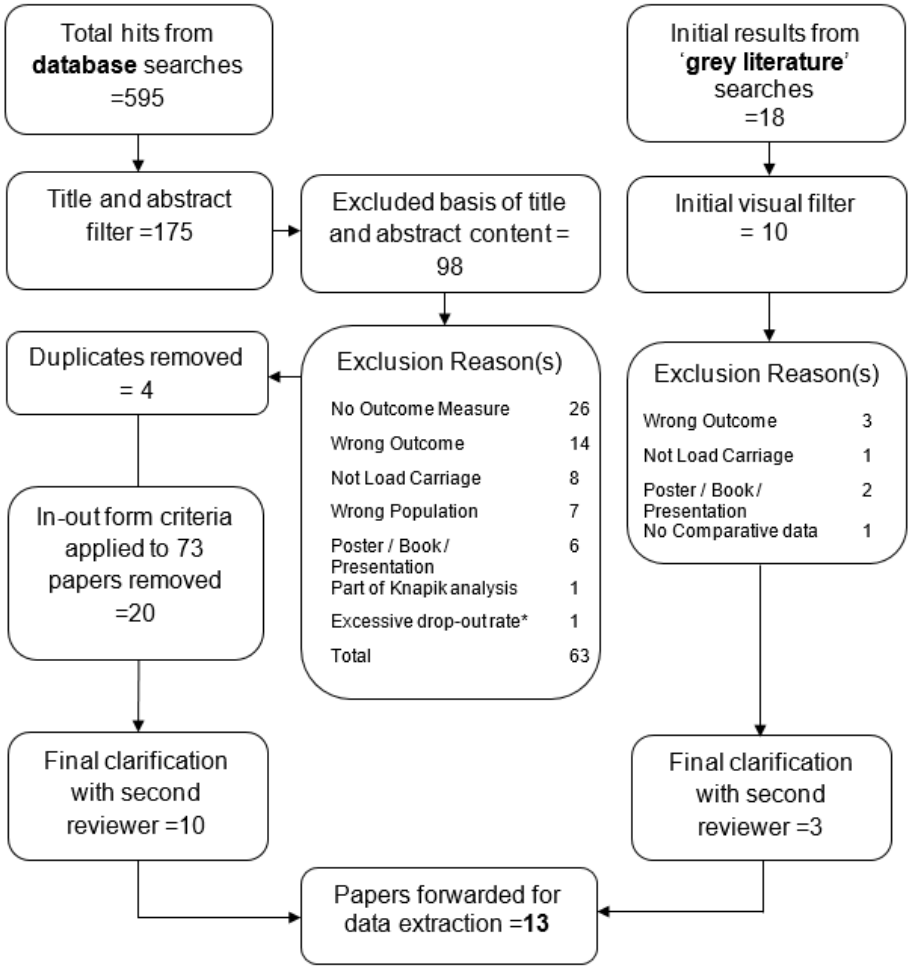


Figure 4-2: Systematic Review Flow Diagram of Study Selection.

The main reasons for paper exclusion are also indicated in Table 4-2. There were:

1) Lack of an outcome measure to report; and
2) Use of an outcome measure that could not be included in a review of physical characteristics (i.e., a task or load characteristic).

It was also decided that papers relating to physical conditioning would not be included, as a recent meta-analysis (Knapik et al. 2012) [3] had sufficiently reported the outcomes in this area.

4.2.3.2 Downs and Black Quality Scoring

The results of the Downs and Blacks checklist are outlined in Table 4-1. The two highest scoring papers were both Randomised Controlled Trials (RCTs). Comparatively, the paper by Birrell and Haslam (2009b) [6] scored poorly; this was due to the observational nature of the study and an under-reporting of the results. Study quality for the three "grey literature" papers (**in bold**) was comparative to "peer reviewed" journals.

Table 4-1: Downs and Blacks Quality Scoring Checklist. ("Grey literature" has been highlighted in bold).

Paper	Reporting (11)	External Validity (3)	Bias (7)	Confounding (6)	Total (28)
Birrell, Hooper and Haslam (2007) [7]	5	1	1	3	10
Simpson et al. (2005) [8]	8	2	3	2	15
Martin and Nelson (1986) [9]	7	3	2	4	16
Bilzon, Allsopp and Tipton (2005) [10]	8	3	3	3	17
Ricciardi et al. (2007) [11]	8	3	3	3	17
Koerhuis et al. (2009) [12]	8	3	4	3	18
Lyons, Allsopp and Bilzon (2005) [13]	8	3	4	3	18
Mello et al. (1988) [14]	8	3	3	4	18
Scott and Christie (2004) [15]	8	3	3	4	18
Dziados et al. (1987) [16]	9	3	3	4	19
Knapik et al. (1990) [17]	9	3	3	4	19
Sutton et al. (2005) [18]	8	3	5	5	21
Taipale et al. (2015) [19]	9	3	4	6	22

4.2.3.3 Selected Papers

Listed in Table 4-2 are the 13 selected papers. The table identifies population by number (max n =127, min n = 12, average n = 40), country of origin and sub-population within the military (an inclusion requirement). All papers (bar one from South Africa and one from the Netherlands) originate from the United States (US) or United Kingdom (UK), thus generalizability across all NATO member nations may be an issue. The load task is explained both in terms of event (distance or time) and load and was not standardized across the papers. The main area(s) of outcome are indicated, as are the associated correlations (Pearsons *r*) and p value. The Downs and Black quality score is again offered by score (out of 28) and as a percentage.

Table 4-2: Selected Papers by Author, Population, Load, Physical Characteristic, Outcome (Correlation with Load Carriage Performance) and Quality Score.

Authors	Subjects Population and Age (mean)	Load Task Distance/load	Physical Characteristic Area	Outcome Pearsons r	Total Score Max 28 (%)
Bilzon, Allsopp and Tipton (2001) [10]	12 male UK military (30 years)	9.5 km/hr to fail, 18 kg	Body mass Body composition (Fat free mass)	0.69 p<0.05 0.71 p<0.05	17 (61)
Birrell and Haslam (2009a) [20]	98 male, 29 female UK military (Officer Training) (21 and 20 years)	120 min (3.6 mph), 20 kg	Sex (foot discomfort) Sex (hip discomfort)	-0.16 p<0.03 -0.23 p<0.03	10 (36)
Dziados et al. (1987) [16]	49 male US military (22 years)	16 k, 19 kg	Strength (hamstrings)	0.45 p<0.003	19 (69)
Knapik et al. (1990) [17]	96 male US military (21 years)	20 k, 46 kg	Body mass	0.22 p<0.05	19 (69)
			Fat free mass	0.26 p<0.05	
			Mood (anger)	-0.46 p<0.05	
			Mood (confusion)	-0.37 p<0.05	
			$\dot{V}O_{2Max}$	0.31 p<0.01	
			Strength (hamstrings)	0.27 p<0.01	
			Strength (quadriceps)	0.22 p<0.05	
			Strength (abdominals)	0.45 p<0.01	
			Experience (time in Service)	0.26 p<0.05	
			Experience (rank)	0.36 p<0.01	
Koerhuis et al. (2009) [12]	23 male NL military (24 years)	15 min (mean), 20 kg +7.5 to failure	Body mass	0.76 p<0.05	18 (64)
			Body composition (Fat free mass)	0.81 p<0.05	
			Strength (squat)	0.62 p<0.05	
			Strength (shoulder press)	0.51 p<0.05	
			Stature	0.72 p<0.05	

Authors	Subjects Population and Age (mean)	Load Task Distance/load	Physical Characteristic Area	Outcome Pearsons r	Total Score Max 28 (%)
Lyons, Allsopp and Bilzon (2005) [13]	28 male UK military (30 years)	4 km/hr for 60 min (gradient 3, 6 and 9) 0, 20 and 40 kg	Body composition (Fat free mass)	0.52 p<0.01	18 (64)
			$\dot{V}O_{2Max}$	0.64 p<0.01	
Martin and Nelson (1986) [9]	11 male and 11 female US military (21 yrs.)	8 k, 0, 9, 17, 29 and 36 kg	Sex (stride rate)	-0.48 p<0.02	16 (57)
			Sex (stride length)	-0.50 p<0.02	
Mello et al. (1988) [14]	28 male US military (22 years)	2, 4, 8 and 12 km. 46 kg	Body fat	-0.48 p<0.05	18 (64)
			Strength (hamstrings)	0.48 p<0.05	
			Strength (quadriceps)	0.49 p<0.05	
Ricciardi et al. (2007) [11]	17 male and 17 female US military (31 years)	30 min slow and moderate pace, 10 kg body armour	Body fat	-0.52 p<0.05	17 (61)
Scott and Christie (2004) [15]	30 male SA military (29 years)	6 min (3.5 – 5.5 km/h), 20, 35 and 50 kg	Stature (stride rate)	0.70 p<0.002	18 (64)
Simpson et al. (2006) [8]	10 UK military males in two units (26 years unit A, 29 years Unit B 10)	2, 29 km, 20 kg	Predictive assessment	0.77 p<0.05	15 (54)
Sutton et al. (2005) [18]	20 male US military (32 years)	120 min (or fail) 3.7 mph (5 gradient), 30% body mass (max 37.7 kg)	Nutrition	No effect	21 (75)
Taipale et al. (2015) [19]	16 male US reservists (27 years) and 18 US Students (21 years)	50 min (4.0 gradient), 16 kg	Fatigue/Recovery	No effect	22 (79)

4.2.3.4 Sub-Grouping of Papers

Papers were further sub-grouped by physical characteristic (see Table 4-3). The majority of papers reported only one physical characteristic, however several papers (notably Knapik et al., (1990) [17]) reported several outcomes. The table also reports the source (paper) of the reportable outcomes and therefore the amount of corroborating evidence in each physical characteristic area. The available data would suggest each a lack of substantiating evidence in each sub-group; however, evidence is available to indicate the probable key areas of influence. In the main, these can be condensed into two core areas:

1) Anthropometric data (e.g., body mass, body fat, fat free mass, stature); and
2) Fitness status (e.g., strength, muscle endurance and cardiovascular ability).

Across both areas, and where comparison allows the relationship between load carriage performance and sex remains a constant narrative.

Table 4-3: Sub-Grouping by Physical Characteristic.

First Named Author	N and Country	Number of Grouped Studies	Quality (Max 27) and (%)	Physical Characteristic Area	Pearsons r and p value
Sutton (2005) [18]	20 US	1	21 (75%)	Nutrition	No effect
Bilzon (2001) [10]	12 UK	3	17 (61%)	Body Mass	0.69 p<0.05
Knapik (1990) [17]	96 US		19 (69%)	Body Mass	0.22 p<0.05
Koerhuis (2009) [12]	23 NL		18 (64%)	Body Mass	0.76 p<0.05
Lyons (2005) [13]	28 UK	4	18 (64%)	Body Comp. (fat free mass)	0.52 p<0.01
Bilzon (2001) [10]	12 UK		17 (61%)	Body Comp. (fat free mass)	0.71 p<0.05
Koerhuis (2009) [12]	23 NL		18 (64%)	Body Comp. (fat free mass)	0.81 p<0.05
Knapik (1990) [17]	96 US		19 (69%)	Body Comp. (fat free mass)	0.26 p<0.05
Ricciardi (2007) [11]	34 US	2	17 (61%)	Body Fat	-0.52 p<0.05
Mello (1988) [14]	28 US		18 (64%)	Body Fat	-0.48 p<0.05
Taipale (2015) [19]	34 US	1	22 (79%)	Fatigue/Recovery	No effect
Knapik (1990) [17]	96 US	1	19 (69%)	Mood (anger)	-0.46 p<0.05
Knapik (1990) [17]	96 US		19 (69%)	Mood (confusion)	-0.37 p<0.05
Knapik (1990) [17]	96 US	2	19 (69%)	$\dot{V}O_{2Max}$	0.31 p<0.01
Lyons (2005) [13]	28 UK		18 (64%)	$\dot{V}O_{2Max}$	0.64 p<0.01

First Named Author	N and Country	Number of Grouped Studies	Quality (Max 27) and (%)	Physical Characteristic Area	Pearsons r and p value
Koerhuis (2009) [12]	23 NL	1	18 (64%)	Strength (Squat)	0.62 p<0.05
Koerhuis (2009) [12]	23 NL	1	18 (64%)	Strength (Shoulder Press)	0.51 p<0.05
Dziados (1987) [16]	49 US	3	19 (69%)	Strength (Hamstrings)	0.45 p<0.003
Mello (1988) [14]	28 US		18 (64%)	Strength (Hamstrings)	0.48 p<0.05
Knapik (1990) [17]	96 US		19 (69%)	Strength (Hamstrings)	0.27 p<0.01
Mello (1988) [14]	28 US	2	18 (64%)	Strength (Quadriceps)	0.49 p<0.05
Knapik (1990) [17]	96 US		19 (69%)	Strength (Quadriceps)	0.22 p<0.05
Knapik (1990) [17]	96 US	1	19 (69%)	Strength (Abdominals)	0.45 p<0.01
Koerhuis (2009) [12]	23 NL	2	18 (64%)	Stature	0.72 p<0.05
Scott (2004) [15]	30 SA		18 (64%)	Stature (stride rate)	0.70 p<0.002
Martin (1986) [9]	22 US	2	16 (57%)	Sex (stride rate)	-0.48 p<0.02
Martin (1986) [9]	22 US		16 (57%)	Sex (stride length)	-0.50 p<0.02
Birrell (2009a) [20]	127 UK		10 (36%)	Sex (discomfort – hip)	-0.16 p<0.03
	127 UK		10 (36%)	Sex (discomfort – foot)	-0.23 p<0.03
Knapik (1990) [17]	96 US	1	19 (69%)	Experience (Time served)	0.26 p<0.05
Knapik (1990) [17]	96 US		19 (69%)	Experience (Rank)	0.36 p<0.01
Simpson (2006) [8]	20 US	1	15 (54%)	Predictive assessment	0.77 p<0.05

4.2.3.5 Summary Statistics

Where possible, the summary statistics were produced and are highlighted in Table 4-4. The summary statistics have been computed where “at least” two independent papers, reported a statistically significant outcome in the same physical characteristic area, and in general suggest a “medium” effect size (Cohen, 1992 [21]). Other grouping analysis could be undertaken, however, these would suffer due to the heterogeneity of

data and simply combining outcomes from a similar (but not the same) area will not enhance the evidence base. Within the sub-category, only data referring to fitness status and anthropometrics offer any real evidence base and should be interpreted with caution due to the amount of data available to substantiate any conclusions.

Table 4-4: Sub-Grouping by Physical Characteristic with 95% Confidence Intervals (CI) and Summary Statistic.

First Named Author	Physical Characteristic Area	p Value	Pearsons r	95% CI Low	95% CI High	Summary Statistic Pearsons r 95% CI Low 95% CI High
Bilzon (2001) [10]	Body Mass	p<0.05	0.69	0.36	0.87	0.38 0.22 – 0.52
Knapik (1990) [17]	Body Mass	p<0.05	0.22	0.21	0.4	
Koerhuis (2009) [12]	Body Mass	p<0.05	0.76	0.51	0.89	
Lyons (2005) [13]	Body Comp. (fat free mass)	p<0.01	0.52	0.18	0.75	0.44 0.30 – 0.56
Bilzon (2001) [10]	Body Comp. (fat free mass)	p<0.05	0.71	0.23	0.91	
Koerhuis (2009) [12]	Body Comp. (fat free mass)	p<0.05	0.81	0.6	0.92	
Knapik (1990) [17]	Body Comp. (fat free mass)	p<0.05	0.26	0.06	0.44	
Ricciardi 2007 [11]	Body Fat	p<0.05	-0.52	-0.22	-0.73	-0.50 0.28 – 0.67
Mello (1988) [14]	Body Fat	p<0.05	-0.48	-0.13	-0.72	
Knapik (1990) [17]	Mood (anger)	p<0.05	-0.46	-0.29	-0.6	N/A
Knapik (1990) [17]	Mood (confusion)	p<0.05	-0.37	-0.18	-0.53	N/A
Knapik (1990) [17]	$\dot{V}O_{2Max}$	p<0.01	0.31	0.12	0.48	0.39 0.23 – 0.53
Lyons (2005) [13]	$\dot{V}O_{2Max}$	p<0.01	0.64	0.35	0.82	
Koerhuis (2009) [12]	Strength (Squat)	p<0.05	0.62	0.28	0.82	N/A
Koerhuis (2009) [12]	Strength (Shoulder Press)	p<0.05	0.51	0,12	0.76	N/A
Dziados (1987) [16]	Strength (Hamstrings)	p<0.003	0.45	0.23	0.69	0.36

First Named Author	Physical Characteristic Area	p Value	Pearsons r	95% CI Low	95% CI High	Summary Statistic Pearsons r 95% CI Low 95% CI High
Mello (1988) [14]	Strength (Hamstrings)	p<0.05	0.48	0.13	0.72	0.22 – 0.48
Knapik (1990) [17]	Strength (Hamstrings)	p<0.01	0.27*	0.07	0.45	
Mello (1988) [14]	Strength (Quadriceps)	p<0.05	0.49	0.14	0.73	0.28 0.11 – 0.44
Knapik (1990) [17]	Strength (Quadriceps)	p<0.05	0.22	0.02	0.4	
Knapik (1990) [17]	Strength (Abdominals)	p<0.01	0.45	0.28	0.6	N/A
Koerhuis (2009) [12]	Stature	p<0.05	0.72	0.48	0.86	0.71 0.54 – 0.82
Scott (2004) [15]	Stature (stride rate)	p<0.002	0.70	0.46	0.85	
Martin (1986) [9]	Sex (stride rate)	p<0.02	-0.48	-0.07	-0.75	N/A
Martin (1986) [9]	Sex (stride length)	p<0.02	-0.50	-0.1	-0.76	N/A
Birrell (2009a) [20]	Sex (discomfort – hip)	p<0.03	-0.23	-0.06	-0.39	N/A
Birrell (2009a) [20]	Sex (discomfort – foot)	P<0.03	-0.16	-0.01	-0.33	N/A
Knapik (1990) [17]	Experience (Time served)	p<0.05	0.26	0.06	0.44	N/A
Knapik (1990) [17]	Experience (Rank)	p<0.01	0.36	0.17	0.52	N/A
Simpson (2006) [8]	Predictive Assessment	p<0.05	0.77	0.5	0.9	N/A
* This result is based on an isometric test.						

4.2.3.6 Discussion

From the included papers, the data suggest that physical characteristics referring to anthropometrics and fitness status, offer the most convincing evidence (Dziados et al., 1987 [16], Mello et al., 1988 [14], Knapik et al., 1990 [17], Koerhuis et al., 2009 [12], Bilzon et al., 2001 [10], Lyons et al., 2005 [13], Scott and Christie, 2004 [15]). Both primary and secondary outcome data are indicative of a consistent sex specific narrative, in that females are physiologically disadvantaged in load carriage tasks. However, more recent research indicates that when controlling for differences in body mass and height, and provided appropriate training, females are as capable as males on typical load carriage tasks. Nevertheless, neither sex is protected from injury (Nindl et al., 2016 [22], Harman et al., 2000 [23]). Even the assumption that females generally have a higher fat mass has been disputed as a disadvantage to load carriage as recent research from the Army Centre for Health Promotion and Preventative Medicine demonstrated that women with higher body mass index (BMI) but who are aerobically fit may be more resilient than their counter parts with low BMIs (Nindl et al., 2016 [22]). The following discussion will delve into the research relating non-modifiable and modifiable factors and their relationships with loaded march performance.

4.2.3.7 Modifiable Factors

Information from the systematic review would suggest fitness status[1], body composition and specifically lean body mass are significantly associated with load carriage performance (Dziados et al., 1987 [16], Mello et al., 1988 [14], Knapik et al., 1990 [17], Koerhuis et al., 2009 [12], Bilzon et al., 2001 [10], Lyons et al., 2005 [13]). These areas also offer the greatest potential for modifiability.

Fitness Status: In the current review, the term 'fitness status' was employed collectively to group the following physical characteristics: strength (functional and specific muscle group) and $\dot{V}O_{2max}$, nevertheless these are further explained as separate entities. However, there is a link between anthropometric characteristics and physical fitness as body composition is incorporated in the components of health related physical fitness (Caspersen. 1985 [24]).

Generally, strength of the lower body demonstrated a moderate positive relationship with load carriage performance. Where possible, data reflective of measures that are dynamic in their nature were utilized, as these have most crossover to functional performance (Baker et al., 1994 [25]). Nonetheless, in the case of Knapik (1990) [17] the results of the isometric testing for the hamstring muscle group and therefore knee flexion have been included. These results should be interpreted with a level of caution as the ability of isometric assessment to predict dynamic capacity and functional capacity is the focus of much contrasting research findings (Baker et al., 1994 [25]). There is general belief that dynamic measures of muscular function can better predict athletic performance (Baker et al., 1994 [25], Wilson et al., 1994 [26]). Beyond lower limb strength, there is support for a relationship between core strength and stability offered by the muscles of the trunk and load carriage performance; nevertheless this is only based on one study (Knapik et al., 1990 [17]). Koerhuis et al., (2009 [12]) have suggested a simple and pragmatic solution to predicting load carriage performance in the form of dynamic and functional muscle strength tests (squat, shoulder press and bench press). While the primary aim of the study was to investigate the maximum load carriage capacity (the maximum load that could be carried in a military backpack by combat soldiers to failure with incremental increase to load mass), these basic tests produced moderate correlations with load carriage performance (less bench press). These conclusions are based on the output of one study and while the approach shows promise, further evidence is required to substantiate any recommendations.

[1] In this review fitness was employed to group the following physical characteristics: strength (functional and specific muscle group) and $\dot{V}O_2max$.

This systematic review would suggest that lower limb strength (specifically hamstrings and quadriceps) is a central element of load carriage performance (Dziados et al., 1987 [16], Mello et al., 1988 [14], Knapik et al., 1990 [17]). However, this is not to say that the gastrocnemius group should be ignored, as propulsion is central to ambulation with or without additional load. Similarly, strength at the shoulder was also shown to be significant (Koerhuis et al., 2009 [12]). What we can take from this is that administrative load carriage requires a whole body approach, and if load or intensity of task is increased, the power and strength requirement will escalate.

It is also clear from this review that good cardiovascular fitness is beneficial to load carriage performance. However, this review suggests that as a component of fitness it may have marginally less influence than strength. Only two papers met the inclusion criteria, with both reporting different outcomes (correlations with load carriage performance) as to the influence of $\dot{V}O_{2max}$ on load carriage performance (Knapik et al., (1990) – 0.31 [17], Lyons et al., (2005) – 0.64 [13]). This is most likely due to the investigation protocols with Knapik et al., setting a load carriage task of 20 km, carrying 46 kg [17], as opposed to the Lyons et al. treadmill-based protocol totalling 6 km (4 km/hr for 60 mins), carrying loads of 0, 20 and 40 kg for a 5 min period (on a graded programme) [13]. From the detail given, the Knapik et al. study has more synergy with administrative load carriage due to the weight and distance involved, however, in this study the soldiers (n = 96) were asked to complete the task 'as fast as possible' [17]. Conversely the lab based task conducted by Lyons et al., parcelled each task into a 5 min test sequence at a set pace for the 28 participants [13]. In a more recent study Pihlainen et al. (2014), assessed an unloaded (5.4 kg) and loaded (24.4 kg) march. The results of the 65 min task (including a 15 min break – mean speed 4.4 km/h), is suggestive of a $\dot{V}O_{2max}$ requirement of between 45 to 50 $mL \cdot kg^{-1} \cdot min^{-1}$ [27].

Anthropometrics: Throughout this systematic review, the term 'anthropometrics' was employed to encompass:

- Body mass;
- Body fat;
- Fat free mass; and
- Stature.

In terms of modifiability it is clear that adiposity is modifiable, whereas stature is not. One might suggest that high levels of fat free mass and low levels of body fat are the same. However, the basic definitions below would indicate otherwise (McArdle et al., 2006) [28]:

- **Fat Free Mass:** All residual lipid-free chemicals and tissue, including water, muscle bone, connective tissue and internal organs. The terms lean body mass and fat free mass are often used interchangeably. There is a subtle difference as FFM is all body mass devoid of all fat and LBM is all body mass devoid of all storage fat.
- **Body Fat:** All extractable lipids from adipose and other body tissue.

Moreover, in the case of load carriage performance the association between fat free mass and body fat is in opposing directions (positive for fat free mass and negative for fat mass). Three studies reviewed in this systematic review supported the notion of a positive relationship between body mass and load carriage performance. Nevertheless, data would suggest that individuals with high levels of fat free mass offer most compelling evidence for enhanced load carriage performance; however, these characteristics do not readily offer a practical outcome to support decision making. Much of the evidence supporting body mass as a predictor of load carriage ability is confounded by fat free mass, to the point that excess body fat is referred to as a 'dead

weight' when performing load carriage tasks (Haisman 1988 [29]). In addition, recent 'population relevant' research would suggest the correlation between body composition (i.e., % fat free mass) and body mass is weak (Drain et al., 2012 [2]).

Further research on the topic has proposed that body composition rather than body mass is more closely associated with the metabolic demands of heavy load carriage tasks as undertaken by the military (Lyons et al., 2005 [13]). When reporting on the metabolic demands of load carriage, Lyons et al. concluded that efficiency in load carriage was profoundly influenced by the amount of lean body mass compared to the dead mass (load + fat mass) [13]. Although beyond the remit of this review, it is distinctly possible that those soldiers with higher levels of body fat experience metabolic changes that can reduce muscle function (i.e., fatigability), oxidative capacity and motor unit activity (Wearing et al., 2006 [30], Newcomer et al., 2001 [31]), thus diminishing their performance capacity.

In addition, studies on body geometry have indicated that abdominal obesity alters postural stability (de Sousa, 2005 [32], Hue et al., 2007 [33]), reduces mechanical efficiency (Xu et al., 2008 [34]), increases mechanical loading [34] and is associated with early muscular fatigue (Capodaglio et al., 2010 [35]). Moreover, it has been recently demonstrated that favourable neuromuscular adaptations to obesity account for the higher strength reported in obese individuals (Garcia-Vicencio et al., 2016 [36]). However, this higher strength generating capacity is strongly associated with a greater extent of muscular fatigue (Garcia-Vicencio et al., 2015 [37]). Evidently, all of these issues could have a profound effect on load carriage performance.

Sex Specific Considerations and Trainability: In terms of the reviewed papers, sex considerations were a prominent feature, yet, the selected papers may not sufficiently reflect current research. Of importance is the fact that female participants are compared to male participants, however, modifiable characteristics such as body mass or lean body mass, training status, and experience are not matched. Recent research from the US Army indicates that in a well-controlled analysis of injury risk of women compared to men controlling for age, race, and several components of measured entry level physical fitness, the only factor that remained significant in the logistic regression was run time (aerobic fitness). Therefore, women matched for physical fitness to men, in particular aerobic weight bearing fitness assessed by run times, can be expected to experience similar risks of injury as men (Nindl et al., 2016 [22]).

Research from Knapik 1997 [38] studied the effects of a 14-week training program in female soldiers (age 29 ± 7 years). The training was conventional, consisting of resistance training three days per week and cardiorespiratory training two days per week. Knapik reported modest increases of 16 to 19 % on the performance of manual material handling [38]. However, when women were given a more intensive six month functional training regimen (load carriage exercises, plyometric exercises, interval training, and simulated occupational tasks) and a periodized model of resistance training, they improved their maximal occupational lifting capacity by 30% to 47%, repetitive lifting capacity by 18% to 32%, load carriage ability by 24%, and aerobic capacity by 14% (Knapik 1997 [38], Harman et al., 1997 [39]). Using the current US military occupational specialty classification system on physical demands, the percentage of women, who could qualify for "very heavy" military occupational specialties increased from 24 to 78 %. In this study Harman et al. demonstrated that a specially designed and implemented physical training program, administered within the normal Army time constraints, can be very effective in improving the ability of women to perform physical demanding jobs, and is much more effective than the physical components of standard Army Basic Training [39].

Similarly, Kraemer et al. (2001) [40] studied the effect of a six month training program on women (n = 83) by administering four different programs focusing on resistance and aerobic compared to aerobic only. The results highlighted the importance of upper body training in women and sex differences in physical

performance, particularly load carriage, were significantly attenuated. These results suggest that training programs for women should include performance of three to eight rep max sets to optimize increases in muscle size/ strength, and thereby reduce sex differences. This research provides powerful empirical data challenging earlier studies questioning the trainability of strength and power in women. The results of the study by Kraemer et al. suggest with the correct training program improvements in strength and aerobic capacity of women can successfully transfer to occupational tasks with women achieving equivalent levels of untrained males (Cooper, 2014 [41]). However, beyond the sanitised environment of training, the issue may arise when well-trained women and well-trained men are brought together for combat tasks requiring optimum levels of occupational fitness. In this instance of 'combat reality' a performance gap may still exist.

To date, numerous studies examining sex specific differences in load carriage performance with backpacks have demonstrated that women perform as well as men when carrying light loads (<15 to 20 kg), but potential differences related to anthropometrics may be noted when loads are > 20 kg (Bhambhani et al., 2000 [42]; Harper et al., 1999 [43]). Ricciardi et al. (2007) [11] studied sex specific differences and body adiposity on physiological responses to physical work while wearing Body Armour (BA) with 34 military persons (17 women, mean height 163.8 cm and 17 men, mean height 173.6 cm). At the slow pace (3.9 km/h), no sex specific differences were found for walking with BA (11 kg) in oxygen consumption, Heart Rate (HR), Respiratory Exchange Ratio (RER), or Respiratory Rate (RR), at the moderate rate 5.7 k pm/h no sex specific differences were found when walking with BA in oxygen consumption, HR, RER, or RR and lactic acid (blood). No sex specific differences were found in stair stepping performance without BA and the number of stairs stepped decreased 14% for women and 17% for men when wearing BA. During walking, seven men and seven women did not complete the moderate pace task due to reported fatigue. While women did report higher Rating of Perceived Exertion during all conditions, body fat was the best single predictor of treadmill test completion while wearing armour (explaining 20 to 26 % of the variance, age accounted for 13% – 17% of the variance). In this study subject sex was not a significant predictor of test completion. When age, sex and body fat were included as independent variables in the model, subject sex did not contribute significantly. Using a forward conditional method of logistic regression, age and body fat contributed significantly to the model of predicting test completion while wearing body armour (sig at $p = 0.0002$) with age and body fat explained 30% to 41% of the variance.

Nevertheless, Martin and Nelson (1986) suggest the load carriage performance gap between male and female soldiers extends as the amount of weight increases [9]. Research into the biomechanics of load carriage indicates that each 1 kg of added load requires an additional 10 N of force (Birrell et al., 2007 [7]). Ricciardi et al., (2007) proposed that even when wearing a relatively light load (10 kg BA), total body fat of female and male participants remained negatively correlated with physical task performance [11].

It is clear that most studies describing sex specific differences do not control for body fat which is one of the most important variables concerning load carriage efficiency. However, even well-trained women athletes have more fat mass than men (Buehring et al., 2014 [44]), thus training programmes aimed at enhancing lean body mass and reducing fat mass may not rectify this sex specific characteristic and could increase the risk of osteoporosis (Khan et al., 2002 [45], Thein-Nissenbaum, 2013 [46]) and reproduction dysfunction (Warren and Perlroth, 2001 [47]).

It should be acknowledged that the ability to successfully modify an outcome may not just involve the individual. It may require different stakeholders and agencies working together towards a common aim. For instance, a soldier may require behavioural change, education and motivation to achieve fitness levels that are commensurate with employment. For physical conditioning, we may know what constitutes the ideal physical training programme for load carriage performance (Knapik et al., 2012 [3]); still, local environment, facilities, instructor skills and individual motivational state may conspire to dilute or disable the desired outcome.

It is clear modifiability will require support (education), opportunity (time and priority) the correct environment and the continued engagement from the Chain of Command.

4.2.3.8 Non-Modifiable Factors

Stature and Gait: In the case of stature there was evidence to suggest that shorter individuals will have an increased total workload and therefore greater physiological stress due to reduced stride length. In essence, shorter men or women will be required to complete more strides compared to a soldier of greater height to cover the same distance. Due to leg length, shorter individuals (primarily women) also increase the amount of time spent with both feet on the ground (Martin and Nelson 1986) [9], potentially increasing both ground and impact forces. Therefore, in heavy load carriage the influence of external load will fatigue a shorter soldier more readily that a taller soldier. Moreover, the likelihood of injury is elevated through increased mechanical (Springer and Ross, 2013 [48]) and joint loading (Polcyne et al., 2002 [49]). These problems may be further amplified as the load increases as heavier loads may result in a nonlinear and greater relative metabolic cost (Soule et al., 1978 [50]), and different (and possibly less efficient) kinematics (Attwells et al., 2006 [51]; Birrell and Haslam, 2009a) [20]).

Further, Scott and Christie (2004) [15] and Koerhuis et al. (2009) [12] reported significant correlations in male soldiers between height and load carriage performance. Martin and Nelson (1986) [9] indicated that as load increases, both men and women demonstrate a decrease in stride length and swing time and an increase in stride rate and double-support (when both feet are in contact with the ground). The authors attempted to compare 11 men to 11 women however they did not match for stature (men were mean of 10 cm taller and approximately 10 kg heavier) since the maximum load carried was 36 kgs this was a difference of 50% body mass for men to 60% body mass for the women. All participants completed each trial and the pace was 6.4 km/hr which is relatively fast, in addition there was no waist belt for the rucksack which has since been demonstrated to allow females to better carry loads on their hips. Not unexpectedly, the females required a higher rate of stepping than the males because of their shorter stride lengths. The results also demonstrated that the walking patterns of both the male and female subjects were affected by the increases in carried load. There was also an increased forward inclination of the trunk but only for the two heaviest loads which were carried in a rucksack. While the changes in gait characteristics were relatively small for the male subjects, the females were affected to a greater extent thereby demonstrating a greater sensitivity to load magnitude.

Ling et al. (2004) [52] suggested that much of the biomechanical changes during loaded marching are initiated due to a lack of strength in women. However, six of the seven female subjects in their study successfully completed the loaded march with 23 kg for one hour at 4.8 km/h, while maintaining a HR under 80% max. This would suggest women can (with the appropriate load carriage system and with a relatively light combat load) complete load carriage tasks comparably with men without increasing cadence or decreasing stride length. The issue of capability may only arise at higher walking speeds (LaFiandra et al., 2002 [53]) due to a decrease in pelvic rotation (Deuster et al., 1997 [54]), greater postural disturbance and therefore more rapid fatigue development (Park et al., 2014 [55]).

In contrast, Silder et al. (2013) [56] used weighted vests representing 10%, 20%, and 30% of each subject's body mass (males 75 kg, females 63 kg). In this study, an equivalent and relative load was imposed on male and females, the results suggest when the load is relative to body mass neuromuscular recruitment and walking mechanics remain stable. It is of note, if fixed and absolute loads were used (as is often the case in mission specific tasks), the same outcome would not have been anticipated (Haisman 1988 [29]; Knapik et al., 2004 [1]). While this information could be used to inform load carriage training (marching pace is usually set by the male soldiers during military training putting women at a disadvantage due to their generally shorter leg length and therefore reduced preferred stride length to maintain pace women or men who are shorter will increase

frequency, or length of stride). The evidence from Chapter 2 across the scenarios suggests combat load carriage weights are regularly in excess of 60% body weight. It could be hypothesised, should the type of loads observed in Chapter 2 be linked to an operational imperative, the speed of the loaded march would most likely increase. In this scenario, as greater postural and locomotor perturbations are often related to size and stature (Martin and Nelson 1986 [9]; Haisman 1988 [29]) smaller individuals, and in particular women, may experience significantly greater instability and fatigue (Taylor et al., 2016 [57]). In this situation the risk of personal injury is enhanced (Bhambhani and Maikala 2000 [42]; Knapik et al., 2004 [1]; Park et al., 2014 [55]), and reductions to individual and collective capability could enhance the risk to mission success.

4.2.4 Limitations

The main limitation to this review was the amount of evidence, or lack of, available to substantiate any conclusions and further literature was added beyond that which qualified for the systematic review. Certain investigations (Birrell and Haslam, 2009a [20]) were primarily laboratory based and therefore lack the reality and some of the contextual nuance allied to military training within military instillations. There are also issues with sample size and thus the influence of the larger studies where summary statistics are given. For the NATO member countries, whilst the populations are contextually sound there may be some generalizability issues as the majority of the information comes from either US or UK military populations. In addition, the report includes some populations that are students or Reservists and University Officer Training Corps; with little or no military experience in loaded marching.

4.2.5 Conclusion

This review on the physical capabilities that affect load carriage performance has identified a lack of evidence across the area and in each of the sub-groups. From the available evidence there is a suggestion that the physical characteristics that fall into the broad categories of anthropometrics and fitness status have the ability to affect load performance. However, further research is required to inform military decision making (see Section 4.6).

Stature featured highly as a significant factor in administrative load carriage ability. Clearly stature cannot be modified; however, changes to training may mitigate (to a degree) not so much the reduction in performance, but the impact of injury due to changes to the biomechanical gait. While it is not a likely tactical decision to group individuals by height, training could be undertaken in this manner, and since the training process is likely to account for more load carriage road miles covered than actual tactical engagement; injuries due to additional biomechanical strain could be reduced. It follows that physical conditioning may need to alter to reflect alterations in actual physical conditioning capability.

While several studies have commented on the trainability of female soldiers to reduce sex differences (Harman et al., 1999 [39], Kraemer et al., [40]) recent studies suggest dedicated exercise programmes can support female soldiers in meeting the physical demands of the most demanding military occupations (Nindl et al., 2016 [22]). The reported consequence would appear to be a reduced physical reserve to meet the dynamic demands of an emergency and the possible step-changes to battle rhythm (Roberts et al., 2016 [58] . For the adaptive process of administrative advance, the absolute sex differences may not manifest, however, the comments of Roberts et al. would suggest a greater impact for those reactive and dynamic combat tasks.

4.3 SYSTEMATIC REVIEW: THE EFFECT OF LOAD CHARACTERISTICS ON LOAD CARRIAGE CAPACITY AND PHYSICAL MOBILITY INTRODUCTION

4.3.1 Introduction

The loads carried by dismounted soldiers on the modern battlefield remain in excess of 55% body mass as shown in Chapter 3. This is despite decades of research that has consistently reported a negative impact upon mobility, load carriage capacity and increases the risk of injury (Orr et al., 2013 [59])[2]. Indeed, most science and technology organizations continue to invest considerable time, money and effort developing strategies in an attempt to reduce the physical burden on the dismounted soldier.

In attempt to manage this issue, several nations have produced 'Commander's Guides' that provide evidence-based recommendations for optimal for load carriage (Leamon and Scott, 2005 [61]; Drain et al., 2012 [2]). In addition, the military have suggested changes to doctrine that aim to attempt to reduce the burden on the dismounted soldier, e.g., the UK Capability Directorate Combat 'Fight Light' Doctrinal Note or changes to acclimatisation and physical training strategies (i.e., attempting to make the soldier in the system more robust and capable of carrying heavy loads (Fordy, 2012 [62])). However, it should be noted that much of the military advice has suggested carrying a percentage of body mass (relative load usually 30 – 45% dependent on task) which is limited in its utility given the fact that soldiers are required to carry an absolute load consisting of the capabilities needed to accomplish a mission safely, efficiently and effectively.

As regards physical mobility, it is generally accepted that for every 1 kg added to the external load mass on the torso, performance decreases by 1 to 1.5 % (Holewijn and Lotens, 1992 [63]) for tasks such as obstacle courses, jumping and sprinting. While this may be the case for loads up to 30 – 35 kg the percentage decrement may become progressively more severe (i.e., a larger percentage decrement per kg of external load mass) with loads in excess of 40 kg as suggested by the findings of Fordy et al., (2011) [64]. It is also well established that increasing external load mass reduces load carriage capacity with the greatest decrement seen with the heavier loads. However, the percentage decrement per kg of external load mass on performance of endurance tasks is less clear.

Although the impact of mass on military task performance has been the focus of much of the empirical work, it is evident that other characteristics such as bulk and stiffness play a role and adversely affect physical performance of military tasks. However, the relative contributions of these attributes to performance decrement remains to be clarified. It should also be noted that comfort and fit play an important role in the ability to complete load carriage tasks. However, it was not possible to highlight any research that specifically examined the effect of comfort and fit on load carriage capacity and as such they are not considered in this review but should be noted as a significant evidence gap.

Therefore, the aim of this work was to critically review the literature that has examined the impact of load mass, stiffness and bulk on mobility (static and high intensity tasks) and load carriage capacity (endurance tasks).

[2] This review does not deal with the injury/medical aspects of load carriage and as such the reader is directed to the excellent reviews of Knapik and Reynolds, 2010 [60]; Orr et al. 2013 [59].

4.3.2 Methods

A Population, Intervention, Comparison and Outcomes (PICO) strategy was used to develop an exam question and identify relevant articles [65]. This method was used as the research typically conducted in defence research, science and technology organizations uses a specific population (e.g., infantry soldiers), intervention (e.g., load mass), comparison (randomised control trial) and outcome (time to complete road march) thus making it appropriate for scrutiny via systematic review.

The exam question used to examine this issue was, "Which load carriage equipment characteristics affect mobility and load carriage capacity and by what magnitude?"

4.3.2.1 Search Terms

In order to address this exam question, four databases were employed with the searches limited from 1990 to 2016. The databases searched were PubMed, the Defense Technical Information Centre (DTIC), Research Gate and Google Scholar[3]. Table 4-5 highlights the search terms/key words used. In addition, specific subject matter experts were contacted to provide supplementary information.

Table 4-5: Search Terms / Key Words Used During Initial Literature Search.

Search Terms*
Military Load Carriage
Heavy Load Carriage
"Load Carriage" AND Performance
Load Carriage Capacity
Combat Mobility
"Load Carriage" AND Mobility
"Body Armour" AND Mobility
"Body Armour" AND Agility
"Body Armour" AND "Range of Motion"
*The UK and US spellings were used

Following an initial screening of the titles and abstracts, the appropriate articles were retrieved, and the reference lists were scrutinised to identify any other studies not previously acknowledged.

All articles were then exposed to the inclusion criteria, these being:

a) Human studies;

b) Published 1990 – 2016;

[3] It should be noted that the author is not affiliated with an academic institution and as such was not able to access the same databases as used in Section 2. However, this is not considered to have detracted from the quality and / or completeness of the searched undertaken.

c) Reported in English;

d) The load mass manipulated was carried on the torso (backpack or vest); and

e) Specifically examined the effect of load carriage on load carriage capacity (endurance) and mobility (static and high intensity) performance[4].

Studies examining the impact of load carriage in adolescent populations were excluded along with those that lacked suitable quantitative data.

The Downs and Black checklist [4], as previously described in Section 2, was then used to assess the methodological quality of those studies that met the inclusion criteria. Two suitably qualified and experienced scientists reviewed all studies and provided a score out of a possible 32 which was converted to a percentage for the Methodological Quality Score (MQS). Inter-rated agreement was assessed using the Cohen's κ statistic. The mean of the two scores was then used as MQS for each study.

The studies were grouped into their methodological sub-groups (static mobility task studies, endurance task studies and high intensity task) for tabulation, henceforth notes as ***static***, ***endurance*** and ***high intensity***. However, it should be noted that three studies fitted into more than one sub-group due to the tasks completed (Armstrong et al. 2012 [66], Knapik et al. 1993 [67] and Peoples et al. 2010 [68]).

4.3.3 Results and Discussion

The initial search identified a total of 591 studies of which 527 were removed after screening of the title and abstract. Four additional articles were kindly provided by colleagues bringing the total of articles retrieved in full text to 68. Of these a further 33 did not meet the inclusion criteria and were excluded from the analysis. On the basis of this screening strategy a total of 35 studies were reviewed in full (see Figure 4-3).

Table 4-6, Table 4-7 and Table 4-8 provide an overview of the studies included in this systematic review. The MQS of the all the studies reviewed was mean (SD) 71.6 (4.3) with a Cohen's κ statistic of 0.79 which is categorised as being 'substantial agreement'[5]. The MQS for static, endurance, and high intensity task studies were 70.5 (3.3), 72.5 (6.5) and 71.8 (3.9), respectively. Taken as a whole this reflects high methodological quality and is unsurprising as all studies have been previously peer reviewed (including those presented as poster presentations at conferences). It is also notable that the MQS was similar between sub-groups.

It is clear that the defence scientific community has focused on the examination of high intensity tasks. This likely reflects the research priorities of the nation's military leadership with most nations continuing to invest many millions of dollars into the research and development of body armour / load carriage systems. Indeed, the current operational trend of asymmetric warfare necessitates that soldiers' wear some form of hard and/or soft armour protection much of the time with the ability to carry an irreducible minimum level of capability that allows them to operate. Therefore, a thorough understanding of the impact on performance of high intensity military tasks remains essential.

[4] It should be noted that studies that examined the effect of load carriage on specific physiological (e.g. energy expenditure, heart rate, neuromuscular function) or biomechanical (e.g., gait) variables were not included. However, these have been reviewed extensively elsewhere (Knapik and Reynolds, 2010 [60]; Orr et al., 2013 [59]).

[5] Kappa statistic overview: < 0 Less than chance agreement, 0.01 – 0.20 Slight agreement, 0.21 – 0.40 Fair agreement, 0.41 – 0.60 Moderate agreement, 0.61 – 0.80 Substantial agreement, 0.81 – 0.99 Almost perfect agreement.

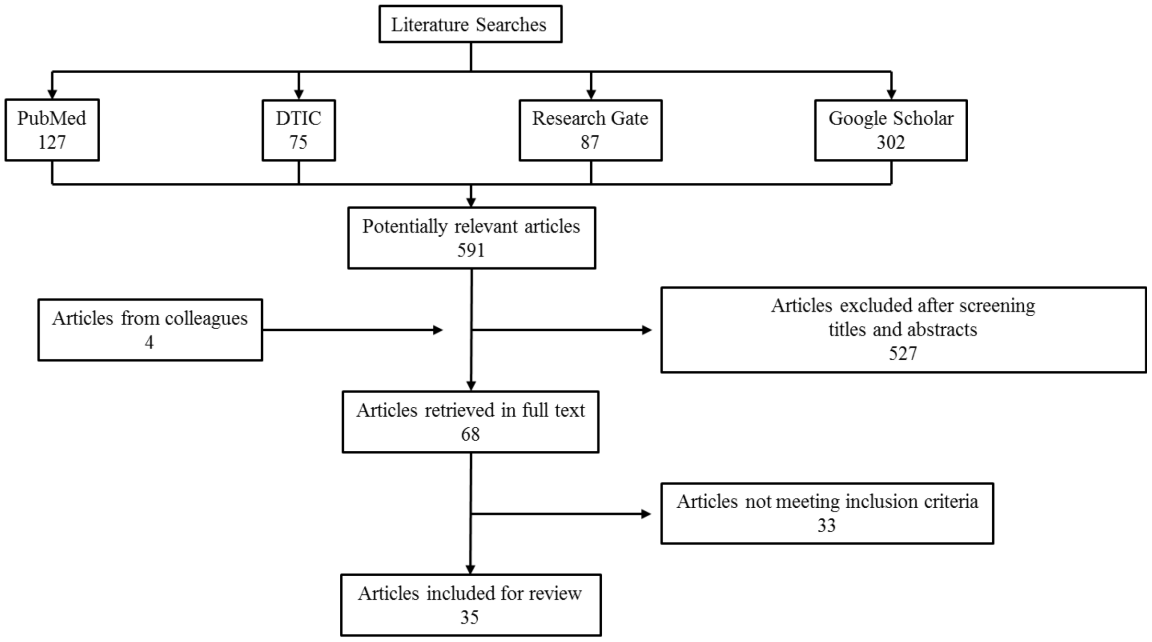


Figure 4-3: Flow Diagram of the Literature Search and Review Process. (PubMed: https://www.ncbi.nlm.nih.gov/pubmed, DTIC: Defense Technical Information Centre – http://dtic.mil/dtic/, Research Gate: https://www.researchgate.net/home, Google Scholar: https://scholar.google.co.nz/ Table 4-8).

Most studies focused on the impact of load mass on task performance. Given the findings of Jones et al. (2014) [69], that suggest up to 70% of performance variance can be explained by the load mass carried, when completing a combat mobility course, perhaps this bias is understandable. However, it should be noted that, more recently, there have been several excellent attempts to explore the relative contributions of mass, stiffness and bulk to changes in task performance (Jones et al., 2014 [69], Bossi et al., 2016 [70], Karakolis et al., [unpublished data, 2014] [71]).

The work of Jones, Bossi, Karakolis and colleagues has used innovative experimental designs when assessing completion of the Canadian Load Effects Assessment Programme (CAN-LEAP) combat mobility course. Taken as a whole, the data show a positive correlation between mass and performance of CAN-LEAP. Bossi et al. (2016) [70] also showed a positive correlation between CAN-LEAP completion time and increased bulk and a negative correlation between course completion time and most range of motion measures. However, it is evident from the work of Bossi and colleagues that considerable overlap exists between configurations with some participants in Full Fighting Order (FFO) plus ballistic protection (25.7 kg) completing the CAN-LEAP course faster than those that were unencumbered (4.8 kg). There is also substantial overlap in the data examining the relationships between course completion time and bulk and stiffness. What is clear is that mass, stiffness and bulk all play a role in performance impediment of high intensity military tasks and further experimentation is required to fully understand the inter-relationships between these characteristics.

It was apparent that most studies exploring the impact of load mass distribution assessed some form of physiological (e.g., energy expenditure) or biomechanical (e.g., gait) variables and were therefore excluded from this review (see Section 4.3.2.1). However, Johnson et al. (1995) [72], Knapik et al. (1993) [67] and (1997) [38] assessed the use of an experimental double pack on road march performance. The results showed that soldiers

performed the road march more rapidly with the backpack than the double pack. It was suggested that this could be explained by the soldiers having greater familiarity with the backpack but there were some design issues that were also highlighted (e.g., waist belt loosening thereby making the system less stable). However, more recent work has shown a 21% reduction in exercise capacity during load carriage tasks when comparing no load and using a weighted vest (22 kg). This was explained by a reduction in the peak aerobic power rather than fatigue of the inspiratory muscles (Peoples et al., 2016 [73]). Undoubtedly, examination of the impact of load distribution on task performance deserves further attention.

The populations recruited for these studies have both been homogeneous (one sex [Examples – All male: Jaworski et al., 2015 [74], All female: (Frykman et al., 2001 [75]) or heterogeneous (both sexes [Examples – Ricciardi et al., 2008 [76]; Laing Treloar and Billing, 2011 [77]]) in nature. Although some female participants were used the majority of studies used only male participants. Whereas historically this may have reflected those expected to engage in dismounted close combat, several nations have initiated a strategy of integration by removing the employment restrictions for females in combat roles. Therefore, it could be argued that the focus of future studies should examine the impact of load on females, specifically in high intensity tasks that simulate dismounted close combat. However, taken as a whole, it is apparent that an effort had been made to recruit appropriate participants e.g., infantry soldiers required to perform simulated dismounted close combat tasks (Billing et al., 2015 [78]) or special forces soldiers required to carry heavy load at pace (Knapik et al. 1993 [67], 1997 [38]).

As regards the loads carried, there was considerable variance in the mass being carried, which ranged from 9.1 kg (Lewinski et al., 2015 [79]) to 61 kg (Knapik et al., 1993 [67], 1997 [38]) with the heavier loads generally carried during endurance tasks. This is reflective of operations where soldiers would be expected to carry sustainment capabilities which would then be removed if required to move at speed, e.g., when moving under fire. As would be expected, these studies reported a reduction in load carriage capacity (i.e., an increased time to complete road march) with increasing load mass. Although perhaps an intuitive finding, it is important to continue to highlight the impact of requiring soldiers to carry heavy loads to the military customer. Improved insight into the issue will certainly assist military decision makers and scientists alike to develop strategies to reduce the burden on the dismounted soldier.

The nature of the load carried was reflective of the type of task being performed. That is, endurance studies generally utilized a backpack load carriage system (e.g., Knapik et al., 1993 [67]) whereas static and high intensity studies used a body armour or tactical vest system with appropriate combat/fighting loads (e.g., Mitchell et al., 2012 [80]; Billing et al., 2015 [78]). Again, this is sensible and represents the types of loads carried in training and/or on operations. With the development of scalable, integrated body armour and load carriage systems, future studies should examine all possible permutations to provide tactical decision makers with the evidence required to inform mission planning.

Within the static studies (n = 7, Table 4-6) the tasks being assessed ranged from balance (Park et al. 2014 [55]) to postural control (Sell et al. 2013 [81]) to joint range of motion (e.g., Mitchell et al. 2012 [80]). The major finding of these studies was that there is impediment to task performance caused by the wearing of PPE. In regards range of motion, restriction of movement was correlated with the body armour protection level i.e., the greater the level of protection, the more severe the restriction to movement [80]. In addition, postural sway and leg muscle activation increased with load particularly when the load was unevenly distributed [55]. Sell et al. [81] highlighted significant decrement to dynamic postural stability with increased load. In general, these findings might be expected but also further highlight the importance of research and development programmes continuing to explore the trade-off(s) between protection, mobility and stability.

For the endurance tasks (n = 7, Table 4-7), the best-effort road march task was commonly used with distances ranging from 3.2 km (Pandorf et al. 2002 [82]) to 20 km (Johnson et al., 1995 [72]; Knapik et al., 1993 [67] and 1997 [38]) using time to complete a given distance as the primary metric (however, the rationale for using the distances chosen in not given). One study (Phillips et al. 2016 [83]) used a graded treadmill exercise protocol using time to voluntary exhaustion as the marker of performance. Both methods are dependent, somewhat, on the motivation of the participants which could be seen as a limitation, one which is true of most human studies examining 'performance' of some kind.

For most high intensity studies (n = 21, Table 4-8), some form of obstacle / combat mobility course was used (e.g., Bennett et al., 2014 [84]; Bossi et al., 2016 [70]; Hasselquist et al., 2008 [85]; Jones et al., 2014 [69]). Other studies used repeated sprints ranging from very short, e.g., 6 strides (Lewinski et al., 2015 [79]) to 30 m (Billing et al., 2015 [78]). It is evident that considerable effort has been spent trying to ensure that the obstacles within these mobility courses are operationally relevant i.e., they would commonly be negotiated by soldiers on the battlefield. Further, the sprint distances have been developed to imitate break contact or fire and movement drills. These studies consistently reported a reduction in task performance such as increased time to complete entire combat mobility course and/or individual obstacles, increased time to complete sprints/bounds or reduced velocity and acceleration. However, the time to cover the distance between obstacles is not reported although it is understood that this data is now collected.

Table 4-6: Summary of Studies Included in this Review – Static Mobility (n = 7).

Author(s) and Date	Participants	Condition	Tasks Completed	Major Findings
Armstrong et al. (2012) [66]	n = 8, Male, Infantry Soldiers	No armour, 4 types of body armour (1 x rigid, 3 x flexible hard armour)	Obstacle course, flexibility / range of motion. Balance, single jump and 30 sec jump test (no armour vs. rigid armour vs. rigid armour and pelvic protection)	Significant reduction in shoulder and thoracic-lumbar range of motion (no armour vs. armour), significant reduction in single and 30 sec jump test performance ($p<0.05$). No effect of adding pelvic protection
Bridger et al. (2014) [86]	n = 26, Male, Infantry Soldiers	4 types of body armour in 'low' and 'high' level of protection	Upper and Lower limb Range of Motion, Trunk Flexion (forward and lateral), Star excursion balance test, standing long jump	Significant reduction in shoulder flexion and abduction, hip flexion, forward and lateral trunk flexion, balance test ($p<0.01$) and standing long jump ($p<0.01$)
Lenton et al. (2015) [87]	n = 16, Male, Active	No armour vs. 4 armour systems (6.4 – 8.6 kg)	Ammo box lift and place, Ammo box lower and place, sandbag lift and place	Significant reduction ($p<0.001$) in trunk flexion (lift tasks) rotation (place tasks)
Park et al. (2014) [55]	n = 7, Male, Military training university students	No armour or load vs. 6 x armour / load configurations (9 – 27 kg)	Static body balance, leg muscle activation	Uneven weight distribution (>9 kg) significantly impaired balance. Elevated peak muscle activation with increased load

Author(s) and Date	Participants	Condition	Tasks Completed	Major Findings
Peoples et al. (2010) [68]	n = 31, Male, Infantry Soldiers	Uniform and boots (4.7 kg) and 5 x configurations of body armour (19.1 – 29.2 kg)	Fire and movement simulation, obstacle avoidance, combat rush, vertical jump, stand and reach	Significant reduction in vertical jump and stand and reach ($p<0.05$ no armour vs. armour conditions). No difference between armour conditions
Sell et al. (2013) [81]	n = 36, Male, Infantry Soldiers	No armour vs. armour (12.5 kg)	Single leg jump landings	Significant reduction in dynamic postural stability ($p<0.05$)
Woods et al. (1997) [88]	n = 12, Male, Infantry Soldiers	T-shirt and shorts vs. uniform vs. 2 x armour configurations	7 x static range of motion assessments	Significant reduction ($p<0.05$) in standing trunk flexion and shoulder abduction (T-shirt/shorts > uniform > armour)

Table 4-7: Summary of Studies Included in this Review – Endurance Tasks (n = 7).

Author(s) and Date	Participants	Load Carried	Tasks Completed	Major Findings
Frykman et al. (2001) [75]	n = 11, Military Police, Female	Body Armour (14 kg) + additional equipment (13 kg): Total 27 kg	Obstacle Course	48% increase in time to complete obstacle course between conditions
Harper et al. (1997) [43]	n = 34 (19 Male, 15 Female), Army Medical Officers,	Personal equipment and rifle (18 kg) vs. additional load (backpack: 27 and 36 kg)	10 km road marches. Individual, voluntary maximal effort	4% increase in time to complete march (18 vs. 27 kg $p<0.01$). 23% increase in time to complete march (18 vs. 36 kg $p<0.01$)
Johnson et al. (1995) [72]	n = 15, Male, Special Operations Forces	Backpack vs. prototype double pack (34, 48 + 61 kg)	6 x 20 km individual road marches	Significant increase in time to complete task ($p<0.01$)
Knapik et al. (1993) [67]	n = 21, Male, Special Operations Forces	Backpack vs. prototype double pack (34, 48 + 61 kg)	6 x 20 km individual road marches	Significant increase in time to complete task ($p<0.01$) ~25% slower 34 vs. 48 kg, ~51% slower
Knapik et al. (1997) [38]	n = 15, Male, Special Operations Forces	Backpack vs. prototype double pack (34, 48 + 61 kg)	6 x 20 km individual road marches	Significant increase in time to complete task ($p<0.001$)

Author(s) and Date	Participants	Load Carried	Tasks Completed	Major Findings
Pandorf et al. (2002) [82]	n = 12, Female, Military Police	Body armour (14 kg) vs. additional equipment (27 and 41 kg)	6 x 3.2 km individual road marches	Significant increase in time to complete task ($p<0.05$). 19% 14 vs. 27 kg, 44% 14 vs. 41 kg
Phillips et al. (2016) [83]	n = 50, Male, Active, used to backpack load carriage	No load vs. 25 kg backpack	Graded treadmill exercise to voluntary exhaustion	Significant decrease (29.8%) in test duration ($p<0.05$) in loaded condition

Table 4-8: Summary of Studies Included in this Review – High Intensity Tasks (n = 21).

Author(s) and Date	Participants	Load Carried	Tasks Completed	Major Findings
Armstrong et al. (2012) [66]	n = 8, Male, Infantry Soldiers	No armour, 4 types of body armour (1 x rigid, 3 x flexible hard armour)	Obstacle course, flexibility / range of motion. Balance, single jump and 30 sec jump test (no armour vs. rigid armour vs. rigid armour and pelvic protection)	9 – 12% reduction (non-significant) in time to complete obstacles (no armour vs. armour)
Bennett et al. (2014) [84]	n = 24, Male, Serving military personnel	3 types of body armour in 'low' and 'high' level of protection	Obstacle Course	Significant increase in time to complete obstacle course with higher level of protection ($p<0.05$)
Billing et al. (2015) [78]	n = 19, Male, Soldiers	5 x loaded conditions (9.8 – 30.1 kg)	5 x 30m Break contact Drills, Fire and Movement simulation (16 x 6m bounds)	Significant increase in time to complete tasks ($p<0.001$)
Carlton et al. (2013b) [89]	n = 6, Male, Tactical Operations Police Officers	Uniform vs. Tactical Load (mean 22.8 kg)	25m mobility task, Marksmanship task	No significant difference in time to complete mobility task but may be an issue if load is <25% body mass. No difference in marksmanship task
Carlton et al. (2013a) [90]	n = 6, Male, Tactical Operations Police Officers	Uniform vs. Tactical Load (mean 22.8 kg)	Tactical movement task, Dummy drag	Significant increase in time to complete tactical movement and dummy drag (p,0.01)
DeMaio et al. (2009) [91]	n = 21 (19 Male, 2 Female), Active Duty Soldiers	Uniform vs. body armour and helmet (9.8 kg)	Maximal incremental treadmill test, 274 m shuttle run, Box agility drill, Rope pull + dummy drag	Significant decrease in time to voluntary exhaustion ($p<0.001$), increase shuttle run time ($p<0.001$)

Author(s) and Date	Participants	Load Carried	Tasks Completed	Major Findings
Dempsey et al. (2013) [92]	n = 52, Male, Police Officers	No load (t-shirt + shorts) vs. Stab-resistant vest and equipment (7.65 kg)	Mobility tasks (Balance, simulated vehicle exit, chin-ups, grappling, manoeuvrability)	Significantly reduced performance in all tasks with load ($p<0.001$)
Frykman et al. (2001) [75]	n = 11, Female, Military Police	Body armour (14 kg) vs. additional equipment (13 kg): Total 27 kg	Obstacle Course	48% increase in time to complete obstacle course between conditions
Harman et al. (2001) [93]	n = 11, Male, US Army Soldiers	Fighting Load (~17 kg), Approach load (~30 kg), Sustainment load (~44 kg)	Energy cost, 2 mile speed march, obstacle course, agility assessments, grenade throw, marksmanship simulation	Significant increase in time to complete tasks with increasing load
Hasselquist et al. (2008) [85]	n = 11, Male, Infantry soldiers	Uniform vs. Body armour (8.7 kg), extremity armour (5.6 – 6.4 kg)	10min walk (1.39 m/s), 10min run (2.43 m/s), Box lift and carry, 5 x 30m sprints, Obstacle course	Significant increase in time to complete tasks and decrease in number of box lifts ($p<0.05$)
Hunt et al. (2016) [94]	n = 19, Male, Airfield Defence	5 x loaded conditions (9.8 – 30.1 kg)	5 x 30m Break contact Drills, Fire and Movement simulation (16 x 6m bounds)	Significant increase in time to complete tasks ($p<0.001$)
Jaworski et al. (2015) [74]	n = 28, Male, USMC Active duty marines	Uniform, 15, 30 and 45% body weight	2x25 yd sprints, 75 yd Casualty Drag, 150 yd Ammunition Carry, Grenade Toss (Total 300 yd)	Significant increase in total time to complete tasks ($p<0.0001$)
Jones et al. (2014) [69]	n = 17, Male, Infantry and Combat Engineers	Uniform (4.8 kg) vs. Experimental vest 1 (7.7 – 8.5 kg) and Experimental vest 2 + load (18.3 – 22.1 kg)	CAN-LEAP Combat Mobility Course	Significant increase in total time to complete obstacles with change in load ($p<0.0001$). No measurable effect of manipulating stiffness or bulk

Author(s) and Date	Participants	Load Carried	Tasks Completed	Major Findings
Knapik et al. (1993) [67]	n = 21, Male, Special Operations Forces	Backpack vs. prototype double pack (34, 48 + 61 kg)	Obstacle course	No difference in time to complete obstacles
Laing Treloar and Billing (2011) [77]	n = 17 (12 Male, 5 Female), Non-combatant soldiers	Uniform vs. weapon, body armour + LCE, helmet	5 x break contact drills (30m sprint)	31.5% increase in time to complete task ($p<0.01$)
Larsen et al. (2012) [95]	n = 11, Male, Non-military recreationally active	No load vs. Body Armour (17 kg)	11 x circuits of obstacle course (including box lift task)	Significant increase in time to complete circuits ($p<0.01$). No diff in box lift task
Larsen et al. (2014) [96]	n = 11, Male, Non-military recreationally active	Plate Carrier (12.6 kg) vs. Full Body Armour (17.5 kg). Dummy rifle carried in both conditions (2 kg)	11 x circuits of obstacle course (including box lift task)	No difference in time to complete circuits between conditions
Lewinski et al. (2015) [79]	n = 20, Male, Law enforcement students	Uniform vs. Weight belt (9.1 kg)	2 x short (6 stride) sprints	Significant decrease in velocity and acceleration ($p<0.01$)
Loverro et al. (2015) [97]	n = 13, Male, Soldiers	3 different armour systems with no fighting load (12.1 – 19.4 kg) and with fighting load (23.1 – 30.4 kg)	10 x 30m sprints, unobstructed walk, walk over obstacle, walk under obstacle	Significant increase in time to complete individual and total rushes ($p<0.05$). No effect on mobility tasks
Peoples et al. (2010) [68]	n = 31, Male, Infantry Soldiers	Uniform and boots (4.7 kg) and 5 x configurations of body armour (19.1 – 29.2 kg)	Fire and movement simulation, obstacle avoidance, combat rush, vertical jump, stand and reach	Incremental increase in bound time for fire and movement

Author(s) and Date	Participants	Load Carried	Tasks Completed	Major Findings
Ricciardi et al. (2008) [76]	n = 34 (17 Male, 17 Female), Military Personnel	No load (t-shirt + shorts) vs. Body Armour (10 kg)	30min graded treadmill exercise, hand grip, stair step test, pull-ups (Males only) and hang time (Females only)	Significant reduction in stair step test, pull-ups (61%) and hang time (63%) performance ($p<0.001$)
Peoples et al. (2010) [68]	n = 31, Male, Infantry Soldiers	Uniform and boots (4.7 kg) and 5 x configurations of body armour (19.1 – 29.2 kg)	Fire and movement simulation, obstacle avoidance, combat rush, vertical jump, stand and reach	Incremental increase in bound time for fire and movement

4.3.4 Conclusions

This systematic review highlights that a large body of high quality research has been conducted which explores the impact of load carriage on performance of endurance and static and high intensity tasks. Cumulatively, this research has reported a progressively negative impact of the addition of load mass upon task performance. Furthermore, it is evident that mass, stiffness and bulk contribute to this impairment but the relative contributions require further examination. While the studies reviewed herein provide important insight into the impact of load carriage upon the ability to perform militarily relevant tasks, the generalisation of the findings is problematic. Soldiers are rarely required to perform 'best-effort' road marches but rather move administratively with regular rest periods in attempt to minimize fatigue. Similarly, individually performed, short (2 to 3 min) obstacle courses do not necessarily represent dismounted close combat. Therefore, assumptions about the impact of load carriage on operational effectiveness based on the findings of studies akin to these must be made with care.

Nevertheless, given the fact that the load mass carried by dismounted soldiers continues to be excessive (as demonstrated in Chapter 3), it is imperative that military research, science and technology organizations continue to examine this issue. It can be concluded that the loads carried by dismounted soldiers negatively impact their ability to move which, on the battlefield, may result in increased vulnerability to enemy action and being more susceptible to injury.

4.4 SYSTEMATIC REVIEW: WHICH PERSONAL CHARACTERISTICS AFFECT LOAD CARRIAGE PERFORMANCE OF SHORT DURATION DYNAMIC TASKS AND CONSEQUENCES OF A LONG LOADED WALK ON THESE PHYSICAL CHARACTERISTICS

4.4.1 Personal Characteristics Which Affect Performance of High Intensity Tasks

To date, military studies have mainly focused on the physical capabilities associated with prolonged load carriage activities. Nevertheless, high intensity tasks of short duration often follow an administrative advance. Therefore, the understanding of the anaerobic component of combat is essential for soldier survivability and mission success. To this end, several studies have examined the effect of load carriage on the ability to perform short duration military tasks.

Studies interested in analysing the anaerobic component have utilized the military obstacle course or repeated short duration high intensity tasks. These tasks vary from single to repeated loaded sprints, lifting, climbing, crawling, physical mobility, and battlefield simulations during short bouts of time at a high intensity. The military obstacle course closely reflects the demands required by the current combatant during assault. Therefore, time to successfully complete the course, would seem to be a good indicator of the performance during assault. Moreover, the capacity to execute strenuous movements by carrying heavy loads, with a maximal level of strength/power during a short bout of time, is essential to task completion and survivability of soldiers (Mala et al., 2015) [98].

The detrimental effect of load on combat task performance (i.e., the increase in time to complete) has been clearly observed by several researchers. For instance, Mala et al. [98] observed that performance of an obstacle course (Figure 4-4) was deteriorated by ~-30% while carrying loads up to 40 kg. Derrick et al. (1963) [99] showed significant decreases in performance of walking, casualty rescue, grenade throw, obstacle course and a combat crawl by carrying loads ranging from 9 to 15 kg. Additionally, Martin and Nelson (1986) [9] have focused on effects of load on the combative movement performance of men and women. Subjects performed a series of tests which included sprint, long jump, agility run, reaction time and ladder climb with loads reaching 37 kg. They showed that decreases in performance time (~-25%) were linearly associated with increases in load. Moreover, they observed a sex-based effect on all test performances mainly explained by a reduced strength/body mass ratio and greater relative loads (normalized to lean body mass) in females.

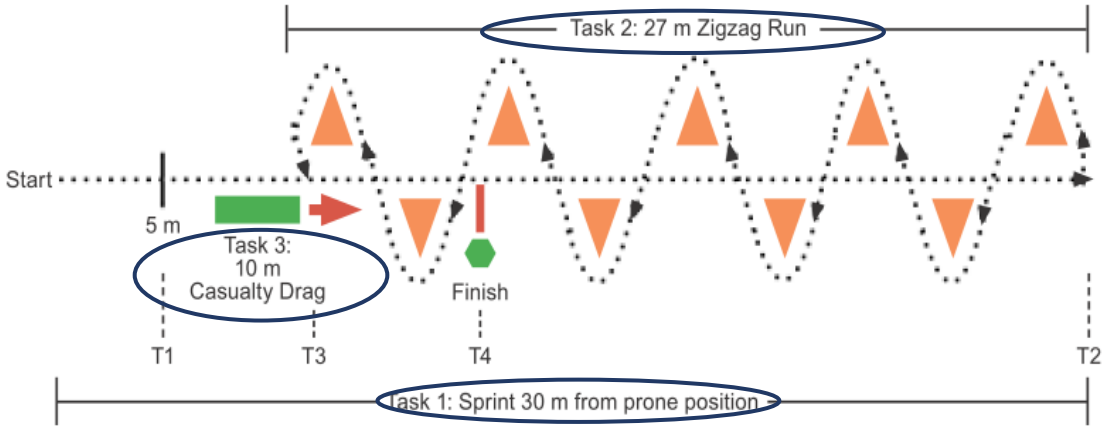


Figure 4-4: Model of Obstacle Course to Assess Effect of Carrying External Load on Time to Complete Short High Intensity Tasks [98].

Pandorf et al. (2002) [82] have also investigated the performance of females undertaking high intensity military tasks (e.g., sprint, low hurdles, zig-zag run, etc.). They reported decrements of performance time of -12% to -26% while carrying a 14 kg fighting load and a 27 kg approach load, respectively. Laing Treloar and Billing (2011) [77] examined the effects of load carriage (21.6 kg) on 30 m timed sprint performance. While performance time was deteriorated while carrying a load, it was mainly affected (-51%) during the first 5 m when subjects are expected to rise from the prone position and start to sprint. Moreover, sprint times were affected to a greater extent in females than males (-36% vs. -29%, respectively) as a result of the increased load (Laing Treloar and Billing) [77]. From these studies we can conclude that external loads have a detrimental effect on explosive high intensity combat tasks. As a consequence, for activities performed at moderate to high

intensity (e.g., ≤ 30 min at ≥ 5.5 km/h) load should be fixed at ~15 – 20 % BM and under 30% Body Mass (BM) respectively (Christie and Scott, 2005 [100], Van Dijk et al., 1996 [101]). In contrast, studies have suggested that load could be set up to 40 to 50 % of the total BM over prolonged tasks at lower to moderate intensity (e.g., ≥ 1 h at < 5.5 km/h). Nevertheless, the total mass carried by soldiers often exceeds these recommendations and sometimes can reach ~70% BM and is often over 60% BM as observed in scenario proposed in Chapter 3.

Interestingly, the performance assessed during the obstacle course seems to be strongly associated with the subject's physical characteristics. In some studies, investigations have focused on the relationship between physical characteristics and the time performance to accomplish an obstacle course without external added load. Indeed, Bishop et al., (1999) found that performance time to accomplish an obstacle course was positively correlated with both total body and fat mass and negatively associated with both relative leg mean power, muscular strength and endurance [102]. However, Jette et al., (1990) observed that both aerobic capacity and muscle strength were good predictors of performance time during a very long obstacle course [103]. It would appear the greater the duration of the obstacle course, the higher the aerobic capacity is required.

However, only a few studies have reported the correlations between physical characteristics and time performance during a loaded obstacle course. Harman et al. (2008) reported that vertical jump (as a measure of explosive power) was the most useful variable in explaining performance time during high intensity short duration obstacle courses with an 18 kg load [104]. In another study and carrying a heavier load of 42 kg, Mala et al. (2015) found that subjects who developed greater maximal strength/power of the lower and upper limbs muscles were quicker over the course [98]. Moreover, this is the only study to compare the alteration of time performance related to the increase of the load in two different populations, one with classical army training and the other with a specific resistance training program. The results of the study indicated that the army-trained group had increased their time to complete the 'loaded' obstacle course loaded more than the resistance-trained group (respectively +10 sec/ +35% vs 7.3 sec/+29%, $p<0.05$). The results suggest resistance training confers superior fitness outcomes opposed to classic army training and may offer the best option to prevent decrement of performance in short high intensity tasks with the load [98].

In the Bundeswehr (German Armed Forces) for assessing Basic-Military-Fitness, the Basic-Military-Fitness-Tool (BMFT) was developed and evaluated from 2011 to 2016 (Hackfort et al., 2017 [105], Rohde et al., 2015 [106]). The development was based on task analyses of realistic pre-deployment training. The sub-tasks BMFT A-D were designed to reproduce a physiological profile of mission essential requirements such as dynamic moving and handling of loads while wearing personal protective equipment. The BMFT reflects four essential military demands:

a) Manoeuver under fire,

b) Casualty rescue,

c) Load carrying, and

d) Load lifting.

The BMFT is performed in a single timed test run wearing field uniform (5 kg), body armour (13.4 kg), and helmet (1.6 kg) which correspond to a total load of at least 20 kg. 190 soldiers of different services and branches (170 male, age 29.4 ± 7.3 years; 20 female, age 28.3 ± 5.6 years) performed the standardized BMFT as well as tests for speed (11 x 10 m shuttle run), endurance (1000 m run), and strength measurements (maximum voluntary isometric contraction of hand grip, elbow flexors, knee extensors, and trunk flexors/extensors). The statistical analyses included correlations and multiple linear regressions. BMFT performance was significantly correlated with the basic motor skills endurance (r = .53), speed (r = .42),

and strength (r < -.54). The highest correlation was found with strength of elbow flexors (r = -.72) but unexpectedly trunk flexion (r = -.61) is also important and better correlated to BMFT performance than endurance or strength of knee extensor. From a practical viewpoint it is very possible those individuals displaying high levels of strength at the elbow flexor are also 'well-conditioned' across the upper body. Data from Hackfort et al. (2017, [105]) and Rohde et al. (2015, [106]) suggest the combination of endurance, speed, and strength explains 67 % of the variance of BMFT overall performance. All results are shown in Table 4-9 and Table 4-10.

Table 4-9: Pearson Correlations Between Specific Basic-Military-Fitness-Tool (BMFT) Sub-Tasks and Overall Performances and Related Parameters for Speed, Endurance, and Strength (MVIC = Maximum Voluntary Isometric Contraction); n = 190.

	BMFT-A	BMFT-B	BMFT-C	BMFT-D	BMFT Total
Speed					
Shuttle run	.544**	.342**	.433**	.296**	.424**
Endurance					
1000 m run	.571**	.402**	.577**	.402**	531**
Strength MVIC					
Hand Grip	-.509**	-.595**	-.544**	-.603**	-.633**
Elbow Flexors	-.639**	-.665**	-.653**	-.651**	-.722**
Knee Extensors	-.459**	-.516**	-.472**	-.512**	-.543**
Trunk Flexors	-.442**	-.606**	-.528**	-.593**	-.612**
Trunk Extensors	-.423**	-.518**	-.463**	-.512**	-.537**
** $p < 0.01$					

Table 4-10: Results of Multiple Linear Regression Analyses of Shuttle Run, 1000 m Run, and MVIC (Maximum Voluntary Isometric Contraction) of Hand Grip, Elbow Flexors, Knee Extensors, Trunk Flexors, and Trunk Extensors as Predictors on Specific Basic-Military-Fitness-Tool (BMFT) Sub-Tasks and Overall Performance as Criterion Measures; R2 and Standardized Coefficient β; n = 190.

	BMFT-A	BMFT-B	BMFT-C	BMFT-D	BMFT Total
R^2	.584	.548	.595	.532	.667
	β	β	β	β	β
Speed					
Shuttle run	.240***	.082	.061	.010	.084
Endurance					

	BMFT-A	BMFT-B	BMFT-C	BMFT-D	BMFT Total
1000 m run	.267***	.170*	.387***	.211**	.291***
Strength MVIC					
Hand Grip	-.067	-.160*	-.057	-.183*	-.142*
Elbow Flexors	-.336***	-.213*	-.271**	-.191*	-.266**
Knee Extensors	-.002	-.010	.015	-.029	-.002
Trunk Flexors	-.063	-.262***	-.199**	-.240**	-.227**
Trunk Extensors	-.055	-.097	-.085	-.103	-.100
*p < .05; **p < .01; ***p < .001;					

Nevertheless, endurance and strength of upper limb and trunk flexors are the most determinant factor. Except for manoeuvring under fire, speed skill is less important than expected. These results indicate that the more pronounced the basic motor skills endurance, speed, and strength are, the better the performance in loaded high intensity military tasks related to dynamic mission. Although the mass described (20 kg) is well below those identified throughout the scenarios in Chapter 2 (often beyond 60% BM), it is distinctly probable that the performance characteristics endurance, speed, and strength are essential basic prerequisites for short-term reactive / dynamic combat tasks.

Yet, in other studies (civilian study population), it has been demonstrated that the higher strength/power capacity of subjects could deteriorate performance as a function of the duration of the task. In essence, the greater the force/power exerted by a muscle or motor unit is, the greater the level of peripheral fatigue is produced (Enoka and Stuart, 1992, [107]; Ratel et al., 2015, [108]). Moreover, Pandorf et al., (2002) showed that muscle endurance of the upper limb and supporting muscles were good predictors of performance time while carrying a lighter 14 kg load corresponding to 22% body weight than a heavier 27 kg load, corresponding to 44% body weight [82].

Key Points

Physical characteristics for performance of short high intensity tasks are inversely correlated with both total body and fat mass and positively associated with legs mean power, muscular strength, and endurance.

When load is added to accomplish short high intensity tasks, it was reported that explosive power, maximal strength/power of the lower and upper limbs muscles are important to limit the impediment of completion time to complete the task related to the load. Moreover, one study suggests resistance training is more efficient to prevent decrement of performance in short high intensity tasks with the load than classical army fitness training.

However, the longer the obstacle course is, the higher the aerobic capacity required is. With repetition of high intensity task, muscular endurance is expected to become more and more important rather than maximal strength.

For the military, the requirement to complete a short, high intensity combat task is often preceded by an administrative advance. Therefore, a full appreciation of the physical and physiological impact of the preceding event is required to understand residual performance availability. But, performance in high intensity tasks with load after a long "administrative advance" has never been properly compared before, thus describing the direct consequences of fatigue on performance in assault is difficult. Hence the following section will comment on the indirect issue of alteration of physical characteristics required for high intensity tasks caused by a previous long loaded walk.

4.4.2 Consequences of Prolonged Carriage Exercise on NM Function and Muscle Strength/Power

To date, military studies have mainly focused on the impact of prolonged load carriage activities on metabolic cost, cognitive functions, mechanical work or spatio-temporal parameters of walking (Lieberman et al., 2005 [109]; Majumdar et al., 2010 [110]; Grenier et al., 2012b [111]). Only few investigations have studied effects of load carrying on Neuromuscular (NM) function (i.e., maximal strength/power production capacity and voluntary activation (VA)) (Grenier et al., 2012a [112]; Blacker et al., 2010a [113]). However, the ability to generate an optimal level of force and/or power during a given task is one of the determinants of the occupational/functional abilities and motor performance in humans (Gandevia et al., 2001, [114]) and a key factor in load carriage ability particularly during high intensity tasks as shown in the previous section (Knapik et al., 1990 [17]).

Fatigue may play a key role in explaining the reduced load carriage capacity and initiating factor of associated musculoskeletal injuries (Goh et al., 1998, [115]; Knapik et al., 1992 [116]; Wang et al., 2013 [117]). In a military context, fatigue is commonly characterized by reduced muscle coordination, increased metabolic cost and perceived exertion (Knapik et al., 2013 [118]). Besides cognitive factors, fatigue is commonly defined as "an exercise-induced reduction in the ability of skeletal muscle to produce power or force irrespective of task completion" [114].

4.4.2.1 Strength Loss and Prolonged Load Carriage Exercise

It is well accepted that several hours of highly strenuous stretch-shortening cycle exercise (e.g., running) has a detrimental effect on NM function (Millet and Lepers, 2004, [119]). Impairments of NM function are generally characterized by decreases in maximal voluntary strength by using isometric or isokinetic i.e., concentric and eccentric, contractions. Maximal strength loss induced by heavy load carriage exercise has been mainly evaluated in the Knee Extensors (KE). However, less attention has been devoted to Elbow Flexors (EF), Plantar Flexors (PF), and supporting muscles such as Trunk Extensors and Flexors (TE and TF) or Shoulder Flexors (SF) and Extensors (SE) which seems to be highly involved in load carrying activities. The main results concerning strength/power loss are presented in Table 4-11.

To date, there is no consensus about effects of prolonged load carriage exercise on strength/power loss. Conflicting results may be observed for peak power generating capacity of the lower limb muscles. Indeed, Fallowfield et al., (2012) showed that the peak power was reduced in ~-5% after a 19 km walking [120] while Knapik et al., (1990) reported no significant differences after a 20 km walking, despite the heavier load carried (46 kg) and the higher levels of perceived fatigue [17]. Unfortunately, no results regarding maximal strength loss of the lower limb muscles were reported in these studies. Besides, Grenier et al., (2012b), determined the magnitude of strength loss of the KE and PF muscles after prolonged heavy load carriage walking in healthy high-experienced subjects [111]. In this study, subjects undertook ~21 h walking, in a mountain environment, carrying a total load which varied between 22 – 37 kg. Despite the long-distance covered (~30 km), the reduced sleep times and the heavy load carried, they only found slight reductions of isometric Maximal Voluntary Contraction (MVC) (~-10%) for both KE and PF *($p = 0.06$)* muscle groups after exercise.

Table 4-11: Studies Assessing Strength Loss After Long Loaded Carriage.

Study	Subject's characteristics			Load carriage protocol					Strength/power assessements		Results
	Age (yrs)	Gender	Anthropometrics and physical fitness	Duration	Terrain gradient	Intensity	Distance	Load carriage	Muscle	Experimental variables	Relative changes (%)
Grenier (2012)	38	10 M	Extensive high-load carriage experience	21 h	Uphill walking	~4km*h^{-1}	~15 km	~22kg (~27%BM)	KE	MVC (N) at 90°	-10.2
			Height: 177 ± 5 cm		570m of positive and			~37kg (~46%BM)	PF	MVC (Nm) at 90°	-10.7 (p=0.06)
			Body mass: 82.9 ± 9.3 kg		240m of negative						
			Body Fat: 19.4 ± 3.1%		elevation change						
			VO2max relative 42.3 ± 5.2 ml*kg^{-1}*min^{-1}								
					Dowhill walking	~5.5km*h^{-1}	~15 km				
					240m of positive and						
					570m of negative						
					elevation change						
Blacker (2010)	~30	10 M	Recreational hikers	2h	Level (0%)	6.5km*h^{-1}	13km	25kg (~31%BM)	KE	MVC (N) at 90°	0%: ~-15 / -8%: -~-15
			Height: 179 ± 0.05 cm								
			Body mass: 79.4 ± 8.3 kg	2h	Downhill (-8%)	6.5km*h^{-1}	13km	25kg (~31%BM)			
			Body Fat: 15.1 ± 2.8%						KE	MVC (Nm) at 60°*s^{-1} and 180°*s^{-1}	0%: -14.1 and -5 /-8%: -15.6 and -12
			VO2max 42.3 ± 5.2 ml*kg^{-1}*min^{-1}						KF	MVC (Nm) at 60 °*s^{-1} and 180°*s^{-1}	0%: ~-13 and -11.4 /-8%: ~-13 and -12
									TF	MVC (Nm) at 15 °*s^{-1} and 60°*s^{-1}	0%: ~-9.6 and -9.4 (NS) /-8%: ~-17.3 and -8.8 (NS)
									TE	MVC (Nm) at 15 °*s^{-1} and 60°*s^{-1}	0%: ~-7.9 and -7.4 (NS) /-8%: ~-13.3 and -10.2 (NS)
									SE	MVC (Nm) at 60°*s^{-1} and 180°*s^{-1}	0%: -5.9 (NS) and -3.5 (NS) /-8%: -4.8 (NS) and +2.4 (NS)
									SF	MVC (Nm) at 60 °*s^{-1} and 180°*s^{-1}	0%: -7.1 and - 1.96 (NS) / -8%: -13.3 and -3.5 (NS)
Blacker (2013)	~30	10 M	Recreational hikers	2h	Level (0%)	6.5km*h^{-1}	13km	25kg (~31%BM)	KE	MVC (N) at 90°	Loaded: -15 /Unloaded: -6.5 (NS)
			Height: 179 ± 0.05 cm								
			Body mass: 79.4 ± 8.3 kg		Level (0%)	6.5km*h^{-1}	13km	unloaded			
Lidstone (in press)	~21	8 F	Physically active	1h	Level (0%)	5.4km*h^{-1}	5.4km	55%BM	LL	Isometric Squat (N) at 90°	-5.3
			Height: 162 ± 0.07 cm								
			Body mass: 59.9 ± 5.9 kg								
			Body Fat: 21.8 ± 4.6%								
			VO2max 43.4 ± 6 ml*kg^{-1}*min^{-1}								
Fallowfield (2017)	~22	12 M	Military trained	270 min	Uphill and downhill	4.3km*h^{-1}	19.3km	31 kg	LL	Vertical jump height (m)	-8
			Height: 178 ± 0.05 cm					38% BM		Vertical jump power (W)	-5
			Body mass: 80.7 ± 6.8 kg								
			Body Fat: 11.8 ± 3.0%								
			VO2max 52.3 ± 2 ml*kg^{-1}*min^{-1}								
Knapik (1990)	~21	84 M	Military trained	~324 min	Flat and hilly	3.7km*h^{-1}	20 km	46 kg	LL	Vertical jump height (m)	(NS)
			Height: 177.6 ± 7 cm							Vertical jump power (W)	(NS)
			Body mass: 77± 10 kg								
			Body Fat: 15.9 ± 4.5%								
			Lean body mass : 64.4 ± 7.9 kg								
			VO2max 57.7 ± 5 ml*kg^{-1}*min^{-1}								

For load carriage studies reporting on shorter-distance, Clarke et al., (1955) reported modest declines in the KE and knee flexor (KF) MVC torque (~-8% and ~-6%, respectively) after a ~12 km road march while carrying loads between 13 and 27 kg in active subjects [121].

In civilian subjects, greater decreases in maximal strength of the KE and KF muscles (~-15% and ~-13% respectively) were showed by Blacker et al. after a 13 km treadmill walk and carrying 25 kg (Blacker et al., 2010a, [113]; Blacker et al., 2013, [122]). The authors observed that supporting muscles were also affected by carriage exercise and that TF and TE MVC declined in ~-8% after exercise similarly to those observed by Clarke et al. 2010a, (1955, [121]), (~-10%) for the same muscle groups. Interestingly, a relationship between the mechanical properties of muscle contraction (i.e., mode and velocity of contraction) and strength loss may be observed in Blacker et al., [113]. An important decrease in maximal strength capacity of the KE muscles was observed during isometric contractions, while lower or absence of significant reduction was found in concentric contractions when muscles contracting fast (e.g., -15% and -5% for KE MVC at $0°.s^{-1}$ and $180°.s^{-1}$, respectively).

It is possible that the lower level of maximal force produced during concentric contractions, at high velocity of contraction, could be associated with lesser metabolic, neural, and mechanical demands required by the active muscle in the fatigued state. This relationship was also supported by a different pattern of recovery observed post-exercise in Blacker et al. (2010a, [113]). While concentric KE MVC, at high velocity of contraction, recovered fully at 24 h post-exercise, isometric KE MVC recovered completely at 72 h. These findings are consistent with our recent results showing that NM fatigue and recovery are strongly associated with the level of maximal force produced by a muscle (Ratel et al., 2015, [108]). Unfortunately, no data is available concerning neither a larger range of velocities of contraction nor during eccentric contractions after prolonged load carriage exercises. If the load carriage specifically increases alteration in eccentric contractions, it could be a risk of fall and could increase the muscle damage in downhill or repeated kneel down movements.

Besides the relationship between mechanical properties of muscle contraction and strength loss, it is well accepted that relative decreases in maximal strength varying as a function of duration and intensity of exercise (Enoka and Stuart 1992 [107]). However, similar reductions in the KE MVC torque/force, by around -8 – 10%, between very different protocols (Grenier et al., 2012a, [112]; Clarke et al., 1955, [121]) have been noted. It is thought that the lack of substantial strength loss of the KE and PF muscles showed in the study piloted by Grenier et al. (2012a, [112]) could be partly explained by the prolonged time (> 10 min) between the end of the loaded walk and strength assessments. This point has some significance as voluntary force generally returns to pre-exercise values within few minutes after exercise (Carroll et al., 2016, [123]). Understanding this outcome and where possible it would be advisable to allow for a brief rest period between load carriage tasks as task performance is likely to degrade otherwise. In Blacker et al., (2010a, [113] and 2013, [122]) the relative KE torque/force loss was greater for a shorter duration and lighter load carried compared to the outcomes of the Grenier et al. (2012a, [112]) study. One possible explanation could be the superior velocity of walking (6.5 km/h\) and the fact that exercise was performed on a treadmill ergometer allowing:

i) A reduced time between the end of the exercise and strength assessments; and

ii) A better control of the intensity of the exercise.

Yet, walking on a treadmill may induce lower muscular stress due to greater shock absorption compared to the ground. Furthermore, subjects in this study were recreational hikers that were very likely less familiar with heavy load carriage compared to the highly trained soldiers participating in Grenier et al. (2012a) [112] investigation. In this study, the participants were soldiers that were trained and experienced with carrying heavy loads, which is an important factor of performance in this task as shown by Knapik et al. (2012) [3].

To date, no study has evaluated the strength loss, induced by prolonged load carriage walking, in subjects with different training status (power vs. endurance-trained) or carriage experience.

In an unpublished study conducted in our laboratory, subjects performed a 3 h treadmill walking with different gradient conditions (flat and +/-12%) while carrying an absolute load of 40 kg. Of note, we found no significant reductions in the isometric KE MVC force in healthy active subjects were detected. Possibly, the reduced velocity of walking during uphill and downhill (3.5 km/h) or the consecutive rest times completed (6 min) between series of 35 minutes could have attenuated strength loss. Surprisingly, the time to maintain an isometric force corresponding to 70% and 25% of the KE MVC was significantly altered after exercise by -33% and -16%, respectively (Figure 4-5).

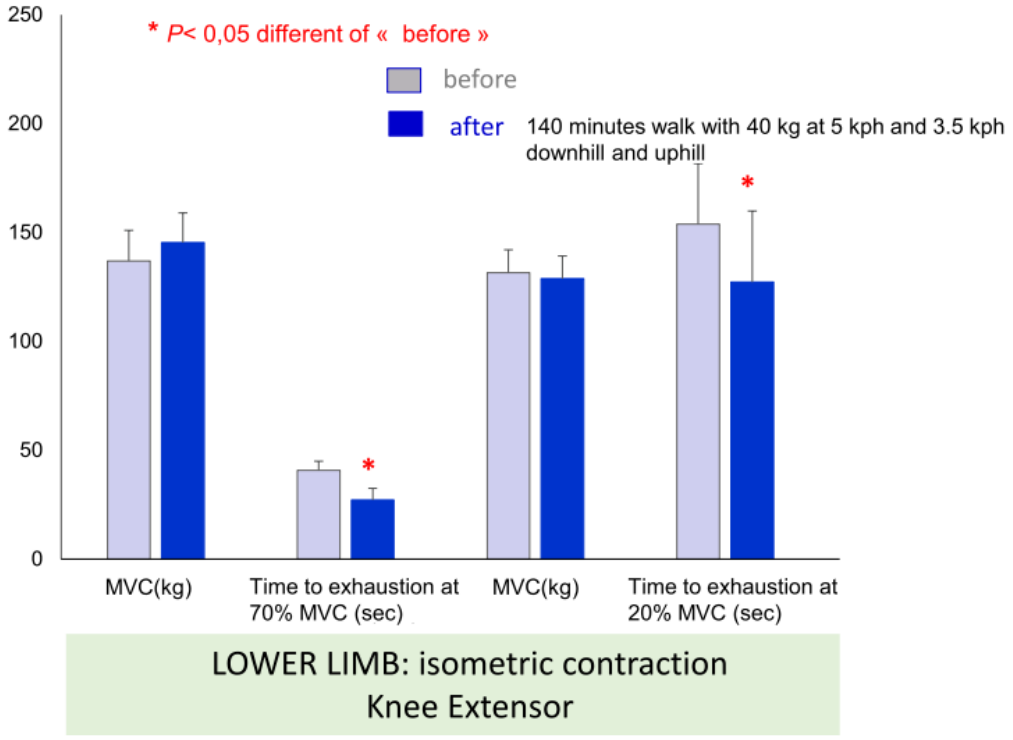


Figure 4-5: Maximal Voluntary Contraction (MVC) and Time to Exhaustion in Isometric Contraction of Knee Extensor Before and After a Long Loaded Walk of 3 Hours.

In this study neither a control group (without load carried) nor a comparison flat vs uphill/downhill was evaluated limiting conclusions. Nevertheless, these preliminary results are the first to suggest an alteration of muscle endurance whereas maximal strength is relatively protected and/or recovers quickly after long walking. It should be noted while maximal strength is required for high intensity tasks, muscle endurance is also important for repetition of military postures, this muscle fatigue could alter close combat efficiency when recovery time is not enough between the two phases of the load carriage (‘administrative advance’ and assault). Moreover, this NM fatigue could have consequences on performance during the loaded walk itself. Contrary to Grenier et al. (2012b [111]), in our study, metabolic cost (Figure 4-6) and discomfort (Figure 4-7) of the loaded walk increased between the beginning and the end of the walk. However, we were not able to establish the relationship between the energy cost of walking and alteration of spatial-temporal parameters of the gait.

Besides, depending on the mechanism of this NM fatigue, which should be further investigated, a central component could have consequences on cognitive function: time to reaction and attention during the walk (Eddy et al. 2015, [124]).

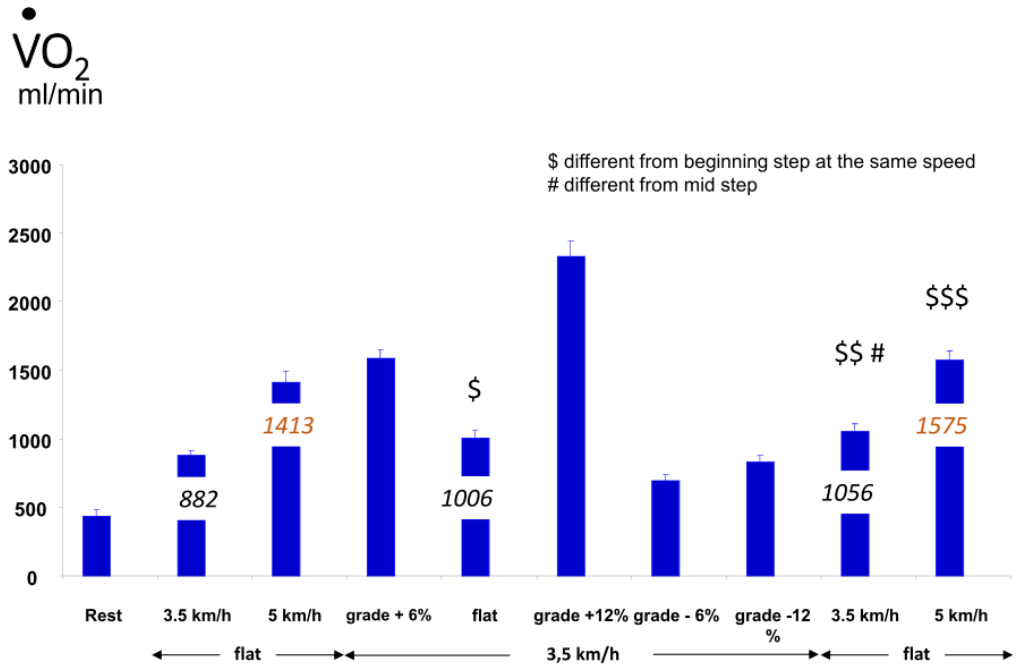


Figure 4-6: Time Course of Oxygen Consumption During a Long Loaded Walk.

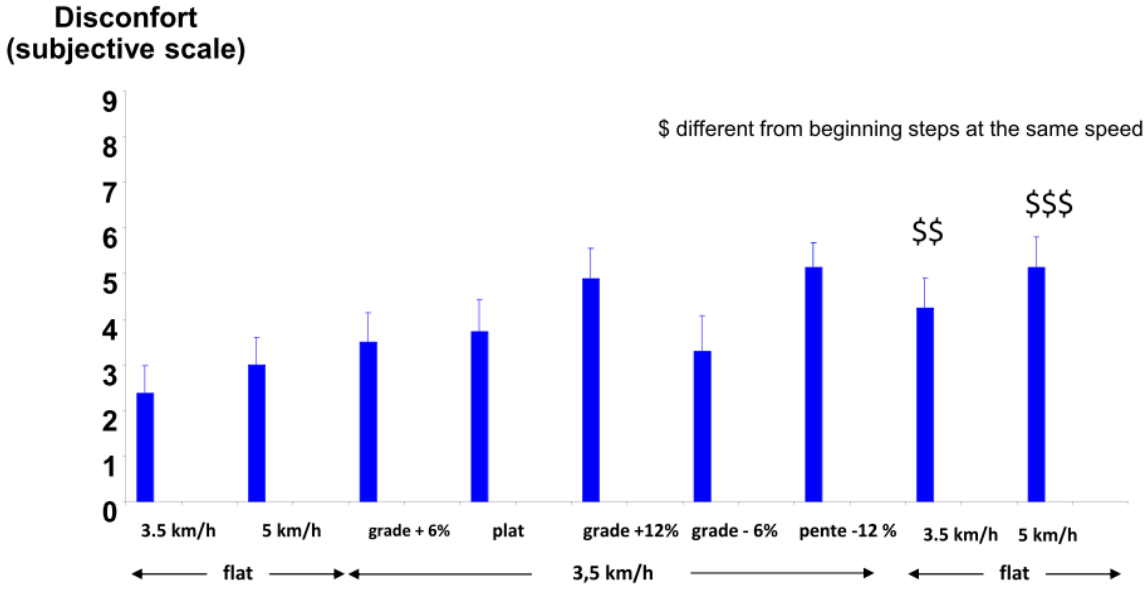


Figure 4-7: Time Course of Discomfort During a Long Loaded Walk.

Other unpublished data shared by the Australian Defence Science and Technology group (DST)[6] was interested in alteration of power delivered during anaerobic test. They studied the effects of a 2 hour march (50 kg load at 4.2 km/hr or 35 kg load at 5 km/h) on power production in the 30-sec bike sprint test. After the loaded march peak power and total work performed during 30 sec were not diminished compared than before (Figure 4-8). This should be interpreted as ability to move quickly in a very short period of time was maintained. Nevertheless, 30 sec is very short and may not sufficiently reflect the time requirement of an actual military assault. As lack of alteration of performance has never been confirmed for repeated loaded sprints (military tasks per se), caution should be observed for these initial findings.

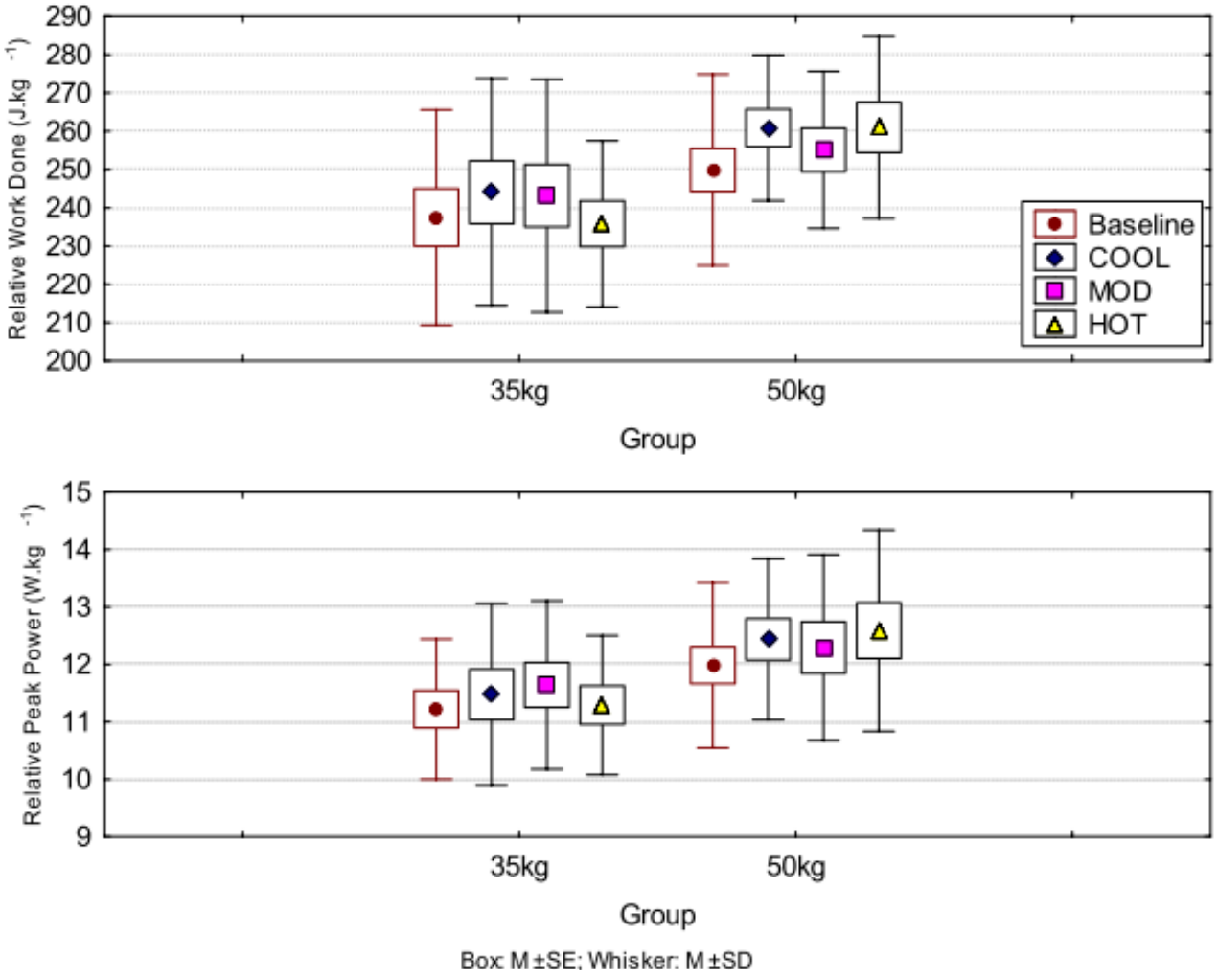


Figure 4-8: Peak Power and Total Work Before (Baseline) and After Two Hours Loaded March in Three Environment Conditions.

[6] Dr Mark Patterson's personal data.

4.4.2.2 Strength Loss and Terrain Gradients

During missions, militaries are often exposed to other external stressor factors such as positive or negative terrain gradients. Heavy load carriage added with rough terrain could considerably accentuate mechanical and metabolic perturbations in the skeletal muscle, increasing the strength requirement and thus, strength loss compared to flat terrain. Blacker et al. (2010a [113]) were the first to investigate directly the impact of 2 h treadmill walking downhill (-8%) while carrying 25 kg on strength loss. Contrary to their hypothesis, a lack of gradient effect (compared to 0%) was observed in all of muscle groups, modes and velocities of contraction. Isometric and isokinetic KE and KF MVC torque was reduced similarly for both gradient conditions (~-15%), whereas Phillips et al. (2016 [83]) have shown an increase of metabolic cost of load carriage upper 4% grade.

This lack of significant differences between walking with load on level and downhill related to the maximal force of the KE muscles is unexpected (Blacker et al. 2010a [113]). Nevertheless, earlier work by Santee et al. (2001 [125]), suggested metabolic differences could only be observed at declines of >8%. We consider that this issue needs to be investigated further because of negative gradients associated with a heavy load carried could induce an important mechanical stress owing to a greater eccentric component. Indeed, Giandolini et al. (2016 [126]) observed that torque of the KE and PF muscles decreased by ~19% and ~25% respectively after an intense downhill trail run with ~-20% of gradient. In a more extreme-duration exercise the authors reported larger MVC decreases, ~35% and ~39% for KE and PF respectively, after a 166 km mountain ultra-marathon with an important component of gradient terrain (Millet et al., 2011 [127]). Unfortunately, these studies were conducted without or with a very light load carried, subjects were required to run as quickly as possible and distances covered were longer than prolonged load carriage studies.

Moreover, supporting muscles seem to be more affected than the lower limb muscles when walking downhill. Despite the absence of significant gradient effect observed by Blacker et al. 2010a, [113], it seems that maximal isokinetic TE and TF torque was greater affected during walking downhill than on level conditions (~-15% *vs.* ~-8% respectively). They also found that recovery patterns of the TF muscles were significantly different between gradient conditions. While TF MVC torque recovered to pre-exercise values in 24hrs on the flat, it recovered fully at 72 h for downhill condition. It is known that EMG activity of the TF muscles is increased with load carriage (Cook and Neumann, 1987 [128]). Moreover, walking and running downhill would produce an important increase in the range of lumbar flexion-extension and other spinal motions compared to "on level" and/or uphill walking (+5%) gradients (Levine et al., 2007 [129]). This extreme mechanical condition would increase metabolic perturbations and muscle damage explaining partly greater strength loss of supporting muscles and prolonged recovery periods compared to flat terrain as observed by Blacker et al. [113].

4.4.3 Individual Characteristics Influencing NM Fatigue of Long Duration Moderate Intensity Load Carriage

Taking into account results from Section 4.2, it seems that the greater the capacity to generate a maximal strength and the higher the muscle mass are, the better the capacity to carry heavy loads is. Yet, this beneficial effect related to the level of force produced may be considerably affected by the duration, of the carriage exercise. Effectively, a higher level of force exerted by a muscle or motor unit could induce greater peripheral fatigue affecting directly muscle performance (Enoka and Stuart, 1992 [107]; Ratel et al., 2015 [108]). Thus, performance time during prolonged walking could be better associated with muscle endurance while carrying loads than with maximal muscle strength.

Unfortunately, in these studies cited above, no correlations were presented between the percentage of torque decrement and performance time. Moreover, strength assessments were made only before the prolonged carriage

exercise for characterizing subject's strength/endurance profile and its impact on walking performance but not for assessing the impact of walking loaded on muscle performance. Finally, most of the 13 studies found for systematic review in Section 4.2 concern relatively short loaded walk from 6 minutes to a maximal time of two hours for six studies. Only three studies have imposed a march of over 15 km. Therefore, based on the current evidence it is difficult to take into account the importance of muscle endurance and its relation to performance in load carriage as this is probably underestimated (due to the relative short duration of the load carriage event). Moreover, the fatigue induced by load carriage during walk and its consequences on the high intensity tasks efficiency cannot be sufficiently investigated with experiments with a march-protocol of less than 2 hours.

Key Points

Maximal strength loss in the lower limb after prolonged load carriage during concentric contraction would seem to be minimal. Nevertheless, this impediment could be increased during eccentric contraction (specifically for supporting trunk muscle). Obviously, experimental data studying alteration of muscle endurance (time to sustain and repetition of contraction) after long loaded walk are missing, whereas this component is essential for the assault. Therefore, the lack of evidence base pertaining to NM fatigue and recovery throughout prolonged heavy load carriage exercise offers a weak evidence base, thus no recommendations can be given.

4.4.4 Conclusions

The relationship between the maximal strength capacity and muscle endurance during heavy load carriage exercise must be further investigated. A greater muscular endurance capacity of the lower body can be advantageous during load carriage over medium to long distances, since individuals with more muscular endurance should have a better resistance to fatigue. In contrast, individuals with higher maximal strength capacity could elicit a better performance while carrying extreme heavy loads, during very short bouts of time; however, they could be more sensitive to muscle fatigue during longer tasks. The current combatant needs to be able to produce the required performance during assault despite the fatigue developed by the previous approaching march. Thus, the ability to resist fatigue is an important factor for combat efficiency with load carriage. And yet, the strongest the muscle is, the most fatigable. An optimal compromise between maximal strength/power and endurance capacity is therefore required and is vital for optimizing performance of soldiers during both short and long-term load carriage tasks. Moreover, the origin of neuromuscular fatigue during long-term load carriage is not yet well understood. Understanding the central and peripheral causes of fatigue is the only way to achieve optimized physical preparation and propose required recovery time and strategies. Thus, better understanding the characteristics of fatigue induced by long-term carriage tasks and individual factors which influence resistance to fatigue should be a key point of future 'load carriage' performance research.

4.5 SYSTEMATIC REVIEW: ENVIRONMENTAL IMPLICATIONS FOR LOAD CARRIAGE

4.5.1 Introduction

Scenario 2 described in Chapter 2 involves a 15 – 20 km loaded march (50 kg – 67 kg) between 24 – 36 hours at a temperature: between 10°C at night and 39°C in the afternoon, rainfall chance 20%, relative humidity 55%, wind velocity 10 km/h, which can increase up to 30 km/hr at night. For this reason, this section will discuss the considerations on cardiovascular and thermal stress on the soldier in the heat.

Heat injury occurs as a direct consequence of physiological heat gain outweighing that of heat loss, meaning that there is a deleterious increase in body temperature. The risk of heat illness can be exacerbated by numerous factors including elevated ambient temperature, high humidity, increased radiative and conductive heat gain, excessive load carriage, and use of Personal Protective Equipment (PPE), hydration status, body composition, work intensity, physical fitness and motivation. During training exercises, allowances can be made regarding the duration of such exercises based on monitoring ambient conditions and the task to be undertaken. This information should be used to inform the specific work to rest durations that personnel are exposed to, in order to minimize the risk of heat injury. However, under combat conditions, such adherence is often impossible and improving tolerance to a thermal challenge becomes of more critical importance in order to minimize the risk of heat related injury.

Heat illness has been shown to affect military personnel on a global, year round basis, with considerable local variation (Stacey et al., 2015) [130]. Clearly, given the wide ranging variation in deployment locations of NATO military personnel, from arctic to tropical locations with often limited time for acclimatisation, the need for better understanding of methods which may improve training and deployed performance, whilst minimizing risk to personnel, is of critical importance.

Current research is investigating models to predict core temperature using environmental, anthropometric, clothing and HR measures (Yokota et al., 2018) [131]. Most recently Buller et al. (2018) have identified that core temperature can be practically estimated from time series heart rate data and, using an adaptive physiological strain index these authors report meaningful predictions of safe work limits that cannot be predicted from only core temperature or heart rate measurements and will provide advances for the applied physiological problem of real-time thermal-work strain monitoring [132]. Despite these monitoring tools, there is evidence that the perception of effort (or perceived exertion) may be the ultimate modulator of behaviour during self-paced exercise in the heat (Schlader et al., 2010) [133].

4.5.2 Individual Characteristics Which Impact Load Carriage Performance in Hot Environment

4.5.2.1 Heat Balance

In many environments the ambient conditions prevent a significant challenge to maintaining heat balance due to the net heat gain induced by ambient temperatures in excess of ~35˚C coupled with high relative humidity. Such conditions result in a net heat gain by the body and are deemed to be un-compensable, resulting in a continual rise in core body temperature. Similarly, in situations where metabolic rate is elevated as a consequence of increased external work, the requirements on heat loss are also increased. The major avenues for heat loss can be further challenged by clothing selection, and in particular the use of PPE. Clothing selection can result in significant heat stress. This risk is brought about by the un-compensable nature of the microclimate that may ensue in response to completing physical activity in PPE. The PPE often provides a barrier to sweat evaporation, thus limiting the capacity to lose heat to the environment and results in a continual rise in core temperature, unless sufficient breaks for work activity are allowed for.

Due to the nature of PPE and its impermeability, this can result in significant physiological and psychological stress on the wearers, it has been shown that wearing PPE increases the metabolic rate by 2.4 to 21 % during continuous walking, stepping, and obstacle course circuits when wearing one of fourteen different military and industrial protective clothing ensembles (Dorman and Havenith, 2009) [134]. As a consequence of the increased protection against external threats, PPE limits the water vapour permeability and increases thermal resistance. The limited water vapour permeability of the clothing retards diffusion of water vapour, creating an extremely humid microclimate that prevents sweat evaporation and thus, active cooling and the ability to transfer heat between the body and the surrounding environment.

Assessing the use of tactical assault, fragmentation and load-bearing vests specific to the Canadian Armed Forces, demonstrated increased thermal strain and significantly decreased exercise time walking at a speed equivalent to a forced march on a treadmill at 40°C and 30% relative humidity (McLellan et al., 2003) [135]. Results demonstrated an increased cardiovascular and thermal strain and significantly reduced exercise time by approximately 30 min, or 30%, from 110 to 80 minutes regardless of whether the Tactical Vest (TV) or in service webbing (WEB) was worn. The 30-minute reduction in exercise time translated into a decreased distance of 3 km covered during the forced march. Therefore, when fragmentation protection must also be provided, the additional heat stress of wearing the FPV will significantly impair work performance.

Similar military research compared:

1) **A Control Trial:** disruptive pattern (camouflage) combat uniform with a cloth hat (clothing mass 2.05 kg and insulation ~0.29 $m^2 \cdot K \cdot W^{-1}$) and shoes;
2) **Torso Armour Trial:** control state plus combat body armour (arimid-lined (Kevlar) vest with ceramic-plate inserts) covering the chest and back (6.07 kg) and a cloth hat (total ensemble mass 8.12 kg); and
3) **Full Armour Trial:** control state (minus cloth hat) plus torso combat armour and combat helmet (1.29 kg), with a total ensemble mass of 9.41 kg (Caldwell et al.,2011) [136].

Participants walked 2.0 km/hr (0.56 m/s) for the first 1.5 hours followed by 1 hour at 4.0 km/hr (1.11 m/s). Results demonstrated a continual rise in Heart Rate (HR) beyond 90 minutes in each clothing condition likely due to a cardiovascular drift associated with the prolonged humid heat exposure. This HR drift was not a result of dehydration since hydration state was rigidly controlled at 1 L/h. Cardiovascular drift is the result of a decline in stroke volume, occurring as a result of increased cutaneous blood flow, and potentially an altered sympathetic tone and rising core temperatures (Caldwell et al., 2011) [136]. This same heart rate drift was observed with $FORCE_{COMBAT}$ research participants when performing the loaded march component (25 kg PPE with 10 kg bag) while researchers measured oxygen consumption (direct) and HR, despite ambient conditions at approximately 20°C inside the gymnasium, with air conditioning (Reilly et al., 2016) [137].

Due to the detrimental effects of heat and PPE, military organizations and industry have adopted protocols and measures to mitigate the risks of heat stress. These incorporate acclimatisation, proper hydration, education, physical training, and use of the Wet Bulb Globe Temperature (WBGT) index to dictate threshold limit values. The benefits of physical training and heat acclimatisation provide an increased sweating rate, a lower sweating threshold, a decrease in heart rate, an increase in blood volume, and most importantly a decrease in core temperature (Nadel, 1974) [138]. However, the effects of encapsulating PPE seem to eliminate these favourable adaptations. Aoyagi et al. (1994) found that after eight weeks of aerobic training or six days of heat acclimation, little or no improvements in physiological responses or tolerance time were observed in subjects wearing Nuclear, Biological and Chemical (NBC) protective clothing [139]. Furthermore, no differences in skin temperature and only minor improvements in tolerance time have been observed in very fit subjects compared with subjects of average fitness during exercise in the heat while wearing NBC clothing (Cheung and McLellan, 1998) [140]. It is thought that these results might be due to the limited water vapour permeability through the clothing, where it is possible that the increased sweat production in trained or heat-acclimated individuals may increase physiological strain by promoting a faster rate of dehydration rather than increased evaporative heat loss.

The metabolic demand for a given activity is closely related to the workload. It is well documented that as workload increases, so does the metabolic cost and therefore the demand for heat loss in order to maintain heat balance. One of the key determinants of metabolic heat production is the external workload, thus the requirement of military personnel to carry often-large loads during exercise and combat, adds additional physiological

demand to a task and increases heat stress. The seminal work of Pandolf et al. (1977) demonstrates the near linear relationship between total weight (encompassing both body mass and external weight carried), terrain and metabolic rate [141]. Therefore, increasing load carriage will elevate the thermal strain of a given activity, compared to when a lesser load is carried. More recently, Bach et al. (2015) have suggested that the distribution of a given load may further elevate energy expenditure and the subsequent metabolic rate [142]. They have shown that wearing explosive ordinance disposal protective clothing resulted in a consistent under-estimation of energy expenditure of the Pandolf equation compared to the measured steady state oxygen consumption, although there was a strong correlation between the observed and predicted energy expenditure. The authors suggest that this discrepancy is due to both the distribution of load around the body resulting in alterations in gait mechanics due to the ensemble size/thickness [142].

DEFSTAN 00-35 details the effect of ambient temperature on load carriage performance and details a decline in the rate of advance as load increases. Recently Taylor et al. (2016a) have demonstrated that with increased load and body coverage, core temperature, skin temperature, heart rate and RPE are all increased, all of which are markers highly indicative of increased heat strain [143].

As one of the main physiological effects of increasing load is to elevate the metabolic rate and therefore heat production and heat storage of a given task, it is likely that a period of training aimed at improving tolerance to elevated thermal strain will benefit load carriage performance and particularly so in hot environments.

4.5.2.2 Heat Acclimatisation

The risk to human health and performance when exposed to elevated ambient temperatures can be reduced by the implementation of a period of acclimatisation before significant physical work is undertaken. Heat acclimatisation refers specifically to physiological responses that occur as a result of the natural environment, whereas heat acclimation brings about changes due to exposure to controlled environmental conditions, such as with the use of climatic chambers. Both processes bring about improvements to the cardiovascular, thermoregulatory, metabolic and perceptual function during exercise, which combine to improve physical capacity of an individual or group (Garrett et al., 2011 [144]; Sunderland et al., 2008 [145]; Taylor and Cotter, 2006 [146]). Acclimatisation to the heat results in a number of physiological adaptations that result in improved thermal tolerance.

Different physiological systems respond to heat exposure at differing rates and start to become evident after approximately 3 days of heat acclimatisation, with approximately 75% of the acclimatisation process complete within 4 –7 days (Pandolf, 1998) [147]. Some of the first adaptations that occur are cardiovascular and include an expansion of the plasma volume and a concomitant reduction in heart rate (Castle et al., 2011 [148]; Garrett. et al., 2012 [149]; Racinais. et al., 2012 [150]) coupled with a reduction in perception of effort during exercise (Morrison et al., 2002 [151]; Weller and Harrison, 1999 [152]). Following 5 – 7 days of heat exposure, reductions in core temperature (Armstrong et al., 2007 [153]; Fujii et al., 2012 [154]; Garrett. et al., 2012 [149]; Stenken et al., 2010, [155]; Sunderland et al., 2008, [145]) and sweat sodium concentrations occur (Delves et al., 2014 [156], Kirby and Convertino, 1986, [157]). Only after 7 –1 4 days is there a significant increase in sweat rate (Cheung and McLellan, 1998 [140]; Karlsen et al., 2015 [158]) which will contribute to an increase in evaporative cooling and allow for increased heat transfer from the body's core, to the skin and the surrounding environment. It is suggested that full heat acclimatisation requires ~14 days of heat exposure to ensure that complete adaptation occurs in all body systems (Armstrong and Maresh, 1991) [159].

Many of the key adaptations to regular exercise in the heat mirror the adaptations that lead to improved cardiovascular fitness. Indeed, it is accepted that by improving physical fitness, independent to heat exposure,

will improve thermal tolerance (Pandolf, 1977) [141]. Therefore, prior to deployment or exercises where load carriage will form a significant component of the mission, improving fitness will help alleviate some of the thermal strain experienced due to additional load carriage. However, in situations where there is likely to be significant thermal strain due to the ambient conditions, specific heat acclimatisation protocols should be considered, either pre-deployment or by deploying with sufficient time to allow for acclimatisation in situ. Training undertaken as part of any heat acclimatisation protocol should be specific to the given task, with gradual increases in load (and therefore heat strain) whilst acclimatisation occurs.

An important factor to consider is the effect that heat stress will have on fluid and nutritional requirements that will have an impact on load carriage performance, particularly in the heat. The addition of load to a given task in the heat will place additional strain on the body's ability to regulate fluid balance, due to the additional need to produce sweat to facilitate evaporative cooling. If fluid intake is insufficient to replace sweat lost during exercise, dehydration will develop and this may deleteriously affect endurance (Fleming and James, 2014) [160], strength (Minshull and James, 2013) [161], skill (Baker et al., 2007) [162] or cognitive performance (Ganio et al. 2011) [163], as well as increasing feelings of lethargy (Shirreffs et al. 2004) [164]. All of these factors might combine to impair performance of military personnel in both training and combat situations.

4.5.3 Impact of Load Distribution on Load Carriage Performance in Hot Environments

The energy cost of walking has 'in the main' being linked to the location of the centre of mass of the backpack. Research suggests the lowest metabolic costs are associated with loads place closest to the centre of mass and close to the body (Datta et al., 1971 [165]; Obusek et al., 1997 [166]). Moreover, this has led to the comparison of several load carriage systems; with systems which distribute the load between front and back of the subjects associated with the lowest physiological cost. Although several studies confirmed that the double pack method has a lower energy cost, it may have a side effect of increasing heat stress symptoms (Koulmann et al., 2005) [167].

An unpublished experiment by Koulmann et al. (2005) investigated the specific effects of load carriage systems and the influence of thermoregulatory response during walking in a thermo-neutral environment [167]. In this study eight healthy male subjects were tested on four separate occasions to complete a 120 min walk on a treadmill at 0% grade, at a velocity of 1.38 m/s (in neutral environment: 20 – 22°C; 50% relative humidity (RH)). The walk was completed with either No added Load (NL) or with one of the three following rucksacks (each loaded with 35% of the participant's body weight):

1) A Backpack with no frame (BP);
2) A Backpack with internal Frame allowing airflow between the backpack and the subject's back (BP-F); and
3) A Backpack with Waist belt, 2/3 of the load was carried in the backpack and 1/3 in the waist belt (BP-W).

In this study Koulmann et al. demonstrated that the physiological strain, as assessed by heart rate and VO_2 (oxygen consumption) was slightly lower with the BP-W than with either of the other carriage systems ($P<0.05$) [167]. In contrast, sweating rate, as assessed by the whole body water loss was higher in the BP-W than in the BP-F trial (Figure 4-9). Moreover, part of water loss was captive in clothes and so, without any thermoregulation function (Table 4-12). In this very compensable situation in a neutral environment, the walking-induced changes in rectal temperature (Tre) were not significantly affected by the mode of carrying load. Nevertheless, higher skin temperature (Tsk) values were reported when subjects used the BP-W system than unloaded walking (NL).

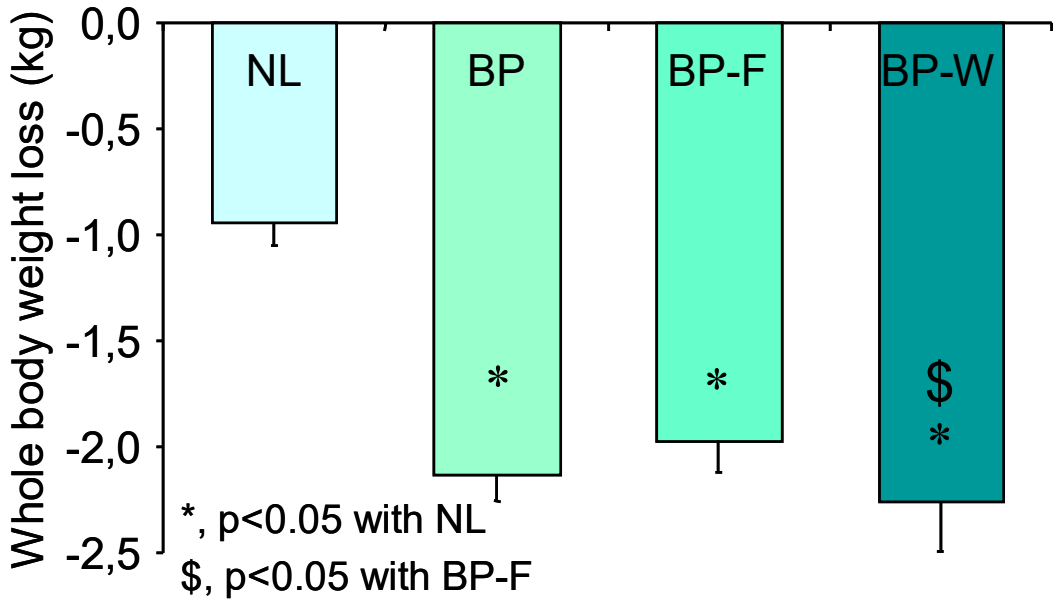


Figure 4-9: Whole Body Weight Loss Over the Loaded Walk [167].

Table 4-12: Repartition of Water Loss and Thermoregulatory Efficiency [167].

Level of hydration		Evaporative sweat loss compared to total water loss	Water loss in clothes
NL	+ 0.3 ± 0.1 % bw	54.7 ± 6.1 %	0.8 ± 0.3 %
BP	- 0.8 ± 0.1 % bw *	72.0 ± 1.6 % *	9.7 ± 1.7 % * #
BP-F	- 0.7 ± 0.1 % bw *	69.0 ± 2.8 % *	8.8 ± 2.2 % * #
BP-W	- 0.7 ± 0.2 % bw *	64.7 ± 2.0 % *	16.3 ± 2.4 % *

* $P < 0.01$ compared to NL

\# $P < 0.05$ compared to BP-W

The results of the study by Koulmann et al. support the possible advantage of the combined front-back system, at least regarding the physiological responses to prolonged walking. However, the potential advantage of the BP-W system was minimized by higher values of whole body water loss and thus increased risk of dehydration. Therefore, the risk to the individual and thus mission success when using such a system during military operations in a hot climate will need to be fully appreciated.

4.5.4 Un-Compensable Heat – Implications and Practical Considerations

4.5.4.1 Definition and Consequences

Due to the nature of the task, equipment carried and environmental conditions, heat production related to metabolic cost of the activity can overtake the capacity of human thermoregulation (Sawka et al., 2001) [168]. At this point, the human body can no longer compensate heat gained through heat loss.

The issue of un-compensable heat has real contextual resonance for military populations. This was illustrated by an Australian unpublished study (Patterson et al., 2003) [169]. In this study infantry soldiers performed three loaded marches on a treadmill for two hours; in three environmental conditions: mild (20°C 50% RH); warm-dry (30°C 30% RH); warm-wet (30°C 70% RH). One group marched with 50 kg loads at 4.2 km/hr (TVL) and other marched with 35 kg loads at 5 km/hr (MB). The energy cost and the physiological strain (body core temperature and heart rate elevations) of the two different loads were comparable (Figure 4-10). In this study the authors suggested a reduction of the marching pace (by 0.8 km/hr), could facilitate an increase in external load of 15 kg without any addition physiological burden [169]. During the study while body core temperature increased, it stabilised in the mild and warm-dry environments. Therefore, this level of work could be conducted for long durations without the threat of heat stroke. In warm-wet conditions, body core temperature continued to rise (~0.7°C/hr) (Figure 4-11), such that heat loss could not match heat production. Hence, it would take ~3 hr for an 80 kg soldier to reach 39°C, which is anticipated to result in 5% of personnel becoming heat illness victims, and it is highly likely that most soldiers would be incapacitated after 5 hr due to body core temperature approaching 41°C (some may even suffer tissue/organ damage).

In the warm-wet conditions described by Patterson et al. (2003, [169]), an un-compensable heat situation was observed at a WBGT of approximately 28°C. Considering the situation described in Chapter 2 where scenario 1 has an estimated WBGT of 33°C and a mean weight loaded by different nations (> 50 kg), it is clear ability to cope with the environmental constraints will be mission critical. Outlined below are practical recommendations to aid mission planning (further detail to aid decision making is given in Chapter 6); possible technological solutions to improve heat tolerance during load carriage are reviewed in Chapter 5.

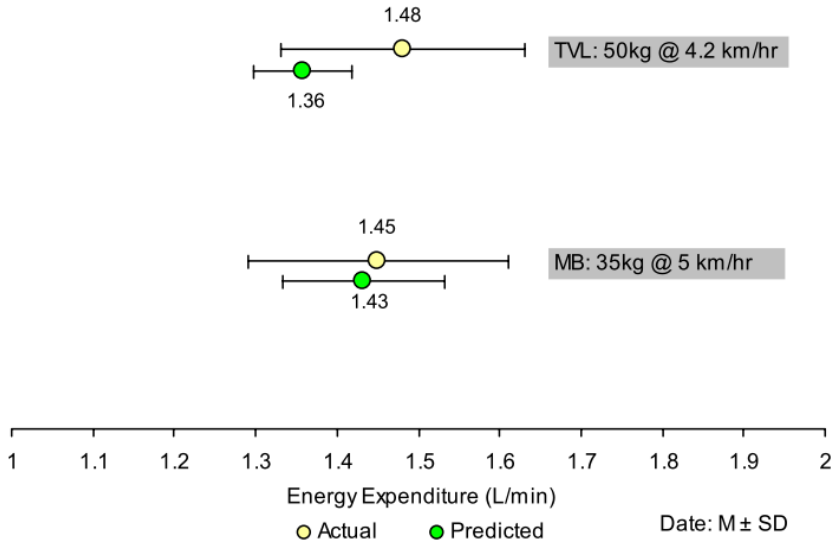


Figure 4-10: Comparison of Mean Metabolic Cost of Two Loaded Walk at Different Speed and Weight [169].

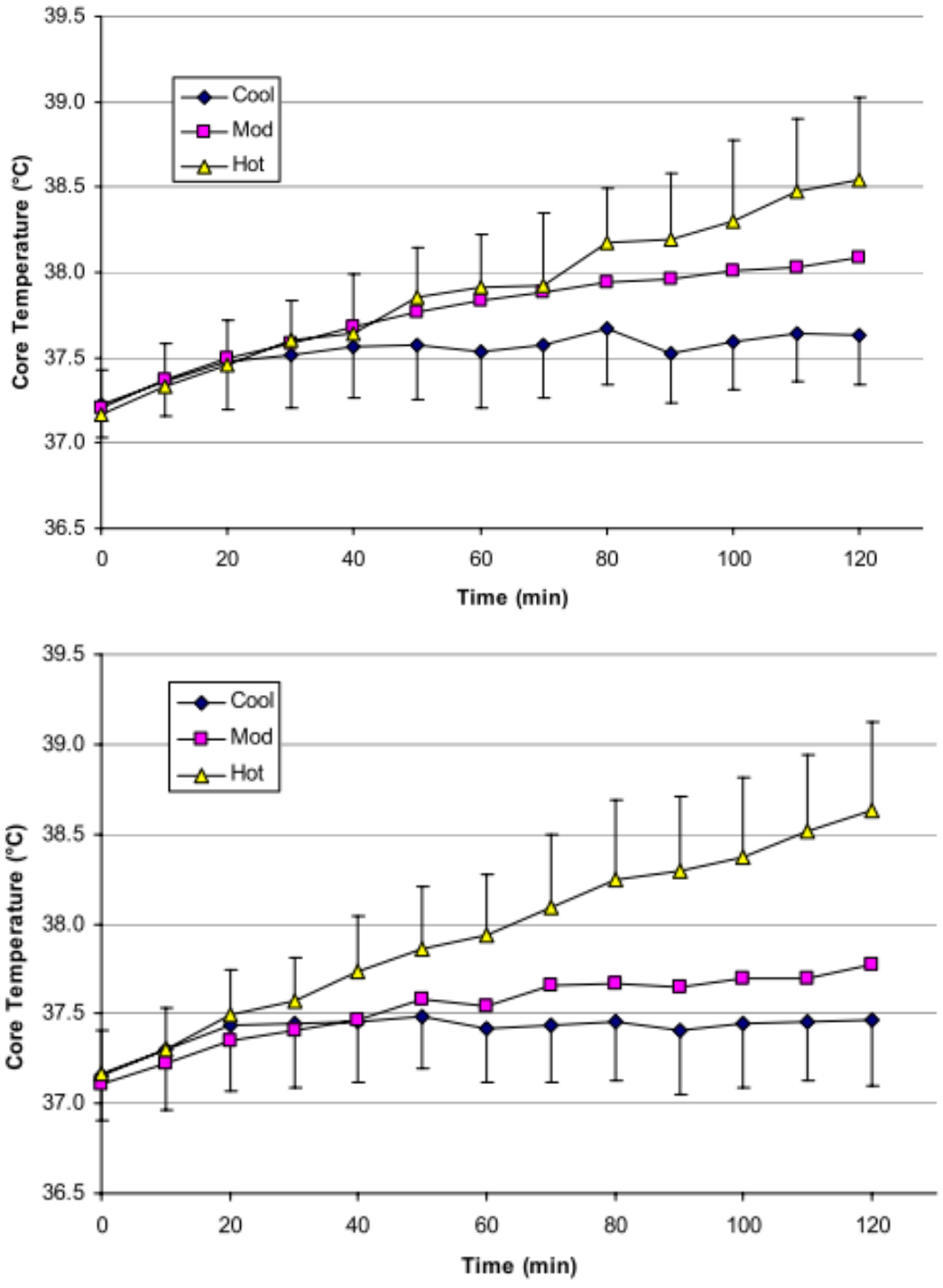


Figure 4-11: Core Temperature Over Loaded Walk at Different Speed and Weight in Three Environmental Conditions [169]. MB: 35 kg loads at 5r km/hr. 20°C 50%, RH – WBGT 18°C, 30°C 30%, RH – WBGT 24°C, 30°C 70% RH – WBGT 28°C.

4.5.5 Practical Recommendations

Military populations are often provided WBGT guidelines for performing loaded marching exercise or training in the heat, however the adherence to these guidelines is questionable and their application to all PPE ensembles may not consider un-compensable conditions. The RTO group HFM-187 has produced a report – Management of Heat and Cold Stress – Guidance to NATO Medical Personnel [170]. This RTO determined that:

1) Current thermal management capabilities are not fully utilized by NATO forces to educate military leaders on optimizing troop health and performance sustainment;
2) Significant scientific and capability gaps exist regarding thermal illness and injury susceptibility, early diagnosis and treatment; and
3) Significant scientific and capability gaps exist regarding thermal management for operational effectiveness.

The report recommends that if wearing body armour, 2.8°C (5°F) should be added to WBGT index in humid climates and if wearing chemical / biological protective clothing (completely encapsulated and impermeable) 5.5°C (10°F) should be added to WBGT for easy work, and 11°C (20°F) to WBGT for moderate and hard work.

Drain et al. (2012) indicated that current evidence does not allow for definitive guidance on quantifying the effect of various thermal stressors on maximum acceptable work duration however commanding officers, mission planners and practitioners may need to consider more conservative maximum acceptable work duration guidelines in hot or humid conditions [2]. Furthermore the work of Drain et al. and the Australian Army (DSTO-TR-2765) has led to the development of a table to estimate the metabolic cost and prescribed time limits and work durations (depending on the task and environmental conditions for load carriage activities considering the parameters of the task, i.e., mass, speed, terrain) [2]. Table 4-13 presents the increase in metabolic cost with the mass of load and the speed of walk.

Thus, it has been possible to rank the severity of load carriage tasks regard of metabolic cost and therefore metabolic heat production during the activity and the level of risk of un-compensable heat and heat stress in a hot environment (Table 4-14). As previously mentioned in the study conducted by Patterson et al. (2003), alteration between speed of walk and mass of load should be considered in the risk assessment of heat stress induced by load carriage [169]. In practical terms if reducing the mass is not possible, reducing the speed will be the only way to prevent un-compensable heat during load carriage.

In the context of hot environments, the first recommendation is to reduce marching speed and or the load mass. gives the maximal distance that should be walked in 6 hours depending of the load mass [169]. Considering the situation described in Chapter 2; scenario 1 describes an estimated WBGT of 33°C and a mean external of > 50 kg (slight international differences are observed). In this situation, the maximal speed recommended by Australian tables should not exceed 9 km in 6 hours, therefore, the only way to successfully complete the load carriage task of 20 km would be to complete 10 km on two separate days.

Alternatively, it may prove beneficial to estimate how long the load carriage can be sustained before heat injuries would occur. Table 4-14 suggests maximal work duration regarding the intensity of the physical activity and environmental conditions (DSTO-TR-2765) [1]. These values are based on a solider of average body mass (83 kg) covering 5 km in hard flat terrain at the speed of 5.5 km/hr with an external load of 40 kg.

Table 4-13: Classification of the Severity of the Load Carriage Regard of Load Mass and Speed. Workload categories based on predicted energy cost (light <1296 kJ/hr, moderate 1296 – 1862 kJ/hr, heavy > 2408 kJ/hr).

External load	Marching speed	5 km march	10 km march
20 kg	3.0 km/hr	Light	Light
	4.0 km/hr	Light	Moderate
	5.0 km/hr	Moderate	Heavy
	6.0 km/hr	Heavy	Very Heavy
30 kg	3.0 km/hr	Light	Light
	4.0 km/hr	Moderate	Moderate
	5.0 km/hr	Heavy	Heavy
	6.0 km/hr	Very Heavy	Very Heavy
40 kg	3.0 km/hr	Light	Moderate
	4.0 km/hr	Moderate	Moderate
	5.0 km/hr	Heavy	Heavy
	6.0 km/hr	Very Heavy	Very Heavy
50 kg	3.0 km/hr	Moderate	Moderate
	4.0 km/hr	Moderate	Heavy
	5.0 km/hr	Heavy	Very heavy
	6.0 km/hr	Very heavy	Very heavy

Table 4-14: Maximal Distance (km) Recommended in 6 Hours at Different Environmental Conditions.

Heat Category	WBGT (°C)	Mass Carried (Kg)					
		20	30	40	50	60	70
1	26-27.5	32	29	26	23	20	17
2 (Green)	27.5-29	27	25	22	20	17	12
3 (Yellow)	29-31	21	20	18	16	13	10
4 (Red)	31-32	21	19	16	12	10	7
5 (Black)	>32	17	15	13	9	7	5

Conditions in scenario 1 (WBGT ~ 33°C) have more potential for environmental impact than the 35°C at 50% RH described in Table 4-14 (as this would equal a WBGT 26°C) where the load carriage should not exceed 20 minutes at 5.5 km/hr. Therefore, frequently stops are recommended however, reducing speed would also be required to prevent heat illness. Patterson et al. (2003) observed that reducing marching speed from 5.0 km/hr to 4 km/hr equated to carrying an additional 15 kg for the same energy cost (and so for the same metabolic heat production) which is the limiting factor given the scenario [169]. Therefore, to increase sustainment time in hot environments when the load mass cannot be decreased, it is recommended (where mission allows) that the pace should be reduced to 3.5 km/hr (Table 4-15).

To perform 9 km per day prescribed in scenario 1, 3 blocks of 3.5 km could be completed according to this pattern: 20 minutes at 3.5 km/hr, 10 minutes rest, 20 minutes at 3.5 km/hr, 30 – 45 minutes rest, 20 minutes at 3.5 km/hr, 10 minutes rest. With this guidance of total distance of 3.5 km in about 3 hours could be completed and un-compensable heat could be prevented. With a maximal speed of 3.5 km/h, continuous walking time of 30 minutes, and sufficient rest time, it would be possible to perform 9 km per day in such environment. It would be very useful for NATO to validate this preliminary Australian study about sustainment time in different environments taking into account climate and workload depending in load mass, speed and terrain (Table 4-15).

4.6 EVIDENCE GAPS

Physical performance in the military is an occupational requirement (Rona et al., 2010, [171]) and for many personnel the ability to carry load is a defining characteristic of the occupational role. In respect to “the personal characteristics that affect load carriage performance”, there has been a historic focus on physiological capabilities and a lack of research into broader socioecological factors that may cause wider reductions in injury risk. However, even for physiological capabilities, literature is not always equivocal about the ideal soldier characteristics mostly because of an approach only focused on load carriage during marching. Few studies consider high intensity military tasks and none the whole mission from administrative advance to assault. Yet the fatigue induced by the long loaded march preceding assault is never taken into account whereas its consequences on strength, power and muscle endurance can be of important regard to efficiency in close combat. Universally all work has focused on the individual participant and performance of tasks by the individual in isolation of group. Clearly group performance is vital for mission success; therefore, future research should seek to identify the group variables (from a small tactical unit to a large group of military training personnel) linked to successful military load carriage.

Table 4-15: Estimated Sustainment Time of Load Carriage Depending on the Intensity of the Task and on Environmental Conditions.

A soldier of average body mass (83 kg)# and physical fitness (3.83 L.min^{-1})* moves 5 km on hard, flat terrain in 55 mins (5.5 km.hr^{-1}) carrying 40 kg (including weapon, pack and body armour) on the torso in a thermoneutral environment at sea level.						
	Ability to complete task and perform subsequent physically (aerobically) demanding tasks following march completion.					
	Likely to complete march task but unlikely to be able to perform subsequent physically (aerobically) demanding tasks following march completion.					
	Unikely to complete march task.					
Load carriage parameter(s)	**Change from baseline mission profile**	**Estimated task intensity (% VO_{2max})**	**Estimated continuous sustainment time**	**Estimated total continuous distance**	**Estimated physiological capability to achieve 5 km**	**References**
Estimated energy cost of baseline task		**50**	**< 3.0 hr**	**14 km**		1
Total external load	- 10 kg (30kg)	45	< 4.0 hr	15^{+} km		1
	+ 10 kg (50 kg)	56	< 2.0 hr	9 km		1
	+ 20 kg (60 kg)	63	< 1.0 hr	6 km		1
Movement speed	Slow (2.5 km.hr-1)	21	> 12 hr	15^{+} km		1
	Moderate (4.5 km.hr-1)	38	< 6.5 hr	15^{+} km		1
	Fast (6.5 km.hr-1)	65	< 1.0 hr	6 km		1
	Very fast (7.5 km.hr-1)	82	< 0.5 hr	2 km		1
Climate ^	Warm, dry (30°C, 30% rh)	50	< 1.0 hr	6 km		1, 3
	Hot, wet (35°C, 50% rh)	50	< 0.5 hr	2 km		1, 3
	Hot, dry (50°C, 10% rh)	50	< 0.5 hr	2 km		1, 3

Ideally, there should be a greater critical mass of research to support evidence-based decisions that offer assurance across DOTMLPF-I[7] and to both senior and junior commanders (Chapter 6 offers a commander's guide written in the context of DOTMLPF-I).

4.6.1 Recovery and Optimal Time

Although a critical issue, rest and type of rest between load carriage exposures were seldom referred to. The effect of long duration loaded marching on the performance of subsequent high intensity military tasks has received little attention. Minimal data is available which has investigated the consequences on maximal strength in lower limbs showing moderate alteration. Except our unpublished personal data, we found no peer reviewed study assessing alteration of muscle endurance.

Only one paper has investigated hormonal changes following load carriage; however, they did not detect any benefits of active recovery (Taipale et al., 2015) [19]. The results could be attributed to the intensity level of load carriage task (50 minutes carrying 16 kg) at below anaerobic threshold. Nevertheless, in a scenario of repeated high intensity missions there is a distinct possibility that evidence to support work-rest cycles would help optimize load carriage missions and specific load carriage training activities. Improvements in knowledge surrounding time course recovery after long loaded marching is essential to advise upon the best strategy and pace to limit neuromuscular fatigue so that subsequent tasks (e.g., an assault) can be undertaken in the best physical and muscular state as possible. Central to this information could be the influence of cortisol either as an aid to recovery (Nindl et al., 2007) [172], or as a marker of physical stress (Adlercreutz et al., 1986) [173].

4.6.2 Motivation

In addition to physiological factors, psychology may play an important role in load carriage capacity. Several papers allude to the importance of motivation in load carriage performance (Dziados et al., 1987, [16], Mello et al., 1988, [14] and Knapik et al., 1990, [17]) as "well motivated soldiers of average strength and endurance would outperform poorly motivated soldiers with high strength and aerobic capacity" [14]. Although not mentioned in any capacity the influence of leadership and leadership styles, allied to internal motivation and external motivation may also offer some confounding effects. For research, it is clearly important to understand and ideally measure the influence and confounding effects of both internal and external motivation. However, this should not be confined the measurement of physical stress within the training environment, as all the potential variables may never be fully appreciated unless measurement is undertaken during live missions. Measures of state and trait motivation plus an understanding of the soldier's self-determination during load carriage activities could help highlight how type of motivation might be altered or supported to elicit better performance. Indeed, a study by Wilson, Markey and Markey (2012) indicated that some military personnel may just "go through the motions" when exercising [174]. Proposing the frequency of exercise may be correct, but the intensity may be insufficient to support health and prevent body fat accumulation (Hausenblas and Fallon, 2006 [175], Stroth et al., 2009 [176]). Understanding the influence of physical conditioning, it may be the motivation to exercise and more specifically the type of motivation to exercise that is the vital component to influence attendance at physical conditioning sessions, and enduring commitment to occupational readiness (Dystad, 2007) [177].

[7] Doctrine, Organisation, Training, Materiel, Leadership, Personnel, Facilities and Interoperability.

4.6.3 Health Behaviours

Health behaviours are rarely referred to in load carriage research, thus, the true baseline measures of health are not accounted for (i.e., sedentary behaviour, nutrition, sleep). This is vital for the military, as personnel who undertake poor health behaviours compromise their own health and reduce the operational effectiveness of their unit (Bray et al., 2006) [178].

4.6.4 Sedentary Behaviour

The independent nature of sedentary behaviour as a risk factor of metabolic syndrome and abdominal obesity (Healy et al., 2008 [179), indicates there are real physiological consequences of being highly sedentary (Bey and Hamilton, 2003) [180]. Of further concern, is the proposition that these physiological changes are amplified by age (Hamilton et al., 2001 [181]), and has occupational resonance for military, where age generally signals a move to sedentary duties and a reduction of Occupational Physical Activity (OPA). A reduction of OPA could lead to a reduction of occupational fitness if not supported by sufficient physical conditioning. In this instance, the risk of musculoskeletal injury is increased (Kyrolainen et al., 2008 [182]) and performance potential in load carriage reduced.

4.6.5 Nutrition

The broad theme of nutrition was the subject of one included study (Sutton et al., 2005) and this randomised controlled trial suggested that ingestion of the amino acid tyrosine by soldiers had no measurable effect on endurance, muscle strength, or anaerobic power [18]. Blacker et al., (2010b) came to a similar conclusion using carbohydrate supplementation on a non-military group [183]. However, Blacker et al., (2011) reported improved recovery post load carriage tasks with the ingestion of both carbohydrate and protein supplementation [184]. Interestingly Blacker and colleagues [184] noted post 48 hrs both experimental groups (carbohydrate and protein) had returned to pre-load carriage task levels. In this study the control group did not reach pre-test levels until post 72 hrs. In the area of supplementation, there is potential to reduce the overflow effects of fatigue thus enhancing unit efficiency during combat operations and load carriage activities. Moreover, nutrition is part of the performance triad and good basic nutrition can improve performance (Rodriguez et al., 2009 [185]), delay fatigue (Beelen et al. 2010 [186]) and accelerate recovery (Flakoll et al., 2004) [187]. In the knowledge that the daily energy requirements for military tasks varies, Tharion et al., (2005) has reported daily energy requirements for military tasks can range from 2332 kcal for administration to 6678 kcal for operational training [188]. To understand the detrimental effect of poor nutrition upon occupational capacity, further research is required to give evidence-based information in relations to supplementation and optimum nutrition to support load carriage activities.

4.6.6 Sleep

The performance triad also includes sleep. Due to the specific nature of the military, sleep patterns are often disrupted (Crowley et al., 2012 [189]), thus some soldiers could be operating at a level of sleep deprivation (Luxton et al., 2011) [190]. Sleep can directly affect several military aspects of life including cognition and application in physical training lessons and general physical fitness [189]. Specifically, in relation to load carriage, the importance of sleep (even allied to fatigue state) is not regularly mentioned as a potential confounder to study data or as part of the conditioning requirement. This area requires further investigation.

4.6.7 Experience

Experience is likely one of the largest modifiable risk factors, experienced load carriers may be able to carry heavy loads with minimal kinematic changes from their natural walking pattern and possibly lower the risk of injury (Wang, Frame and Ozimek, 2013) [117]. In addition, many studies required participants to walk at an mandated pace, often faster than their normal chosen walking pace, which negatively modifies movement kinematics, therefore more research is needed to examine self-paced loaded marching recognizing that operational pace may in fact be relatively slow 5kph (Reilly et al. 2016). [137].

4.6.8 Age

Although one study involving 96 service personnel suggested that experience expressed as "time served" and by "rank" were positively associated with load carriage Knapik et al., (1990 [17]), it well known that skeletal muscle mass, decreases with age (Janssen et al. 2000 [191]) as does strength (Thom et al., 2007 [192]) and maximal aerobic capacity (Heath et al., 1981 [193]), and these changes occur in both non-trained and (to a lesser extent) trained individuals (Bortz and Bortz, 1996 [194]). Military studies have indicated that transition from active operational roles into more sedentary managerial employment linked to advancing age may reduce activity levels and could induce changes to body composition (Helmhout, 2009 [195], Napredit et al., 2005 [196]). Thus, experience gained preparing for and completing load carriage tasks, could be confounded by age related physiological decline. Additionally, the relationship between age and obesity (Lindquist and Bray, 2001 [197], Robbins et al., 2001 [198], Flegal et al., 2010 [199]) and general physical fitness (Robbins et al., 2001 [198], Santtila et al., 2004 [200]) is well reported. If physiological decline is not buffered (through specific physical conditioning); a reduction in occupational fitness and a positive energy balance is the likely outcome, thus reducing physical capability (strength and endurance) and increasing the load burden (load + fat mass). The influence of age and experience is worthy of further investigation, specifically if a tipping point exists where physiological decline negates skill and experience.

4.7 THE IDEAL SOLDIER CHARACTERISTICS

As described in Figure 4-12 it is vital for soldiers to manage adequately their body mass and other heavy loads during both prolonged *(*e.g., *approaching march)* and short *(*e.g., *assault)* bouts of time at different intensities. As well as effects of prolonged load carriage activities on soldier's performance have been well described the last decades (Beekley et al*.,* 2007 [201]; Knapick et al*.,* 1992 [116]; Grenier et al*.,* 2012a and 2012b [111], [112]; Blacker et al*.,* 2013 [122]), it is only a single component of the multivariable occupational demands which militaries are now confronted. Today, the continuous challenge between endurance and maximal strength/power capabilities is inevitably observed during prolonged and short duration.

Aerobic capacity is an essential component for prolonged loaded walk since time to exhaustion is inversely correlated to the relative metabolic cost of the activity expressed in maximal aerobic capacity of the subject (Drain et al., 2012) [2]. Moreover, aerobic capacity is a key factor to heat acclimation and tolerance, which limits the cardiovascular strain induced by heat exposure. Nevertheless, these aerobic qualities are not sufficient, and fat free mass has also been shown important for performance in this bout; particularly, strength in lower limb but also in upper limb.

In the prevention of injury and to support performance, good muscular endurance without imbalance between trunk flexor and extensor would be recommended to prevent back pain. Moreover, it seems that trunk muscle endurance could be important for load carriage in downhill to limit the fatigue specifically increased by the load

and the relative instability of the trunk. Besides physical characteristics, the specific effect of load carriage on trunk muscle endurance could be taken into account for optimizing load distribution regard of the decline grade. Currently, there is a lack of knowledge of relation between muscle endurance and long-term load carriage since only two studies (Mello et al., 1988 [14] and Dziados et al., 1987 [16]) have assessed this muscle characteristic while almost data focused on maximal strength. This gap is even larger if we consider that time course of load carriage walking is almost all under two hours.

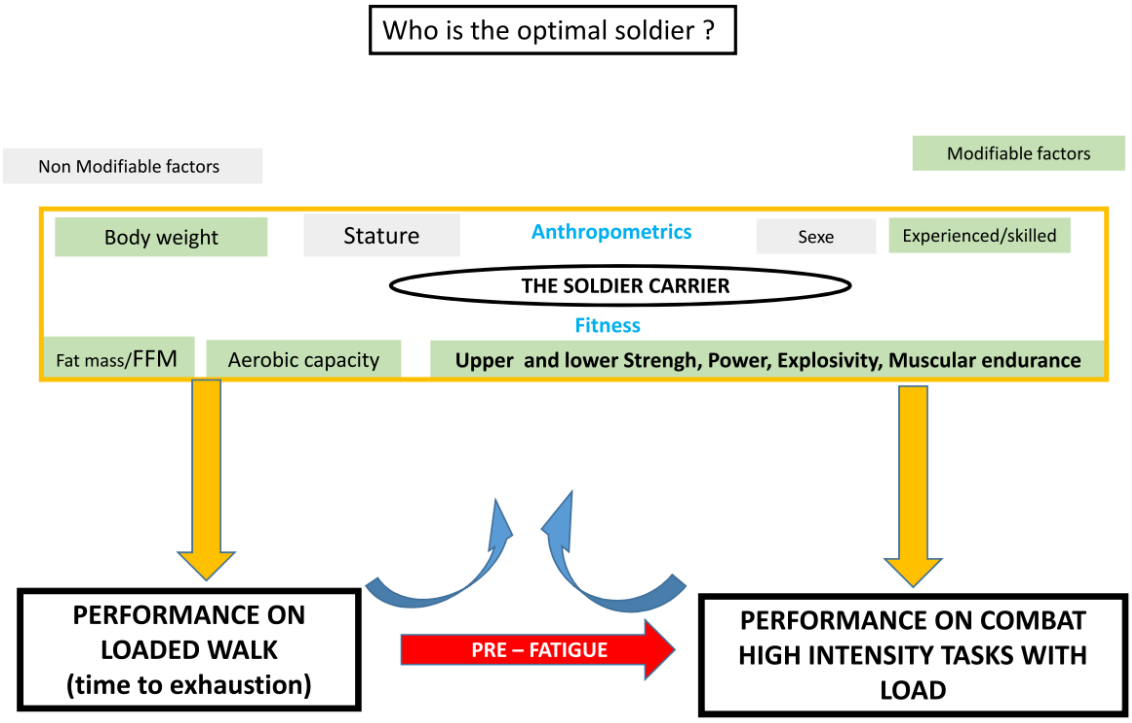


Figure 4-12: The Characteristics of the Ideal Soldier.

For high intensity loaded tasks, strength muscle of lower limb and upper limb are well correlated to time trial only for change of position and acceleration, but not for task > 30sec. As for long loaded walking, only two studies have assessed endurance muscle during high intensity tasks (Pandorf et al., 2002 [82]; Jette et al., 1990 [103]), the others focused on maximal strength/power. Thus, a minimal threshold of strength in lower and upper limbs probably exists to perform high military tasks with a load which should be determined precisely for each task to give practical recommendations and targets of resistance training. Nevertheless, the greater the force/power exerted by a muscle or motor unit, the greater the level of peripheral fatigue and the shorter the duration of the exercise (Enoka and Stuart, 1992 [107]; Ratel et al., 2015 [108]). Thus, a soldier with a high level of musculature could have a drawback when high intensity task as are extended or repeated. Moreover, an excessive increase of muscle mass can increase metabolic cost of long loaded walk and thus fatigability. The optimal body composition between relative fat mass and fat free mass considers that fat mass is a "dead" burden. But this assertion does not mean that the soldiers with the highest fat free mass can produce the best load carriage performance.

Further investigations are therefore needed to determine the ideal parameters i.e., strength and muscle endurance, and body composition on medium- to long-term walking carriage performance. It is very likely the requirements

of the optimal soldier are a combination of different functional physical capacities and skeletal muscle properties to find the ideal balance between aerobic ability, strength and muscle endurance. Nevertheless, depending on load carriage task (slow and deliberate or dynamic and reactionary), there is much interplay between the constructs of fitness, with different load carriage tasks requiring different physiological input. Consequently, the conclusions by Knapik (1989,) still hold true: "for military purposes it is possible to combine the concepts of muscular strength and endurance since they are highly related on an absolute basis" [202].

The other big concern is the optimal training to prescribe and the interactions related to concurrent training. There is the distinct possibility that the diverse requirements of modern warfare are not reflected in training, and a real possibility that the excessive training volume of some military training programmes may not reflect the reality of load carriage activities undertaken on the battlefield (Orr et al., 2010) [203].

If changes are to occur it should be acknowledged that these will often be beyond the individual level. Modification or change can be dependent on several factors some of these factors are reliant on the individual and some are reliant on the organization. In fact, this statement does not fully reflect the complex nature of change as in many instances change will require the interaction of person, organization, policy, environment, and for the military, the Chain of Command. If all of these elements are not engaged and supportive, it is likely that change will only be at the individual level, transient in nature and open to relapse and reversibility.

4.8 SUMMARY CONCLUSIONS

In Section 4.2 the physical capabilities that affect the adaptive "administrative advance" with load were the subject of systematic review. From the available evidence, there is a suggestion that the physical characteristics that fall into the broad categories of anthropometrics and fitness status have the ability to affect load performance. However, further research is required to inform military decision making. From this chapter, those characteristics that fall into the modifiable section such as physical conditioning and body composition offer most promise. It is clear that stature and age cannot be modified; however, changes to training may mitigate (to a degree) the impact on performance and possibly the rate of injury. Nevertheless, conditioned state can better support performance specifically for female soldiers undertaking dedicated load carriage training and submaximal combat tasks.

Beyond the person, there exists a possibility of performance threshold, specifically where load and load mass degrade performance. From Section 4.3, it is evident that mass, stiffness and bulk contribute to this impairment, but the relative contributions require further examination. Moreover, the loads carried by dismounted soldiers negatively impact their ability to move which, on the battlefield, may result in increased vulnerability to enemy action and being more susceptible to injury. Clearly in this area further research is required to inform soldier mobility and survivability.

In Section 4.4 the impact of an administrative advance load carriage event on combat tasks of short duration were investigated. It is clear a greater muscular endurance capacity of the lower body can be advantageous during load carriage over medium to long distances, since individuals with more muscular endurance should have a better resistance to fatigue. In contrast, individuals with higher maximal strength capacity could elicit a better performance while carrying extreme heavy loads, during very short bouts of time; however, they could be more sensitive to muscle fatigue during longer tasks. Therefore, an optimal compromise between maximal strength/power and endurance capacity is therefore required and is vital for optimizing performance of soldiers during both short and long-term load carriage tasks.

Section 4.5.2.2 also suggested that dedicated physical training as part of a dedicated heat acclimatisation protocol, with gradual increases in load (and therefore heat strain) might improve thermal tolerance and general physical fitness.

For the ideal soldier, the physiological requirements can be diverse and demanding. It is clear that a platform of health to support occupational and operational fitness is required and that currency is needed throughout career to support the changing physiological, health and occupational needs. What is often misunderstood is that it is not always within the gift of the individual to be the best they can be. This is often a brokered process between several 'stakeholders' and can involve doctrine, local policy, chain of command, environment, subject matter expertise and correct provision. Often these problems are viewed as disparate elements; it is very possible the complexity of the issues have stifled any real progress in the areas of research as they have failed to acknowledge the transdisciplinary nature of the problem.

4.9 ACKNOWLEDGEMENTS

The following persons are acknowledged by the authors for their invaluable contribution to this chapter in defining the scenarios, executing the load exercises/workshops, and/or assisting with data collection and analysis. These persons are:

- Hervé Sanchez (France);
- Nathalie Koulmann (France); and
- Mark Patterson (Australia).

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Chapter 5 – TECHNOLOGICAL SOLUTIONS FOR MITIGATING AGAINST PHYSICAL BURDEN EFFECTS

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5.1 INTRODUCTION

As demonstrated in the preceding chapters, today's dismounted Soldiers are extremely overburdened, and while some physical burden effects might be mitigated through modification of personal characteristics, alternative, "skin-out" technological approaches could also be used to reduce the physical effects of carried load. An understanding of the benefits and limitations of such approaches is needed to inform future investments in research, development, and acquisition for physical burden mitigation. The purpose of this chapter is to review available technological approaches to mitigate effects of physical burden, present the current state-of-the-art of these approaches, and discuss how they might be implemented in operational scenarios.

In the process of developing this technology watch, an initial list of technological areas with potential to mitigate burden effects was developed by the RTG and each partner nation was asked to identify available technologies within these areas. The surveyed technology areas included:

1) Active and passive cooling systems;
2) Material solutions;
3) Exoskeletons/physical augmentation devices;
4) Off-loading mechanisms;
5) Precision resupply;
6) Wearable technologies for measuring Soldier state;
7) Network-enabled Soldier; and
8) Load decision aids.

Nutrition, physical training, and genetic engineering approaches were deliberately excluded from consideration.

Identified technologies were submitted to the US Army Research Laboratory, who was asked to consolidate and report on data provided by each partner nation. The submitted technologies were consolidated into three general categories:

1) Cooling systems;
2) Load mitigation systems; and
3) Load decision aids.

Specific information regarding each of the included technologies was obtained from manufacturer websites, previous work conducted by member nation organizations, open literature research publications, subject matter expert feedback, and reports generated by related NATO RTGs (e.g., RTG HFM-187 Management of Heat and

Cold Stress). Based on the available information, technologies within each category were considered against their mechanism of action, cost, technology readiness level, potential benefits, and limitations. Unless otherwise noted, performance of the included technologies has not been independently assessed by NATO or members of RTG HFM-238. The intent of this chapter is to provide an overview of skin-out technology that can be used to mitigate Soldier physical overburden. The chapter is not intended to be an exhaustive list of every possible technology.

5.2 COOLING SYSTEMS

As discussed in Chapter 4, dismounted Soldiers often experience uncompensable thermal burden imposed by high physical workloads, multiple clothing layers, and PPE, particularly in high temperature environments. Increased hydration needs, degraded physical, cognitive, and working abilities [1] and increased susceptibility to heat injury are potential consequences of heat strain. Therefore, identifying approaches by which the thermal burden of dismounted Soldiers can be mitigated is critical to individual health and mission outcomes.

Body heat is lost through four mechanisms:

- Conduction (heat transfer through direct contact between skin and cooler object);
- Convection (heat transfer through movement of cooler air or water over skin);
- Radiation (heat transfer through infrared rays); and
- Evaporation (heat transfer through conversion of liquid to gas) [2].

Sweat evaporation serves as our primary mechanism for cooling during exercise, accounting for more than 80% of total heat loss, however, the efficacy of evaporative heat loss is inversely related to the amount of water vapor in the air (i.e., inhibited by high relative humidity) [3]. Impermeable clothing layers and equipment such as those worn and carried by dismounted Soldiers (e.g., body armor, rucksack, chemical protective suit) additionally limit the available surface area over which evaporative cooling can take place [4].

Personal cooling systems provide a means to mitigate thermal burden and increase physical comfort when effectiveness of these mechanisms is limited and thermoregulation cannot be achieved through traditional behavioral responses (e.g., removal of clothing layers) or alternative means of cooling (e.g., movement to cool environment, cold-water immersion of extremities). These systems can be active or passive in nature and are generally classified into four categories:

- Liquid circulating;
- Air circulating;
- Phase Change Material (PCM); and
- Passive evaporative.

Detailed descriptions and examples of current technologies from each category are provided in Sections 5.2.1 to 5.2.4.

Personal cooling systems have previously been used by people who work in hot environments, such as athletes [5], [6], [7], [8], [9], construction [10], industrial (e.g., steel mills) [11], and agricultural workers [12], as well as surgeons during long or strenuous procedures [13], [14]. Additionally, some individuals with heat-intolerant health conditions (e.g., Multiple Sclerosis) use these systems to alleviate heat discomfort effects [15], [16], [17]. Space suits have also utilized liquid and ventilation cooling garments for astronauts [18], [19], [20], [21].

While personal cooling approaches have also demonstrated utility for military personnel in armored vehicles [4], their efficacy for dismounted operations is yet to be established. Trade-offs between personal cooling approaches, potential limitations for dismounted operations and recommendations for future development of cooling technologies are provided in Section 5.2.5.

5.2.1 Liquid Circulating Systems

Liquid circulating cooling systems transfer heat away from the body via conduction to chilled liquid circulated by a powered pump through flexible tubing embedded within a garment (e.g., shirt, vest). The circulating liquid can be chilled by movement through an ice-containing reservoir or using Vapor Compression Cycle (VCC). These systems have proven effective for people who work in hot environments, such as athletes, construction, industrial (e.g., steel mills), and agricultural workers, as well as surgeons during long or strenuous procedures. Liquid circulating cooling systems have also been used in space suits for astronauts.

The garments used for liquid circulating systems are designed to be worn in close proximity to the body (direct to skin or over base-layer clothing) and are generally compatible with personal protective equipment (body armor, protective suits) typically worn by dismounted Soldiers. Both ice and VCC cooled systems involve circulation of liquid from the garment to an external ice-containing housing or powered chilling unit which may be portable (body-mounted, battery powered) or non-portable (large cooler or vehicle-mounted, AC or DC powered). Cooling rates are comparable for both types of systems, ranging from 79 to 244 W [22], [23]. However, performance is somewhat reduced (61 to 188 W) when the system is worn under a standard military uniform [22], [24]. Liquid circulating cooling systems are capable of continuous cooling provided that an adequate power supply and source of chilled liquid are available. However, in applications where portability is required, operation time is limited to between 45 and 120 minutes. While VCC cooled systems have fewer logistical limitations associated with use during dismounted operations, they are generally more expensive than their ice cooled counterparts ($1,500 – $8,000 versus $400 – $1,000).

Examples of liquid circulating systems are provided in the figures below.

Cold Flow® Cooling Vest System
(Polar Products)



Cooling source: Ice, cooler (9- or 15-quart)

Cooling duration: Dependent on power supply and availability of ice

Power: AC power or Li-Ion rechargeable battery

Benefits: Vest is light mass and can be worn under body armor, fitted and adjustable versions of vest available, temperature control (40 to 70 °F)

Limitations: Cooling source is non-portable, requires access to ice source to replenish cooler, limited mobility during cooling (must be within 4 to 8 ft of cooler)

TRL: 6+

References:
http://www.polarproducts.com/polarshop/pc/home.asp; [25], [26].

Figure 5-1: Cold Flow® Cooling Vest System (Polar Products).

Cold Flow® Arctic Chiller Cooling Vest
(Polar Products)



Cooling source: VCC, 1/15 hp chiller

Cooling duration: Dependent on access to power

Power: AC power

Benefits: Vest is light mass and can be worn under body armor, fitted and adjustable versions of vest available, temperature control (40 to 70 °F)

Limitations: Cooling source is non-portable, requires access to AC power, limited mobility during cooling (must be within 4 to 8 ft of chiller)

TRL: 6+

References:
http://www.polarproducts.com/polarshop/pc/home.asp

Figure 5-2: Cold Flow® Arctic Chiller Cooling Vest (Polar Products).

BCS4 Body Cooling System
(Med-Eng)



Cooling source: Ice, leg-mounted ice bottle

Cooling duration: Dependent on power supply and availability of ice

Power: NiMH rechargeable battery

Benefits: Fully portable, available in multiple configurations (vest, hood, or three-piece garment), can be worn under body armor and bomb disposal/EOD protective suits

Limitations: Requires access to freezer or ice supply to replenish cooling source, leg-mounted cooling source may interfere with task performance

TRL: 6+

References: https://www.med-eng.com/Products/CrewSurvivability/ThermalManagement.aspx; [27], [28], [29].

Figure 5-3: BCS4 Body Cooling System (Med-Eng).

LCG Military Vest
(Med-Eng)



Cooling source: VCC, vehicle-mounted Portable Liquid Chiller (PLCU)

Cooling duration: Dependent on access to vehicle

Power: Vehicle power supply

Benefits: Light mass vest, can be worn under body armor, continuous cooling when tethered to PLCU

Limitations: Cooling source is non-portable, no active cooling when untethered from PLCU, PLCU requires access to vehicle power supply

TRL: 6+

References: [30]

Figure 5-4: LCG Military Vest (Med-Eng).

Personal Thermal Management System
(Rini Technologies)



Cooling source: VCC, vest-mounted Thermal Management Unit (TMU)

Cooling duration: 2 – 4 hours

Power: Battery pack

Benefits: Fully portable, light mass (vest and TMU: 3.6 lbs., batteries: 3 lbs.), circulating water maintained at 72 °F in operating temperatures up to 140 °F, can be worn under body armor

Limitations: Requires access to batteries for continuous operation, placement of battery pack and TMU may interfere with task performance

TRL: 6+

References: http://rinitech.com/wp-content/uploads/2016/03/MILITARY_COOLING.pdf

Figure 5-5: Personal Thermal Management System (Rini Technologies).

Personal Cooling System
(Veskimo)



Cooling source: Ice, insulated backpack

Cooling duration: 6 hours or continuous

Power: DC power or Li-Ion rechargeable battery

Benefits: Fully portable, can be worn under body armor, insulated backpack can serve as hydration pack

Limitations: Requires access to batteries or power supply for continuous operation, requires access to ice to replenish cooling source, insulated backpack may interfere with task performance or Soldier equipment

TRL: 6+

References: http://www.veskimo.com/

Figure 5-6: Personal Cooling System (Veskimo).

Wearable Personal Cooling System
(Cobham)



Cooling source: VCC, vest-mounted cooling unit

Cooling duration: Dependent on battery life

Power: Battery pack

Benefits: Fully portable and light mass (3.9 lbs. without battery), vest can be worn under body armor, cooling unit and battery pack are compatible with Modular Light mass Load-carrying Equipment (MOLLE) attachment system and offer flexibility in mounting location

Limitations: Requires access to batteries for continuous operation, placement of cooling unit and battery pack may interfere with task performance or Soldier equipment

TRL: 6+

References: http://www.cobham.com/mission-systems/thermal-management/wearable-personal-cooling-systems/

Figure 5-7: Wearable Personal Cooling System (Cobham).

5.2.2 Air Circulating Systems

Circulation of air as a cooling mechanism increases convective and evaporative heat loss. Air circulating systems provide the most efficient cooling effects when they are worn close to the user's body as opposed to over other clothing [31]. Two common types of air circulating cooling systems are those that use compressed air and those that use ventilation.

Compressed air systems consist of a garment with a perforated inner liner connected to a compressed air source through a vortex chamber. The vortex chamber separates the compressed air source into hot and cold streams, transferring the cooled air to the garment and venting the hot air to the environment. The cost of compressed air-cooling systems range from $150 to $300. When a compressed air-cooling vest is worn under standard uniforms, the cooling rate is 190 – 288 W [24]. Continuous cooling can be applied as long as there is an indefinite supply of compressed air. However, a significant limitation of this cooling mechanism is that the user must be tethered to the compressed air system which could limit movement.

In comparison, ventilated cooling vests use fans to circulate air from the environment over the body to improve convection and evaporative cooling. This approach has been found to significantly lower skin temperature compared to using no cooling system [31], with reported cooling rates of 77 to 127 W [23]. Because they make use of ambient air, the efficacy of ventilated cooling systems is dependent on environmental conditions, performing best in low humidity. Additionally, these systems can be noisy during use, and operating time is limited to between 120 and 140 minutes if batteries cannot be readily replaced.

Examples of compressed air and fan-ventilated air circulating systems are provided in the figures below.

Personal Air Conditioner Vest
(Vortec)



Cooling source: Compressed air, vortex chamber

Cooling duration: Dependent on availability of compressed air

Power: None

Benefits: Vest is light mass and can be worn under protective clothing, no restriction to range of motion, adjustable temperature control

Limitations: Limited portability, requires connection to compressed air supply, vest is impermeable and may increase thermal burden when not actively cooling

TRL: 6+

References: https://www.vortec.com

Figure 5-8: Personal Air Conditioner Vest (Vortec).

Vortex Cooling Vest
(Allegro Industries)



Cooling source: Compressed air, vortex chamber

Cooling duration: Dependent on availability of compressed air

Power: None

Benefits: Vest is light mass and can be worn under protective clothing, no restriction to range of motion, adjustable temperature control

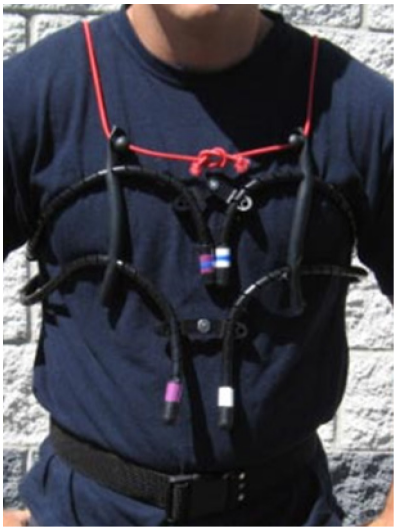
Limitations: Limited portability, requires connection to compressed air supply, vest may increase thermal burden when not actively cooling

TRL: 6+

References:
http://www.allegrosafety.com/asp/product_detail.aspx?prodID=127

Figure 5-9: Vortex Cooling Vest (Allegro Industries).

Thermal Star® Body Cooling System
(Electric Fan Engineering)



Cooling source: Fan ventilation, 12V fan motor

Cooling duration: Dependent on battery life

Power: Battery pack

Benefits: Completely portable, light mass (2 lbs. without battery), fully adjustable to accommodate wide range of users

Limitations: May not be compatible with Soldier clothing and equipment, tubing may create pressure points under body armor, requires access to batteries for continuous operation

TRL: 6+

References:
http://www.electricfanengineering.com/thermal-star-body-cooling-systems/thermal-star-body-cooling-system/

Figure 5-10: Thermal Star® Body Cooling System (Electric Fan Engineering).

5.2.3 Phase Change Material (PCM) Systems

Phase Change Material (PCM) cooling systems operate through passive absorption of body heat by a PCM material. As the PCM absorbs heat it changes from a solid to liquid state. For personal cooling, this method is often used with a vest which contains pockets close to the body in which to store the PCM. Due to its phase changing properties, PCM cooling performance depends on latent heat absorbed in the phase change which can vary depending on ambient conditions and the user's workload. Typically, cooling can be maintained for up to 3 hours. However, once cooling effects have diminished, the PCM acts solely as additional mass until recharged. Depending on the properties of the PCM, recharging is accomplished via movement to a cool environment (below 55 to 60 °F), immersion in ice water, refrigeration, or placement in a freezer. PCM systems are relatively inexpensive (around $200) compared to liquid and air circulating systems. The cooling rate for PCM systems is 6 – 132 W when worn under standard military uniforms and 68 – 157 W when worn under chemical protective uniforms [23], [24]. Compared to no cooling system, PCM cooling has been shown to significantly lower sweat rate [32]. However, in one study, Soldiers' perceptions and physiological responses with the PCM cooling system were not significantly improved compared to the no cooling system condition [33]. Examples of PCM cooling systems are provided in the figures below.

Kold Vest
(ProKold)



Cooling source: Flexible ice sheets

Cooling duration: Up to 2 hours

Power: None

Benefits: Completely portable, vest is light mass and adjustable, remains dry during use

Limitations: Vest may increase thermal burden once cooling capacity is depleted, requires access to freezer to store and recharge ice packs

TRL: 6+

References: http://www.prokold.com/dkmain.html

Figure 5-11: Kold Vest (ProKold).

Cool Vest
(ICEEPAK Australia)



Cooling source: Flexible ice sheets

Cooling duration: Unknown

Power: None

Benefits: Completely portable, light mass (3 lbs.), adjustable and available in multiple sizes

Limitations: Vest may increase thermal burden once cooling capacity is depleted, requires access to freezer to store and recharge ice packs

TRL: 6+

References: http://www.iceepak.com.au/

Figure 5-12: Cool Vest (ICEEPAK Australia).

SWEDE Basic Cooling Vest
(First Line Tech)



Cooling source: PhaseCore pouches, freeze solid below 82°F

Cooling duration: Up to 4 hours

Power: None

Benefits: Completely portable, light mass and comfortable, available in multiple sizes, can be recharged in environment below 82°F without need for ice, refrigeration, or electricity

Limitations: May be too bulky for use under body armor, vest may increase thermal burden once cooling capacity is depleted, requires access to cool environment/refrigeration to recharge

TRL: 6+

References:
https://www.firstlinetech.com/product/swede-basic-cooling-vest/

Figure 5-13: SWEDE Basic Cooling Vest (First Line Tech).

Cool58® Phase Change Cooling Pack Vests
(Polar Products)



Cooling source: Cool58 cooling pack, freeze solid below 58°F

Cooling duration: Up to 3 hours

Power: None

Benefits: Completely portable, light mass and comfortable, available in multiple sizes

Limitations: May increase thermal burden once cooling capacity is depleted, requires access to ice water, refrigerator, or freezer to recharge

TRL: 6+

References:
http://www.polarproducts.com/polarshop/pc/home.asp

Figure 5-14: Cool58® Phase Change Cooling Pack Vests (Polar Products).

Zip Cool-UnderVest™
(Steele Cooling Vests)



Cooling source: Thermo-Phase strips

Cooling duration: Up to 4 hours

Power: None

Benefits: Completely portable, light mass and comfortable, fully adjustable to fit variety of sizes, zipper closures enable removal/exchange of cooling strips when worn under body armor

Limitations: Vest may increase thermal burden once cooling capacity is depleted, requires access to ice water or refrigerator to recharge

TRL: 6+

References: http://steelevest.com/; [34], [35], [36]

Figure 5-15: Zip Cool-UnderVest™ (Steele Cooling Vests).

RPCM® Cool Vest
(Glacier Tek)



Cooling source: PureTemp pouches

Cooling duration: Up to 2.5 hours

Power: None

Benefits: Completely portable, light mass (less than 5 lbs.), fully adjustable to fit variety of sizes

Limitations: May increase thermal burden once cooling capacity is depleted, requires access to ice water, refrigerator, or freezer to recharge

TRL: 6+

References: http://www.glaciertek.com/

Figure 5-16: RPCM® Cool Vest (Glacier Tek).

5.2.4 Passive Evaporative Cooling Systems

Evaporative vests are immersed in water prior to wear and utilize the passive evaporation of water as the mechanism of cooling. Cooling effects from evaporative vests are limited by the time it takes for the water absorbed by the vest to evaporate, which can vary from 10 – 150 minutes. Evaporative vests provide a relatively inexpensive ($40 – $100) and convenient means of cooling, however, their efficacy is highly dependent on environmental conditions. Evaporative cooling vests work best in low relative humidity conditions and are more effective when there is air movement. They are relatively ineffective if worn inside of unventilated outer garments, a concern for Soldiers who at times wear several layers of clothing and protective equipment with little ventilation. Another concern with evaporative cooling vests is that they tend to remain wet for extended periods of time which can cause skin irritation and bacterial growth. No cooling effect is reported when the evaporative vest is worn under a chemical protective uniform, but when it is worn under a standard uniform, the cooling rate is 0 – 69 W [24].

Examples of evaporative cooling systems are provided in the figures below.

Evaporative Cooling Military Vest
(Polar Products)



Cooling source: Passive evaporation

Cooling duration: Dependent on environmental humidity

Power: None

Benefits: Completely portable, vest is light mass and can be worn under body armor

Limitations: Wet clothing in contact with skin, requires water to recharge, effectiveness degraded when worn under clothing and protective equipment or in high-humidity environments

TRL: 6+

References:
http://www.polarproducts.com/polarshop/pc/home.asp

Figure 5-17: Evaporative Cooling Military Vest (Polar Products).

Evaporative Cool Vest
(Cool Down Australia)



Cooling source: Passive evaporation

Cooling duration: 5 to 10 hours depending on environmental conditions

Power: None

Benefits: Completely portable, vest is light mass and can be worn under body armor

Limitations: Wet clothing in contact with skin, requires water to recharge, effectiveness degraded when worn under clothing and protective equipment high-humidity environments

TRL: 6+

References: http://www.icevests.com.au/

Figure 5-18: Evaporative Cool Vest (Cool Down Australia).

Body Cooling Vest
(Arctic Heat)



Cooling source: Passive evaporation

Cooling duration: Up to 2 hours

Power: None

Benefits: Completely portable, vest is light mass, available in multiple sizes, vest surface can be dried after activation of gel crystals, can be worn under clothing

Limitations: Vest may increase thermal burden once cooling capacity is depleted, requires water to recharge

TRL: 6+

References:
https://www.firstlinetech.com/product/swede-basic-cooling-vest/

Figure 5-19: Body Cooling Vest (Arctic Heat).

Dry Evaporative Chill Vest
(Cool Down Australia)



Cooling source: Passive evaporation

Cooling duration: Unknown

Power: None

Benefits: Completely portable, light mass and comfortable, available in multiple sizes, vest is completely dry following water activation, can be worn under clothing

Limitations: May increase thermal burden once cooling capacity is depleted, requires water to recharge

TRL: 6+

References: http://www.icevests.com.au/

Figure 5-20: Dry Evaporative Chill Vest (Cool Down Australia).

5.2.5 Cooling Systems Summary

Many personal cooling options have been successfully implemented for military personnel operating within vehicles or crew spaces [30], [37]. However, few, if any, are currently suitable for dismounted operations due to a wide range of challenges including: high power demands (for active air or liquid cooling); requirement to be tethered to the cool air/liquid source and power supply; excessive system mass; short duration of effectiveness (all options); and burden imposed by the cooling vest or carrier when not active [38], [39]. Each of the four categories of personal cooling systems presented in this technology watch have unique benefits and limitations which must be considered carefully and weighed against mission requirements when selecting an appropriate cooling solution to mitigate the thermal burden of dismounted Warfighters (Table 5-1).

Table 5-1: Summary of Personal Cooling System Categories.

	Liquid Circulating	Air Circulating	Phase Change Material	Passive Evaporative
Cooling Mechanism	Conduction	Convection, Evaporation	Conduction	Evaporation
Cooling Source	Ice or vapor compression cycle	Vortex chamber or ambient air	Ice or phase change gel packs	Water absorbed by hydrophilic gel
Cooling Rate	60 – 250 W	70 – 290 W	60 – 160 W	< 69 W
Cooling Time	2 – 6 hours (battery), indefinitely with access to power and cooling source	2 – 9 hours (battery), indefinitely with access to compressed air source or replacement batteries	2 – 4 hours	10 minutes to 2.5 hours
Power Source	Rechargeable Li-ion or NiMH batteries, AC power, 12V DC external power supply	Compressed air, batteries	Passive	Passive
Portability	Limited	Limited	Full	Full
Cost	Ice: $400 – $1,000 VCC: $1,500 – $8,000	$150 – $300 (does not include compressed air source)	~ $200	< $50
TRL	6+	6+	6+	6+

	Liquid Circulating	Air Circulating	Phase Change Material	Passive Evaporative
Benefits	Effectiveness, compatibility	Low cost for the level of effectiveness	No need for power or tether	Low cost overall Ease of use
Limitations	Operational time Tethered or Powered	Not portable	Long time to 'recharge'	Limited cooling rate

In terms of cooling rate, active approaches (air and liquid circulating) are substantially more effective than passive approaches (PCM and passive evaporation). Air circulating systems, which employ the body's most efficient cooling mechanism of sweat evaporation, may be the most beneficial approach in terms of thermal comfort [4], [40], [41], [42], however, they are most effective when the air being passed over the sweating skin is conditioned (drier and cooler than the microclimate under Soldier armor). Passive evaporative vests are similarly affected by environmental conditions. Therefore, systems which depend on evaporative cooling may not be the best option in extremely hot or humid environments. In these operational environments, liquid circulating and PCM systems may provide more consistent cooling performance.

The greater cooling rate associated with active approaches comes at a financial and logistical cost. Active systems are substantially more expensive than passive options. While they have the potential to be used indefinitely if adequate resources (power, cooling source) are available, many active systems provide limited mobility due to their requirement for tethering to the cooling source (ice chest, VCC unit, compressed air tank). The additional body-borne components required by those active systems which are designed to be portable (e.g.; battery pack, ice reservoir, cooling unit, fan unit) add carried mass while potentially interfering with task performance, and may affect compatibility with other Soldier equipment. Portable active cooling systems additionally require batteries for operation beyond a period of a few hours, potentially further increasing the Soldier's overall carried load during long missions. Until that holy grail of light mass, long-duration, portable power is developed or discovered, active cooling during dismounted Soldiering is unlikely to be realized, and passive options must be considered.

Although less effective at cooling, passive approaches are less complex and substantially cheaper than active systems. These systems can be worn completely under body armor and create little to no interference with dismounted task performance. While passive approaches additionally overcome the power challenges associated with active systems, they are dependent on access to water, ice and/or refrigeration for activation or recharging. Depending on mission requirements this may not be logistically feasible during dismounted operations, resulting in reduced durations during which the passive system can provide cooling.

With respect to all of the reviewed systems, during periods of time for which the system is not providing cooling there is a risk that it might actually increase the wearer's thermal burden by acting as an impermeable insulating layer. Depending on the mission, it may not be feasible for the dismounted Soldier to mitigate this effect by removing the cooling system layer. Therefore, in situations where mission time is anticipated to exceed the range of the portable cooling system and use of tethered systems are not feasible, it may be more effective to cool intermittently [40], [43]. There is evidence that extremity cooling before or after periods of intense activity may be successful in mitigating thermal strain [23], [44], [45], [46]. It is likely that similar effects might be achieved by applying this approach to personal cooling systems, for example, during rest breaks when dismounted Soldiers are supported by transport vehicles, manned or unmanned carriers or robots.

Given the limitations of the cooling systems detailed in this technology watch, exploration of novel approaches to overcome challenges associated with cooling during dismounted operations is warranted. A passive self-cooling gradient body armor shell composed of light mass, thin metal foil routed to the outside of the body armor to dissipate heat [38] offers one such approach and its potential should be investigated. Further development of a conditioned air distribution system underneath the armor that appropriately directs the airflow and does not impose added burden due to mass or added air insulation when the soldier is not plugged into the cooling system should also be explored. Papers examining this concept [42], [43], [47] suggest that it might be achievable in the near- to mid-term. Such a system would leverage the superior cooling efficiency of an air circulating system while overcoming the previously discussed limitations of current systems for use in dismounted operations.

5.3 LOAD MITIGATION SYSTEMS

Physical effects of carrying heavy loads include musculoskeletal strain and fatigue which can result in decreased task performance and increased risk of musculoskeletal injury. Previous research indicates that loads as small as 12% body mass elicit potentially harmful compensations in performance, including increased impact force, double stance time, and metabolic cost [48], [49], [50]. According to Epstein et al. [51], load carriage that requires a work intensity at greater than 50% of an individual's maximum rate of oxygen consumption will lead to gradual increase in energy cost over time as fatigue progresses. The consequences to Soldier performance due to fatigue from extended load carriage tasks could be debilitating to the Soldier and unit. Prolonged load carriage and execution of physically demanding operational tasks can pose a greater risk of musculoskeletal injury and physical burden on the Soldier. Physical and physiological effects from load carriage may inhibit the Soldier from sustaining performance of a current task for a prolonged period of time and may negatively impact performance on subsequent tasks.

Load mitigation systems can mitigate the physical burdens associated with dismounted task performance within operational environments by transferring or redistributing carried load, assisting with movement of the individual during load carriage, or providing an alternative means to transport the carried load. Beyond mitigating these physical effects, some of these technologies additionally provide an opportunity to enhance Warfighter physical performance beyond inherent human capabilities. Current load mitigation technologies can be classified into three groups: anthropometric assistive devices, load redistribution systems, and tactical mobility systems. Detailed descriptions and examples of current technologies from each category are provided in Sections 5.3 to 5.3.4.

5.3.1 Anthropometric Assistive Devices

Anthropometric assistive devices, more commonly referred to as exoskeletons, are a fast-growing area of development in the military setting with an aim to reduce physical burden of load carriage and task execution through physical augmentation and joint assistance. Grabowski et al. [52] reported that supporting body mass accounts for 28% of net metabolic cost of normal, unloaded walking while the work required to redirect and move mass forward accounts for about 50% of net metabolic cost of loaded walking. Anthropometric assistive systems take advantage of this concept, incorporating structural and/or mechanical components which operate in parallel with the user's musculoskeletal system to transfer load to the ground and/or provide assistive torques about their joints. Exoskeletons can be passive (unpowered) or active (powered) in nature and are designed to enable the user to carry out specific tasks with minimized physiological and physical effort. Systems within this category of load mitigation technologies have shown great potential in reducing metabolic cost while augmenting joint power which would benefit Soldiers during load carriage in operational environments.

Many of the current anthropometric assistive devices suitable for dismounted operations originated from or are being developed under government- or military-funded projects or programs. In early 2000 the Defense Advanced Research Projects Agency (DARPA) Exoskeletons for Human Performance Augmentation (EHPA) program funded Sarcos Corp. and University of California (UC) – Berkeley to develop exoskeletons for enhanced strength, speed, and agility. While both teams demonstrated working prototypes at the conclusion of the program, system bulk and technological limitations in power and actuation limited their transition to operational use. Following the EHPA program, Lockheed Martin continued development of the UC-Berkeley system for dismounted Soldier applications, resulting in the Human Universal Load Carrier (HULC). Approximately 10 years following the conclusion of EHPA, DARPA initiated the Warrior Web program. While EHPA was focused on providing Soldiers with super-human abilities, Warrior Web sought to develop light mass, low-power exoskeleton systems to reduce the metabolic cost and musculoskeletal injury risk associated with prolonged load carriage. One of the systems developed as part of the Warrior Web program, the Harvard University/Wyss Institute Soft Exosuit, successfully met program requirements for mass and power while demonstrating reductions in metabolic cost for Soldiers carrying a loaded rucksack over distances up to 12 miles.

In parallel to the Warrior Web program, US Special Operations Command began their Tactical Assault Light Operator Suit (TALOS) initiative, the goal of which is to develop an integrated suit to provide Special Operations Forces (SOF) with additional ballistic protection while maintaining mobility and situational awareness. It is envisioned that an exoskeleton will be integral to TALOS, serving to support and move the increased load associated with the added protection and other suit components. In response to the TALOS initiative, the Mawashi UPRISE™ Tactical Exoskeleton and Revision Military Prowler knee exoskeleton were developed. Natick Soldier Research Development and Engineering Center (NSRDEC) is currently funding the development of the Dephy ExoBoot with the goal of to increasing self-selected walking speed for level ground and inclined surfaces and reducing ankle-specific metabolic cost across walking speed, ground incline and military relevant load. Outside of government-funded programs, additional exoskeleton concepts are being developed, such as TNO and InteSpring's ExoBuddy.

Although development of exoskeletons is a growing and active field, little is still known about the biomechanical and physiological implications of wearing these devices to mitigate the physical burden of load. Before these systems can be implemented in an operational environment, further research and development is required to understand and address differences in individual responses to assistive devices and implications of their long-term use. Other areas of investigation highlight challenges of developing devices that can function within the dynamic and robust nature of a military environment. Exoskeletons developed for tactical use must account for a wide range of Soldier-relevant movements, aside from gait, by reducing kinematic constraints imposed on the user while wearing these devices. Additionally, to ensure overall mission effectiveness, exoskeletons should not interfere with execution of any task performed by the Soldier, even those for which the exoskeleton is not specifically designed to assist. In addition, exoskeletons must be rugged enough to withstand impact and heavy use by the Soldier while in the operational setting. Compatibility with Soldier clothing and equipment and logistical concerns related to maintenance and power requirements of these systems will also need to be addressed.

Examples of current anthropomorphic assistive devices and exoskeletons designed for dismounted Soldier applications are listed in the figures below. It should be noted that many of the included devices are still in early development and to date none have been fielded for tactical use. However, it is expected that such systems will have matured to a point of operational readiness within the next 10 to 20 years.

Human Universal Load Carrier (HULC)
(Lockheed Martin)



Purpose: Reduce musculoskeletal strain associated with load carriage

Form factor: Anthropomorphic structure attached in parallel with the legs and terminating in a foot plate under the user's boot, hydraulic actuator, battery, and electronics in backpack frame

Action: Load transferred to ground through hydraulically powered structural components

Power: Hydraulic actuation, lithium polymer battery pack

Benefits: Supports carried loads up to 200 lbs., does not interfere with user's ability to squat, crawl or hand carry objects, may assist with stabilization of load

Limitations: Mass of system, limited adjustability/sizing, does not actively assist motion, may result in undesirable gait mechanics, and increased metabolic demand

TRL: 4-5

References: http://www.lockheedmartin.com/us.html; [48], [53]

Figure 5-21: Human Universal Load Carrier (HULC) (Lockheed Martin).

Warrior Web Soft Exosuit
(Harvard University/Wyss Institute)



Purpose: Reduce lower extremity muscular work associated with load carriage

Form factor: Actuation cables spanning hip and ankle anchored to body through textile components and brackets installed on boots, mechanical actuation unit attached to rucksack, backpack, or waist belt

Action: Torques applied at hip and ankle to assist with leg extension and push-off during forward progression of walking, closed-loop control of actuation based on inputs from sensors incorporated in suit components

Power: Mechanical/cable-driven actuation, lithium polymer battery pack

Benefits: Demonstrated reduction in metabolic cost during prolonged load carriage, light mass, low-power, minimal interference with non-gait tasks

Limitations: Only provides assistance during walking, no transfer of load away from body, complexity of system components and controls, limited ruggedization

TRL: 4-5

References: https://wyss.harvard.edu/technology/soft-exosuit/ [54]

Figure 5-22: Warrior Web Soft Exosuit (Harvard University / Wyss Institute).

Tactical Assault Light Operator Suit (TALOS)
(US Special Operations Command)



Purpose: Support additional load associated with added ballistic armor and advanced communications equipment while sustaining or enhancing mobility of Special Operations Forces

Form factor: To be determined

Action: To be determined

Power: To be determined

Benefits: Notionally will enhance survivability while maintaining or improving mobility

Limitations: Potential for overall system to be very heavy, energy requirements will likely be substantial

TRL: 2-3

References:

Figure 5-23: Tactical Assault Light Operator Suit (TALOS) (US Special Operations Command).

UPRISETM Tactical Exoskeleton
(Mawashi)



Purpose: Reduce musculoskeletal strain associated with load carriage

Form factor: Anthropomorphic spine and lower extremity structures terminating at load-transferring soles integrated into footwear

Action: Load transferred to ground through passive load-bearing structure, range of motion maintained through flexible spine and ergonomic leg design

Power: Passive

Benefits: Transfers load to the ground without impeding natural range of motion, no external power required, light mass in comparison to active exoskeleton systems

Limitations: Load-bearing benefit only applicable during tasks in which the feet are in contact with the ground, effects on operational task performance unknown

TRL: 4-5

References: http://www.mawashi.net/en/uprise-tactical-exoskeleton

Figure 5-24: UPRISETM Tactical Exoskeleton (Mawashi).

Knee Stress Release Device
(K-SRDTM)/Prowler
(B-Temia/Revision Military)



Purpose: Reduce musculoskeletal strain, prevent musculoskeletal injuries, enhance strength, endurance, and stability

Form factor: Low-profile "dermoskeleton" structure surrounding lower extremities

Action: Mechanically assist knee flexion and extension during tasks such as walking, running, stair climbing, squatting and lifting

Power: Mechanical actuation, battery pack

Benefits: Light mass and compatible with most Soldier clothing and equipment, may reduce metabolic cost during walking and running

Limitations: No empirical data regarding performance in comparison to baseline condition

TRL: 4-5

References: http://www.b-temia.com/; [55]

Figure 5-25: Knee Stress Release Device (K-SRDTM)/Prowler (B-Temia/Revision Military).

Exobuddy
(TNO and InteSpring)



Purpose: Improve safety and performance during load carriage

Form factor: Structural components and hydraulic actuators to support carried load

Action: Pressure in hydraulic system used to apply upward force to carried load during heel strike

Power: Passive hydraulics

Benefits: Light mass, quiet, no power required, potentially able to offset up to 50% of load without affecting gait, does not hinder movement over hilly terrain and obstacles

Limitations: No empirical data regarding biomechanical and physiologic effects or impact on operational task performance

TRL: 3-4

References: http://www.intespring.nl/#exo

Figure 5-26: Exobuddy (B TNO and InteSpring).

5.3.2 Load Redistribution Systems

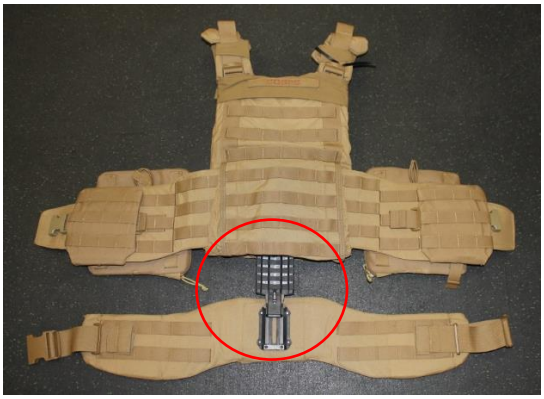
The majority of body-borne load is carried by Soldiers on the shoulders and back via backpack load carriage systems. As a result, many non-battle injuries of the shoulders and lower back are reported due to prolonged load carriage [56]. Research is underway to understand how distributing load from the shoulders and back to the hips may assist with increasing load-carrying capacity, enhancing perceived comfort, and decreasing negative effects of chest borne load on cardiopulmonary function and risk of musculoskeletal injury. Load redistribution systems aim to mitigate physiologic effects of load carriage, such as metabolic cost, by modifying the load path to adjacent body segments or to the ground. Reduced metabolic cost and perceived feeling of carrying less mass may impose an unsolicited desire for the Soldier to carry additional mass, which could cause greater injury risk to the Soldier. Current devices range in load offset capabilities and performance (i.e., comfort, mean force, and pressure).

Although body armor and ballistic plates add load, they are crucial components to the survivability of Soldiers. Consistent usage of protective equipment can impose limitations in agility and mobility which could hinder performance in operational environments. Body armor restricts ventilatory function by about 6% [57]. Agility and mobility have proven a challenge to quantify for developing improved systems, but evidence exists indicating that modified systems improve spirometry. Modifications to current body armor and ballistic protection systems have been developed to improve ventilatory function and reduce mass cost without compromising the safety of the Soldier.

It should be noted that limited research has been done to support redistribution of load to the hips, and implications for gait mechanics, muscular function and cardiovascular response are presently unknown. Although there is currently little literature on this concept, it is of great interest to the military community and warrants further exploration. Reduction in load is not an anticipated solution to the general Soldier population due to the increasing requirement of equipment and technology for mission completion, but a better understanding of how to distribute the load would allow for safer and more effective Soldier performance during load carriage tasks.

Examples of current load redistribution systems are listed in the figures below.

Modular Scalable Vest – Load Distribution System (MSV-LDS)
(US Marine Corps)



Form factor: Spine inserted into back of plate carrier and connected to padded hip belt

Benefits: Decreased back and knee discomfort, more neutral posture during load-carrying, decreased ground reaction forces

Limitations: Hip discomfort, performance during non-gait operational tasks unknown

TRL: 4

References: [58]

Figure 5-27: Modular Scalable Vest – Load Distribution System (MSV-LDS) (US Marine Corps).

Structural Kinetic Support System (StKSSTM)
(Crye Precision)



Form factor: Extendable supports attached to sides of armor vest transfer mass to hips through hip belt

Benefits: Simple, light mass, improved shoulder and back comfort, minimal impact on range of motion

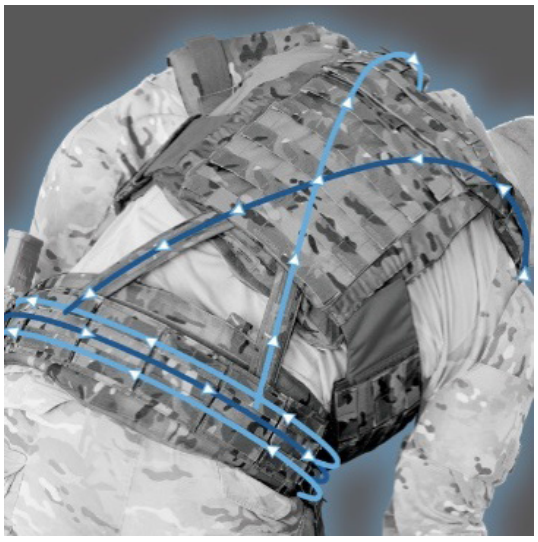
Limitations: No objective data regarding performance, compatibility may be limited to other Crye products

TRL: 9

References:
https://cryeprecision.com/ProductDetail/blc03902000_chassis-stkss-adapter

Figure 5-28: Structural Kinetic Support System (StKSSTM) (Crye Precision).

XFrame Dynamic Load Carriage System
(TYR Tactical)



Form factor: Carbon-fiber stays oriented in X configuration between vest and belt from shoulder to opposite hip

Benefits: Allows free range of motion

Limitations: No empirical data regarding performance, may not be compatible with vests and belts from other manufacturers

TRL: 9

References:
http://www.tyrtactical.com/products/details/xframe-dynamic-load-carriage-system-epicf/tyr-tactical-xframe-stays

Figure 5-29: XFrame Dynamic Load Carriage System (TYR Tactical).

VIRTUS Dynamic Mass Distribution (DWD) System (SOURCE Tactical)



Form factor: Adjustable spine bar attached between vest and belt

Benefits: Improved comfort, adjustability feature allows changes in load transfer between shoulder and hips to be made on-the-go

Limitations: Single point of attachment at hip belt can create pressure point at low back and strain on belt

TRL: 9

References: https://sourcetacticalgear.com

Figure 5-30: VIRTUS Dynamic Mass Distribution (DWD) System (SOURCE Tactical).

5.3.3 Tactical Mobility Systems

As an alternative to supporting or redistributing load on the Soldier, tactical mobility systems have been developed to carry loads traditionally donned by Soldiers. All-terrain vehicles and other remote-controlled systems (robotic assets) remove the physical burden of load carriage from the Soldier allowing for longer and less physically demanding activity. These systems serve multiple functions in addition to load carriage such as a platform for casualty evacuation and tactical resupply. Developers suggest a potential 15 – 30 % reduction in Soldier load carriage could be the result when using a tactical mobility system compared to the Soldier carrying the entire load.

Although tactical mobility systems could significantly reduce the physical burden on Soldiers from load carriage, limitations exist which may warrant further investigation in future developments. Tactical mobility systems require external power to operate, either through fuel or a battery, which may limit the duration of system's functional capability during missions. Refueling or recharging batteries requires additional resources and storage space that may otherwise be used to carry essential operational equipment. Additionally, there is some debate as to how well tactical mobility systems can operate over uneven terrain, which is a natural condition of any operational setting. Noise signature is an additional concern which must be considered for these systems. While new technology may be capable of addressing these limitations, further development and investigation is crucial to building tactical mobility systems for load carriage.

Because these are systems that Soldiers ride on or in, or that carry load for Soldiers (and therefore have a much less intimate interaction with the Soldier), a highly thorough review of this technology is beyond the scope of this panel, and examples of these systems are omitted.

5.3.4 Energy Harvesting Technologies

Battery mass makes up a substantial portion of load carried by today's Warfighters (~20 lbs. for 72-hour mission). Energy harvesting technologies offer a potential strategy to eliminate a portion of this load from the Soldier be providing a continuous source of power. These technologies convert human movement into electrical power which can be stored in a rechargeable battery for later use. Early work in this area focused on harvesting energy from in-shoe devices, however, energy returns were minimal (on order of milliwatts) [59] and likely insufficient for most Soldier applications. More recently, energy harvesting devices that span joints or are in the form of oscillating masses (e.g., backpacks) have been found capable of generating 5 to 7 watts of electricity during walking [60], [61] Even greater values may be achievable depending on system design (e.g., greater energy return from heavier oscillating mass).

Energy harvesting backpacks and knee braces are currently being developed specifically for dismounted Soldier applications. While prototypes show promise in terms of energy harvesting capabilities, further research and development is needed to understand the impact of these technologies on the Soldier and optimize their design for operational use. Factors such as the oscillation frequency of the backpack or stiffness of the knee brace could have significant effects on metabolic cost and muscular demands of the individual wearing the energy harvesting system. Trade-offs between energy harvesting system mass, power generation capabilities and required battery power will also need to be made during mission planning to determine whether use of the energy harvester is advantageous over simply carrying the required number of batteries.

Example of current energy harvesting devices are provided in the figures below.

Energy Harvesting Backpack/Rucksack
(Lightning Packs)



Form factor: Backpack or rucksack attached to sled which oscillates relative to a body-mounted frame during walking and running, mechanical energy

Benefits: Multiple pack options (US assault pack, medium and large MOLLE rucksacks), potential to reduce carried battery mass, oscillating mass may reduce felt load burden and assist mobility

Limitations: System mass, effect of system motion on human dynamics and metabolic cost not well understood, performance in operational setting unknown

TRL: 5-6

References:
http://www.lightningpacks.com/lightningpacks.com/Products_%7C_Lightning_Packs,_LLC.html

Figure 5-31: Energy Harvesting Backpack/Rucksack (Lightning Packs).

PowerWalkTM Kinetic Energy Harvester
(Bionic Power)



Form factor: Lower extremity anthropomorphic mechanical structure with gearbox at knee to convert joint rotation into electrical power

Benefits: Light mass, reported high energy return (10 – 12 W), active braking reduces fatigue during downhill walking, does not interfere with knee range of motion during tasks such as squatting

Limitations: Effect of system behavior on human dynamics and metabolic cost not well understood, performance in operational setting unknown

TRL: 4-5

References: http://www.bionic-power.com

Figure 5-32: PowerWalk™ Kinetic Energy Harvester (Bionic Power).

5.3.5 Load Mitigation Systems Summary

Tactical load burden has operational implications on the dismounted Soldier. Redistributing load via mechanical systems or utilizing alternative off-loading mechanisms are the current solutions to this recurring issue. Although progress in the field has made successful strides in addressing this problem, future development is still warranted to overcome the consistent physical burden and reduced combat effectiveness of load carriage. A variety of approaches to mitigating physical effects of Soldier burden are currently available, each with their own benefits and limitations (Table 5-2) of load mitigation approaches during dismounted operations will likely also depend on mission requirements (e.g., duration, terrain, required equipment).

Anthropometric assistive devices, load redistribution systems, or energy harvesting systems are likely the best option for applications in which mobility is of greatest importance and utilization of off-body load transfer are not feasible (e.g., terrain inaccessible by vehicle/robot). Each of these approaches have the potential to reduce the physical strain associated with load-carrying during dismounted task performance in a completely self-contained manner. Anthropometric assistive devices, particularly those which incorporate active actuation, would likely provide superior assistance overload redistribution systems and energy harvesting systems in support and movement of the carried load. However, in environments with complex terrain or situations where high mobility and agility are required, there is a risk that such systems could impede rather than aid Soldier mobility if the embedded control strategies are not able to account for or adapt accordingly. In these cases, passive load-bearing anthropometric assistive devices or load redistribution systems might be a better option. While the amount of assistance provided to the wearer may be less than that of active systems, passive approaches tend to be less complex and lighter mass in design with the additional advantage of not requiring a power supply to function. Like active anthropometric assistive devices, energy harvesting technologies may provide some benefit to the user in terms of metabolic cost and physical strain while reducing the overall carried

mass by eliminating the need for spare batteries. With respect to all of these body-worn technologies, however, further research and development are required to understand their impact on human dynamics and physiological demand, particularly during the performance of non-gait tasks in operational environments. Anthropometric assistive devices and energy harvesting technologies will likely not reach sufficient maturity for operational implementation until several years from now. However, because of their simplicity and higher TRL, load redistribution systems are currently being integrated into soldier ensembles and information regarding their success if operational environments should be available in the near future.

Table 5-2: Summary of Load Mitigation System Categories.

	Anthropometric Assistive Devices	Load Redistribution Systems	Tactical Mobility Systems	Energy Harvesting Systems
Mechanism	Exoskeleton to provide joint assistance and reduce metabolic cost	Mechanical modifications of carrier systems to redirect load path	Vehicle and other remote-controlled systems to carry load	Use the movement of the user to move a generator to harvest and store electricity
TRL	2-3	7	varies	4-6
Benefits	• May reduce metabolic cost	• Load still easily accessible to user	• Removes majority of load from off of user	May offer solution for carrying multiple batteries
Limitations	• Limited objective data • Ruggedness of systems • Robustness of control systems • Additional mass from system	• Belt/hip discomfort • Objective data unclear • May impede Soldier outfitting requirements	• Requires external source of power (fuel, batteries) • Noisy • Limited irregular terrain capabilities	• Changes user's movement and results in increased metabolic cost • Does not yet provide enough power to offset mass of system
Notes	More research is needed to optimize these systems for Soldier use	The effect of redistributing load is still being investigated		

Tactical mobility systems represent a distinctly different approach to reducing physical burden in that they serve as a platform to which Soldier equipment can be off-loaded versus mitigating effects of the load being carried by the Soldier. These systems may be best employed in situations where Soldiers must travel on foot but there is no need to have all of their equipment readily available (e.g., low threat environment). By transferring the bulk of carried load to a tactical mobility system, physical strain on the Soldier can be drastically reduced compared to what can be achieved by wearable load mitigation approaches. This might translate to improved mobility performance (e.g., higher rate of march) as well as reducing musculoskeletal injury risk and fatigue.

5.4 LOAD DECISION AIDS

As an alternative to physical technological solutions for load mitigation, planning tools and digital applications can be used to as a means to mitigate physical burden effects on dismounted Soldiers during the mission planning process. By understanding the potential implications of load on operational outcomes within the context of personnel capabilities, terrain, environmental conditions, threat level and mission objectives it might be possible to develop a strategy which optimizes selection of required equipment and distribution of load among team members and other resources (e.g., vehicles, robots). Several such applications currently exist or are in development. However, the efficacy of these tools will be highly dependent on the quality of the performance data and models of load effects on which they are based. It is critical that recommendations provided by these tools be well validated before implementation for operational use. An example of a load decision aid being developed for the US Army is provided in Figure 5-33.

Ground Guidance®
(Primordial/Polaris)



Form factor: Software application incorporating maps (elevation, land cover, tactical) and algorithms (effects of speed, concealment, load, etc.) to support route planning

Benefits: Runs on Windows, Linux and Android platforms, can be integrated with existing military platforms (NETT Warrior, ATAK, etc.), accounts for multiple scenarios and constraints (speed, concealment, threat locations, inaccessible areas, etc.)

Limitations: Limited user tests conducted but no independent validation of tool or component algorithms

TRL: 9

References:
http://www.primordial.com/index.php/products/ground-guidance

Figure 5-33: Ground Guidance® (Primordial/Polaris).

5.5 CONCLUSION

This technology watch has presented four categories of technologies to mitigate load burden for dismounted Warfighters: cooling systems, load mitigation systems, training devices and load decision aids. These approaches provide opportunities to reduce thermal burden, musculoskeletal strain, fatigue, and physiological and cognitive deficits associated with carrying heavy loads during dismounted operations. While many of these approaches show great promise, additional research and development are needed to fully understand and address human factors, biomechanical, physiologic and performance issues associated with their application to dismounted Soldier task performance in operational environments.

Given the broad range of technologies available and rapid rate at which systems are being developed and matured it is critical that government researchers work together to evaluate performance of existing and emerging systems in the context of dismounted operations. The results of these evaluations should be shared with the broader community, including other government agencies, academic and industry partners interested in or actively developing load mitigation technologies. In doing so, we can accelerate the rate at which these technologies can be placed in the hands of Soldiers and improve the overall efficacy of fielded technologies.

It should also be noted that the technologies discussed here are representative of the state-of-the-art at the time of writing but alternative approaches to load burden mitigation may emerge with technological advances and changes in operational requirements. This technology watch will need to be updated periodically to reflect these additional developments as well as improvements in the technologies presented here.

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Chapter 6 – FRAMEWORK FOR BURDEN REDUCTION

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6.1 BACKGROUND

Utilizing a common risk management framework illustrated in Figure 6-1. Work Package 1 established the context by discussing the extent of the enduring load burden problem. Work Package 2 then identified, analysed, and evaluated the key factors influencing soldier burden. Work Package 3 discussed potential technological solutions or treatment options to mitigate load burden which could range from avoiding, treating (reduce likelihood or consequence), transferring/sharing and or accepting the risk. The purpose of this work package was to develop a framework for burden reduction that has the potential to achieve a systematic and positive impact, based on the outcomes and insights identified in earlier chapters of this report.

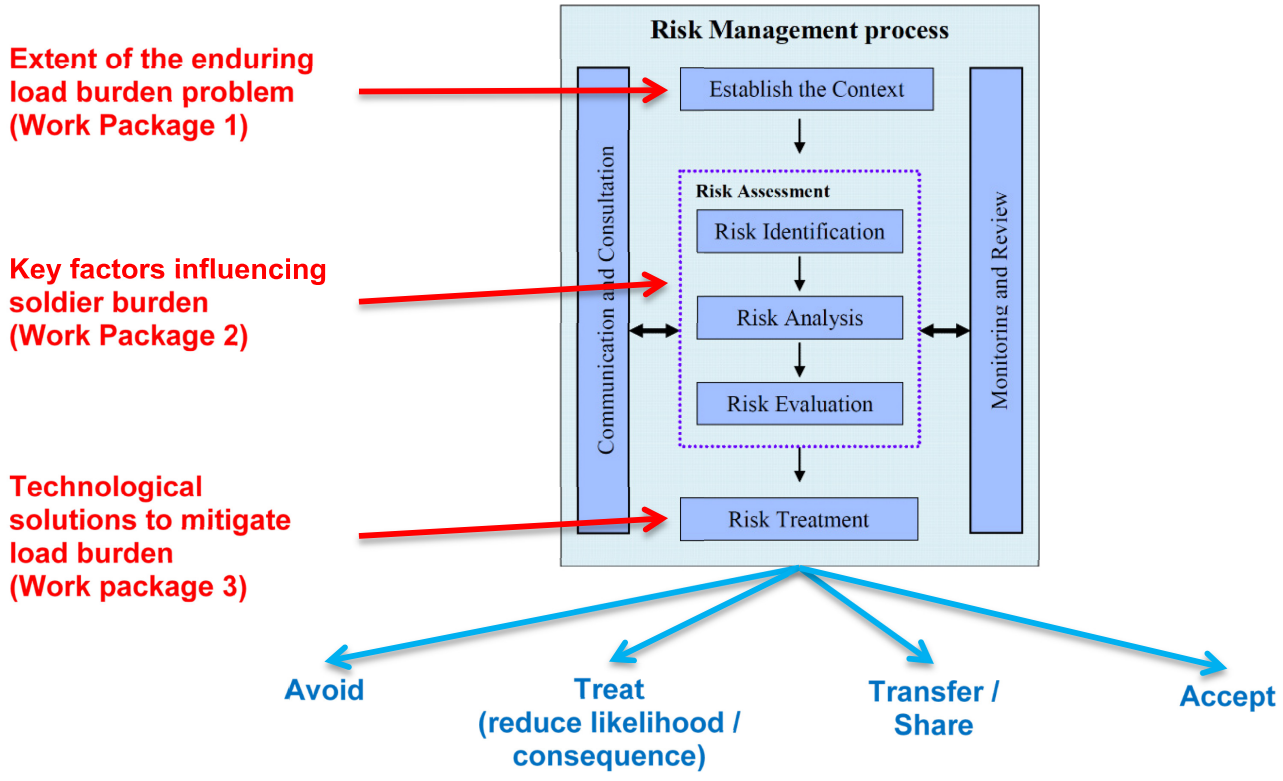


Figure 6-1: Common Risk Management Framework.

6.2 INTRODUCTION

Well intended burden reduction treatments or interventions continue to be implemented in isolation (i.e., a point solution at a tactical level) across and within many militaries. However, soldier burden remains an enduring problem. It is the belief of this panel that the problem of load burden does not stem from a lack of suitable treatment options. Rather, the problem relates to how the treatment options are implemented or transitioned into service in order to achieve systematic and sustainable change and ensuring the treatments act in concert to achieve marginal gains (or small positive improvement) through a range of concurrent treatment options (i.e., avoid + treat + transfer/share).

In order to address these issues this Chapter provides a framework whereby; the challenge of burden reduction is addressed using a systems level approach. This considers the full soldier lifecycle (strategic preparedness, pre-deployment, during deployment, post-deployment); at the strategic, operational and tactical level (levels of control or spheres of influence); and across all capability areas (doctrine, organization, training, materiel, leadership and education, personnel, facilities, interoperability, policy).

Table 6-1 illustrates the broad three-dimension structure of the burden reduction framework. At different stages of the soldier lifecycle there are different accountabilities and responsibilities and thereby control or influence on the challenge of soldier physical burden. In this particular context, the strategic level has most control or influence at the strategic preparedness and post-deployment stages of the soldier lifecycle. Similarly, the operational and tactical levels have limited scope at the post-deployment stage of the soldier lifecycle. The critical requirement for achieving a systematic and sustainable change is to ensure there are built in mutual dependencies and feedback loops across the soldier lifecycle and strategic, operational and tactical levels (Figure 6-2).

Table 6-1: Structure for the Burden Reduction Framework.

<table>
<tr><td colspan="2"></td><td colspan="3">(2) Levels of Control or Spheres of Influence</td></tr>
<tr><td colspan="2"></td><td>Strategic Level (Campaign)</td><td>Operational Level (Battle Group)</td><td>Tactical level (Company Through to Squad/Section)</td></tr>
<tr><td rowspan="4">(1) Full Soldier Lifecycle</td><td>Strategic Preparedness</td><td colspan="3" rowspan="4">(3) Across all Capability Areas (DOTMLPFIP)
• Doctrine – the way we fight
• Organization – how we organize to fight
• Training – how we prepare to fight
• Materiel – equipping the force to operate effectively
• Leadership and education – how we prepare leaders to lead the fight (strategic, operational, and tactical level)
• Personnel – individuals and teams who can safely and effectively perform required tasks and roles
• Facilities – installations that support the force
• Interoperability – ability to be interoperable with other forces
• Policy – policy that impacts the above 8 elements</td></tr>
<tr><td>Pre-Deployment (Mission-Specific Preparedness)</td></tr>
<tr><td>During Deployment (Pre/During/Post-Mission)</td></tr>
<tr><td>Post-Deployment (Recovery and Reconstitution)</td></tr>
</table>

If actions or interventions are taken that achieve marginal gains (or small positive improvements) across all levels of influence (Dimension 2), throughout the soldier lifecycle (Dimension 1) and within the DOTMLPFIP framework (Dimension 3), then there is the potential to achieve a compound positive effect on reducing soldier burden. Further, taking a systems level view ensures that there is a coherent approach where treatments are mutually dependent (i.e., in some instances a strategic level treatment or intervention is required to support a tactical treatment or intervention).

The outcomes and recommendations documented in previous work packages have been integrated and exploited to provide a practical guide on how a system level approach can be taken to reduce burden. The framework for burden reduction is not intended to be prescriptive, but rather provide a guide for addressing the problem that can be customized to the specific national context.



Figure 6-2: Feedback Loop Across the Soldier Lifecycle and Strategic, Operational and Tactical Levels.

6.3 STAGES OF THE SOLDIER LIFECYCLE (DIMENSION 1)

Control of influence at the strategic, operational, or tactical levels can be executed at multiple stages throughout the soldier lifecycle. The soldier lifecycle includes the following key stages:

- Strategic preparedness: basic training, initial training, and continuous employment.
- Pre-deployment (mission-specific preparedness): from first notification of deployment until deployment occurs.

- During deployment (sustainment): from departure until demobilization.
  - Pre-mission: immediately prior to conducting a mission.
  - During mission: whilst conducting a mission.
  - Post-mission: immediately after returning from a mission.
- Post-deployment (recovery and reconstitution): from arrival at home station to 180 days after arrival.

It should be noted that the periods in a soldiers' lifespan prior to entry and upon retirement have not been considered here. This does not denote the reduced importance of these areas. Rather, they are simply outside the strategic, operational, and tactical level controls or spans of influence.

6.4 STRATEGIC, OPERATIONAL AND TACTICAL LEVELS (DIMENSION 2)

Control or spheres of influence can be defined as belonging to a certain level based upon the effect or contribution to achieving strategic, operational, or tactical objectives. Based on accountabilities and responsibilities of personnel serving at the three different levels, there are a range of available burden reduction actions or interventions that could be implemented.

6.4.1 Strategic Level (Campaign)

The strategic construct essentially sees the bigger picture (e.g., including 'cost' in terms of casualties and affordability) where the politicians and the most senior commanders may consider criteria for 'acceptable campaign outcomes' to highlight the 'balance of risk' to achieving their desired outcome. As such, senior commanders can use such information to devote time to design possible actions or interventions.

- Who has control/influence: politicians and highest military commanders?
- How do they exercise control/influence: government intent and policies and frameworks for conducting operations?
- When and where do they exercise control influence: primarily at the strategic preparedness and post-deployment stages of the soldier lifecycle?

6.4.2 Operational Level (Battle Group)

The operational construct develops plans (or priorities) that may best achieve the desired strategic outcome within the boundaries of the strategic resources.

- Who has control/influence: theatre and sub-theatre commanders?
- How do they exercise control/influence: deployment of forces, their commitment to or withdrawal from battle, and the arrangement of battles and major operations to achieve operational and strategic objectives?
- When and where do they exercise control influence: at various key stages in the soldier lifecycle including pre-deployment, during deployment, pre-mission, during mission and post-mission?

6.4.3 Tactical Level (Company Through to Squad/Section)

The tactical construct develops plans (or priorities) that may best achieve the desired operational outcome within the boundaries of the operational resources.

- Who has control/influence: sub-theatre commanders down to individual soldiers?
- How do they exercise control/influence: local direction and control of movements or manoeuvres to accomplish the mission?
- When and where do they exercise control influence: at various key stages in soldier lifecycle including pre-mission, during mission and post-mission?

6.5 DOTMLPFIP FRAMEWORK (DIMENSION 3)

The DOTMLPFIP framework is a valuable tool to match capabilities to solutions. It provides a framework to consider all aspects of a problem and to identify necessary actions. The DOTMLPFIP framework is detailed below inclusive of framing questions to assist in identifying solutions. It is important to recognize that there is some degree of overlap between the capability areas. This is intentional as it serves to ensure a systems level, mutually dependent approach to the problem.

- **Doctrine:** the way they fight, e.g., emphasizing manoeuvre warfare and combined air-ground campaigns.
  - Is there existing doctrine that addresses or relates to the issue of dismounted soldier overburden? Joint? Service? Agency?
  - Is the doctrine relevant, up to date, informed by lessons learnt and readily implementable?
  - Are there operating procedures in place that are not being followed which could, at least in part, reduce dismounted soldier burden or lessen its impact?
  - If no doctrine or procedures are in place which pertain to dismounted soldier overburden, does new doctrine or do new procedures need to be developed and implemented which provide either a complete or partial solution to the issue of dismounted soldier overburden?
- **Organization:** how they organize to fight, e.g., divisions, air wings.
  - Where is the issue of dismounted soldier overburden occurring? What organizations is the issue of dismounted soldier overburden occurring in?
  - What is the mission / management focus of those organizations?
  - Is logistics support fully trusted?
  - What are the organizational values and priorities (primary and secondary missions)?
  - Is the organization properly staffed and funded to deal with the issue of dismounted soldier overburden (cost considerations)?
  - Are commanding officers / senior management aware of the issue of dismounted soldier overburden?
  - Is the issue of dismounted soldier overburden already in some type of organizational issue list? If so, why isn't the issue being resolved?
  - Who exactly is aware of / impacted by dismounted soldier overburden?
- **Training:** how they prepare to fight tactically, e.g., basic training to advanced individual training, various types of unit training.
  - Is dismounted soldier overburden caused, at least in part, by a complete lack of or inadequate training?

- Does training exist which addresses the issue of dismounted soldier overburden?
- Is the training evidence-based and delivered using best practice principles?
- Is the training being delivered effectively?
- Is the issue of dismounted soldier overburden caused by a lack of competency or proficiency on existing systems and equipment?
- Do personnel affected by dismounted soldier overburden have access to training? Is training properly staffed and funded?

- **Materiel:** all the "stuff" necessary to equip the forces so they can operate effectively, e.g., weapons, spares.
  - Is the issue of dismounted soldier overburden caused, at least in part, by inadequate systems or equipment?
  - What current systems are in the family-of-systems where issue of dismounted soldier overburden is occurring?
  - What functionality would a new system provide that currently does not exist?
  - Is the issue of dismounted soldier overburden caused by a lack of competency or proficiency on existing systems and equipment?
  - Who would be the primary and secondary users of the proposed systems or equipment?
  - Is there an appropriate roadmap for future acquisitions that take advantage of enabling/emerging technologies?
- **Leadership and education:** how they prepare their leaders to lead the fight from squad leader to 4-star general/admiral, e.g., professional development.
  - Is the issue of dismounted soldier overburden caused, at least in part, by inability or decreased ability to cooperate/coordinate/communicate with external organizations?
  - Do the senior officers understand the scope of the dismounted soldier overburden problem?
  - Does command have resources at its disposal to correct the issue of dismounted soldier overburden?
  - Is leadership being trained on effective change management principles?
  - Has command properly assessed the level of criticality, threat, urgency, and operational risk of dismounted soldier overburden?
  - Is senior leadership aware of the drivers and barriers to resolving the issue of dismounted soldier overburden within her/his own organization?
- **Personnel:** availability of qualified people for peacetime, wartime, and various contingency operations (applies to primary users, maintenance personnel, and support personnel).
  - Is the issue of dismounted soldier overburden caused, at least in part, by inability or decreased ability to place qualified and trained personnel in occupational specialties?
  - If the resolution of dismounted soldier overburden is likely to involve new material, systems, or equipment, are different occupational specialty codes needed to properly staff new systems?
  - Do new training programs need to be developed for newly recruited personnel?

  - Are there specific standards that require consideration (e.g., medical acceptance criteria, National Institute for Occupational Safety and Health standards)?
- **Facilities:** real property; installations and industrial facilities that support the forces, *e.g.*, government owned ammunition production facilities, health, and fitness facilities.
  - Is the issue of dismounted soldier overburden caused, at least in part, by inadequate infrastructure?
  - If so, was the issue of dismounted soldier overburden a result of aging / wear? New engineering didn't meet needs? Battle damage/threat?
  - Was the issue of dismounted soldier overburden caused by lack of proper environmental controls?
  - Is the issue of dismounted soldier overburden caused, at least in part, by inadequate – roads/trails? – Main supply routes? – Force bed-down? – Facilities operation and maintenance? Hardening? Field fortification support?
- **Interoperability:** the ability to be interoperable with forces throughout the NATO alliance.
  - Does the issue of dismounted soldier overburden effect Joint and multi-national operations (e.g., demographic differences between nations)?
- **Policy:** interagency, national government, or international policy that impacts the other eight elements.
  - Are there specific political mandates that require considered when addressing the issue of dismounted soldier overburden (e.g., gender integration)?
  - Are there specific risk tolerance issues that require considered when addressing the issue of dismounted soldier overburden (e.g., combat casualties)?

6.6 FRAMEWORK FOR BURDEN REDUCTION IN ACTION

The entire range of potential treatment options for burden reduction cannot be explored here. As such, the panel has selected three examples that:

1) Appear to have high potential payoff, from the limited knowledge base available in the literature;
2) Illustrate the importance of considering opportunities (and negative impacts) across the full range of DOTMLPFIP; and
3) Can be addressed meaningfully in the near, or mid-term (within 5 years, 5 – 10 years, respectively).

The individual examples are detailed below along with a final summary that seeks to bring the treatments together as an integrated solution. These examples are by no means exhaustive, rather, the purpose is to demonstrate the framework in action.

- **Near-Term –** burden reduction through the provision of and appropriate use of modular, scalable body armour systems (Table 6-2) – the first step at the strategic level is to ensure that procurements appropriately balance protection, performance and adaptability for the intended operational environments and integration with other in-service equipment (trade-space for protection versus integrated survivability). At the operational level it is critical that personnel are fitted appropriately, educated on proper use and afforded time to adapt to wearing the system during pre-deployment training. Once deployed, it is important that mission planning identifies essential load lists, considers environmental factors, and manages equipment carried as well as ensuring equipment is optimally packed and distributed across shoulders and hips. Opportunities for re-supply should be identified to reduce load carriage requirements and commanders should be empowered with tools and discretion to adapt equipment to the mission (and reduce protection to afford greater performance if appropriate).

- **Mid-Term –** burden reduction through the transition into service of a passive (unpowered) exoskeleton (Table 6-3) – the first step at the strategic level is to ensure a rigorous, evidenced-based evaluation of the exoskeleton is undertaken to establish efficacy and identify any potential unintended consequences. At the operational level it is important to consider how the device integrates with other equipment and platforms and that targeted use-case(s) have been identified. At the tactical level, individuals and small teams must be afforded opportunities to train in the device and gain experience in various use-cases. Before deployment, logistics and sustainment plans must be developed as well as considering the evacuation strategy for the device if it were to become inoperable. During deployment, regular assessments are required to identify any negative effects of utilizing the device (task compatibility issues or physical issues such as pain, soreness and discomfort which has not previously been identified). An operational review should be completed post-deployment to optimize the devices use in future operations.
- **Near-Term –** burden reduction through the optimization of personnel physical and physiological readiness (Table 6-4) – the first step at the strategic level is to establish evidenced-based recruiting and employment standards that apply to all personnel regardless of age, sex or rank; provide the systems and structures for physical conditioning of personnel. At the operational level, personnel should be educated on behaviours that facilitate optimal health and fitness and at the tactical level it is important to ensure personnel are at a level of physical conditioning that is readily scalable to any operation/mission. During pre-deployment training personnel should be progressively conditioned to the likely demand of mission to be undertaken in the operational environment. At an operational level during deployment, personnel should be allowed adequate rest and recovery between missions and surveillance systems should be employed to monitor health and wellbeing. At a tactical level during deployment it is important to ensure personnel are well nourished and hydrated prior to undertaking missions and that frequent rest breaks and opportunities to replenish fluids and fuel stores are provided during the mission. Post-mission it is important to expedite recovery through fluid replacement and nutritional support and monitor fatigue levels and injury state. Finally, at the post-deployment stage operational physical and physiological readiness reviews should be undertaken to optimize the readiness of future deployments.
- Concurrent treatment options implemented in a systematic and sustainable manner (Figure 6-3) – successfully implementing the three treatment options presented in Table 6-2, Table 6-3 and Table 6-4 has the potential to achieve a substantive reduction in soldier burden.

6.7 CONCLUSION

There are many treatment options available or actively being developed today and more will become available as technology continues to advance. However, these treatments or interventions continue to be implemented in isolation (i.e., a point solution at a tactical level) across and within many militaries without achieving a substantive positive impact on soldier burden. Is it the belief of HFM 238 that until a systems level approach, as recommended herein, is implemented, physical burden will remain an enduring problem for dismounted soldiers'? A three dimensional framework has been provided herein to help facilitate the successful implementation and transition into service of concurrent treatment options (avoid + treat + transfer/share) which has the potential to achieve systematic and sustainable change through a compound reduction in soldier burden.

Table 6-2: Burden Reduction Through the Provision of and Appropriate Use of Modular, Scalable Body Armour Systems.

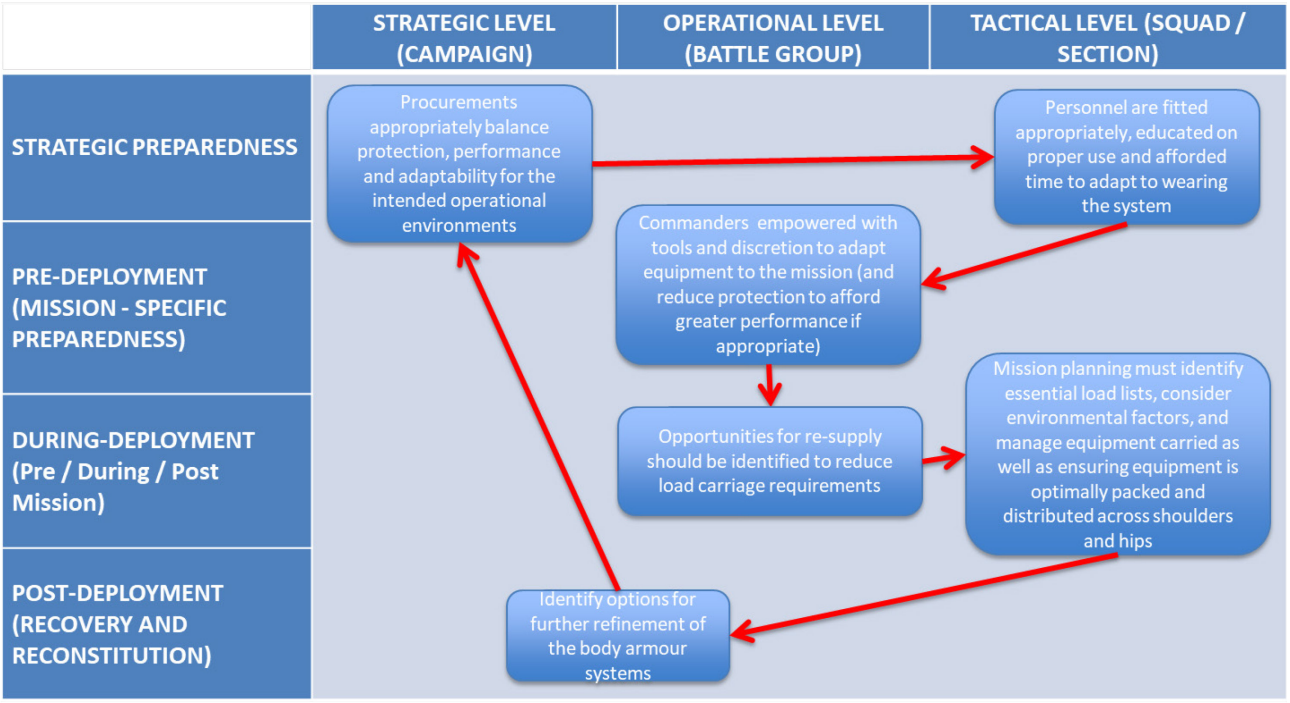


Table 6-3: Burden Reduction Through the Transition into Service of a Passive (Unpowered) Exoskeleton.

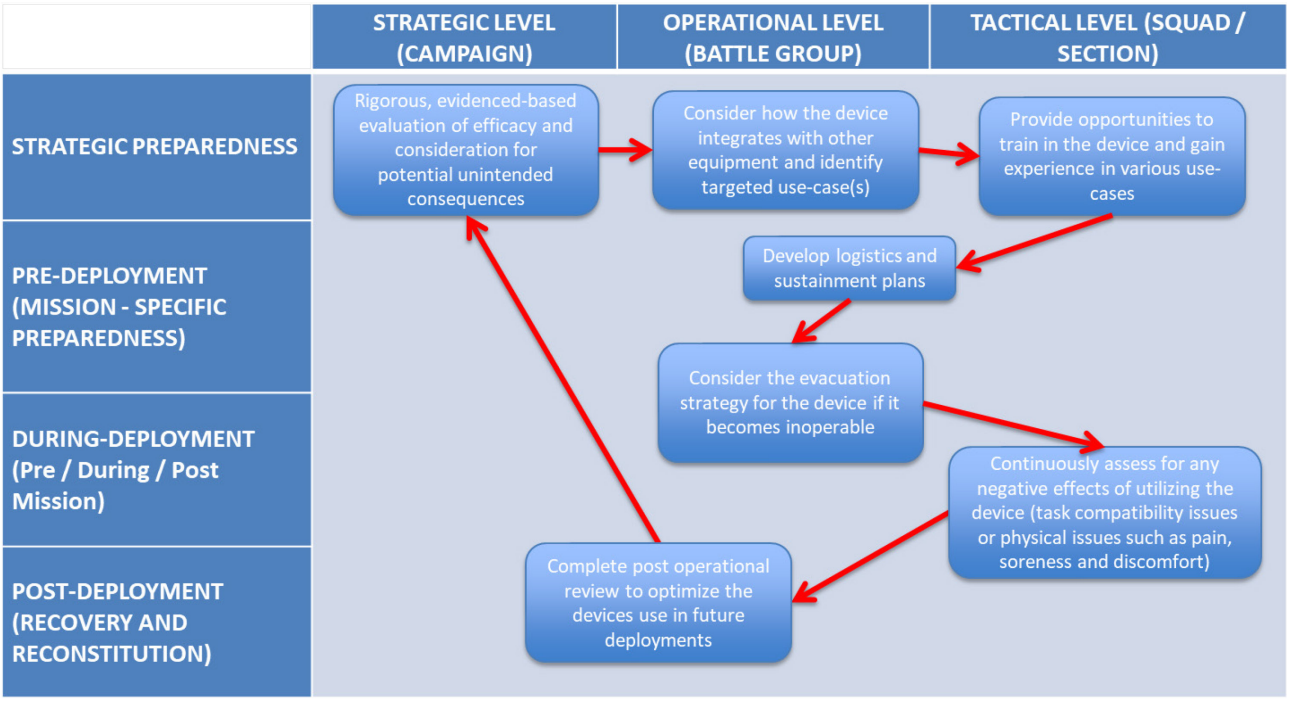


Table 6-4: Burden Reduction Through the Optimization of Personnel Physical and Physiological Readiness.

	STRATEGIC LEVEL (CAMPAIGN)	OPERATIONAL LEVEL (BATTLE GROUP)	TACTICAL LEVEL (SQUAD / SECTION)
STRATEGIC PREPAREDNESS	Establish evidenced-based recruiting and employment standards that apply to all personnel regardless of age, gender or rank; provide the systems and structures for physical conditioning of personnel	Educate personnel on behaviors that facilitate optimal health and fitness	Ensure personnel are at a level of physical conditioning that is readily scalable to any operation / mission
PRE-DEPLOYMENT (MISSION - SPECIFIC PREPAREDNESS)		Progressively condition personnel to likely operational load carriage requirements and environmental conditions	
DURING-DEPLOYMENT (Pre / During / Post Mission)		Allow adequate rest and recovery between missions and employ surveillance systems to monitor personnel	Ensure personnel are well nourished and hydrated prior to undertaking missions Take frequent rest breaks and ensure regular intake of fluids and fuel and be mindful that individuals within the team will respond differently
POST-DEPLOYMENT (RECOVERY AND RECONSTITUTION)	Complete post operational physical and physiological readiness review to optimize the readiness of future deployments	Expedite recovery through fluid replacement and nutritional support; monitor fatigue levels and injury state	

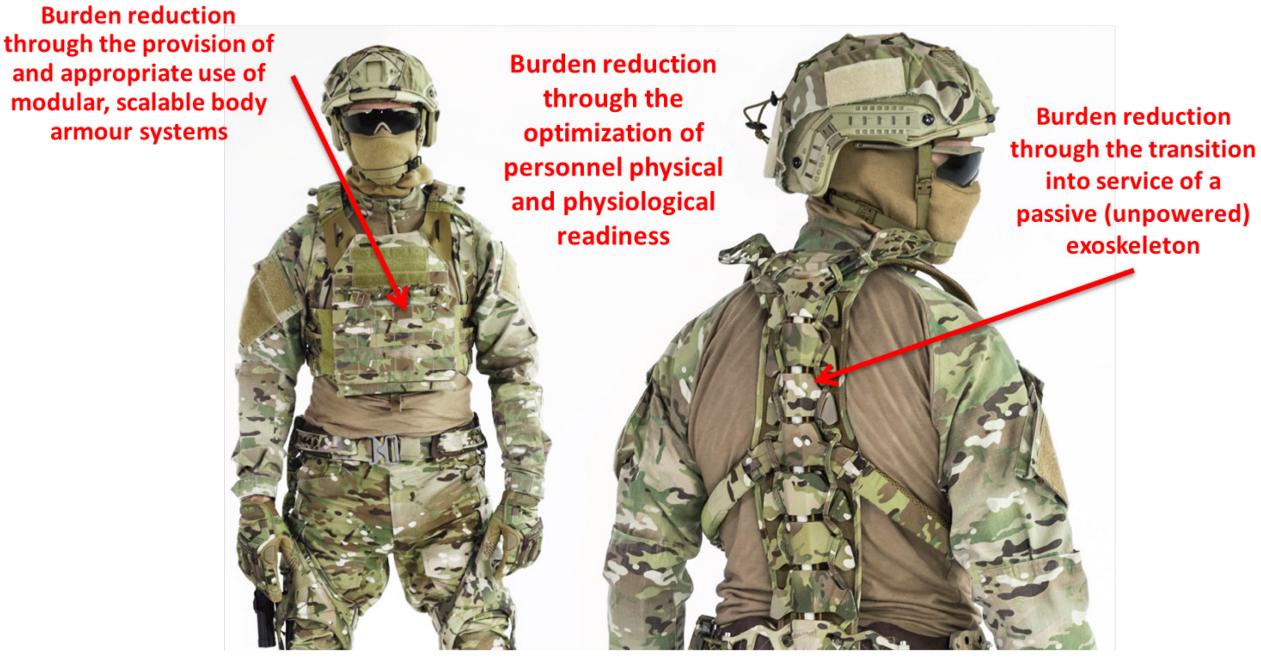


Figure 6-3: Concurrent Treatment Options Implemented in a Systematic and Sustainable Manner.

Chapter 7 – CONCLUSIONS AND RECOMMENDATIONS

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The aim of NATO Human Factors and Medicine (HFM) Research Task Group (RTG) 238 "Reducing the Burden on the Dismounted Soldier" was to establish a more coherent and co-ordinated approach to address the problem of soldier burden. This was achieved through four work packages designed to:

1) Define the burden;
2) Identify those factors known to influence the size and nature of the burden; and
3) Identify strategies to mitigate the threats in order to maintain operational effectiveness.

A scenario-based approach was used to define the scope and focus of the task. Three scenarios were developed and defined in collaboration with Land Capability Group Dismounted Soldier Systems (LCG DSS) in order to frame the context within which the problem was addressed. These scenarios differed in length, climatic conditions, threat, and task (Chapter 2).

The data collection exercise conducted under Work Package 1 highlighted distinct differences in the design and composition of the soldier systems used by the NATO nations. Furthermore, differences between the nations were also evident in the specific equipment selected by the soldiers for each scenario. It is unclear if this is a reflection on the methodology used, soldier demographics or interpretation of the scenarios by the investigators/soldiers. Despite these differences, the "Protection Systems" and "Weapon Systems" categories represented the greatest contribution to the overall load carried by each group. Recommendations for reducing the mass and modifying the make-up of these particular equipment categories have been provided within Chapter 3. The interventions suggested include new materials, technological solutions, training requirements, logistics and behavioural adaptations.

Differences in the equipment carried between the scenarios were analysed for each nation. In general, minimal adaptation was observed despite differences in threat, environmental conditions, and mission characteristics. For example, some nations maintained the same level of protection despite a change in threat level. The inability/unwillingness of commanders to adapt to mission characteristics presents a significant challenge to reducing soldier burden. Possible mitigations for this have been recommended within Chapter 3, which include examples of where further education, training, reward, technologies, and further research could be applied.

Current doctrinal guidance which provides recommendations for load limits are based on body mass. The data from Work Package 1 indicates that the loads carried in each of the scenarios ranged from 144% to 276% of these doctrinal load limits. Whilst body mass based guidelines are simple to implement, they are not transferable to the military environment. Therefore, it is recommended that more appropriate tools for determining load limits are developed for the dismounted soldier, which take into account the specific characteristics and requirements of the military setting.

Strategies to reduce the impact of load carriage on soldier performance can target the user, equipment, environment, or task. To inform the development and implementation of burden mitigation strategies, systematic reviews were undertaken (Chapter 4) to consolidate existing literature on how the personal characteristics of

the soldier and the equipment affect performance within the context of the developed scenarios. Given the characteristics of the scenarios, particular emphasis was placed on the administrative advance and hot environments.

Review of the personal characteristics that affect an administrative advance confirms that there are modifiable and non-modifiable characteristics of the soldier that make them less susceptible to the detrimental effects of carrying load. The available evidence suggests that these characteristics are related to anthropometrics and fitness status. With regard to the load carriage equipment characteristics that affect mobility and load carriage capacity, previous research intuitively indicates that load mass, stiffness, and bulk lead to a progressively negative effect on the soldier performance (including high intensity tasks, road marching and agility/mobility). Such decrements to performance may ultimately increase vulnerability to enemy action and the risk of injury during training and operations.

Further research was recommended into the broader socioecological factors that are associated with injury risk, the physical capabilities required for high intensity load carriage tasks and how to manage the effects induced by an administrative advance on subsequent tasks. Addressing these knowledge gaps and others identified in Chapter 4 will support understanding of what the ideal characteristics of the Soldier are.

Recommendations for reducing the risk of thermal injury during load carriage tasks have previously been reported elsewhere and are summarised in Section 4.5.5. Specifically, when wearing body armour, 2.8°C (5°F) should be added to WBGT index in humid climates and if wearing chemical/biological protective clothing 5.5°C (10°F) should be added to WBGT for light work, and 11°C (20°F) to WBGT for moderate and hard work. Guidance is also available on the maximum acceptable work duration that should be applied, which takes into account the environment, marching speed, duration, and mass carried. Considering that uncompensable heat can exist in certain situations, it is particularly important that this guidance is validated to prevent heat injury and loss of capability.

Despite the large body of load carriage research, it is often challenging to translate key findings to the military context and thus use available research to support military decision making. This is often the case where well designed laboratory studies are not representative of the operational / training environments, tasks, and military populations. Given the ever changing characteristics of the load carried, operating environment and increased inclusion of females in dismounted roles, research examining the effect of load on the soldier should continue. Specific evidence gaps have been highlighted throughout Chapter 4 and are summarised in Section 4.6.

A number of technological solutions have been identified in Chapter 5 to mitigate against the threat of physical burden on the soldier, so as to maintain operational effectiveness. These solutions have been tailored to reflect the demands of the developed scenarios and capture strategies for operations in hot environments, heavy load carriage and improved decision making. At the time of writing, several concepts have potential but are not sufficiently mature to be transitioned into service. However, due to the rapid rate at which these systems are being developed and matured it is recommended that government researchers work together to evaluate the performance of existing and emerging systems. In doing so, the efficacy and rate at which these technologies can be placed in the hands of soldiers can be accelerated. It is essential that any technology solution added to the soldier is appropriately and independently tested / developed for military use to establish efficacy. Furthermore, integration with other items of equipment should be considered a priority. The technology watch presented will need to be updated periodically to reflect additional developments as well as improvements in the technologies presented.

Several recommendations for reducing soldier burden have been discussed throughout this report, however, it is recognised that the implementation of such solutions is equally as important as the solution itself. Over the years,

a number of interventions have been introduced which target a specific stage of the deployment cycle and have been implemented in isolation (e.g., physical training programmes, improvements to equipment). As soldier burden spans many stakeholders, significant improvements can only be achieved by addressing this challenge at a systems level. The framework reported in Chapter 6 uses the DOTMPLF framework across all stages of the deployment cycle to shape potential solutions. Further the structure of this approach allows each nation to tailor solutions to meet their own specific needs and ways of working. It is recommended that future strategies to reduce soldier burden move away from a point solution approach and apply a systems approach to implementing burden mitigations. This will achieve a sustainable and progressive solution to soldier burden.

The work of HFM-238 has focussed on the physical aspects of soldier burden. It is recognised that carrying load also has an impact on cognition therefore understanding the risk this poses to the soldier should also be considered. It is recommended that a research task group be established to ensure that the threat of carrying heavy loads on soldier cognition is appropriately mitigated.



REPORT DOCUMENTATION PAGE

1. Recipient's Reference	2. Originator's References	3. Further Reference	4. Security Classification of Document
	STO-TR-HFM-238 AC/323(HFM-238)TP/950	ISBN 978-92-837-2274-8	PUBLIC RELEASE

5. Originator

Science and Technology Organization
North Atlantic Treaty Organization
BP 25, F-92201 Neuilly-sur-Seine Cedex, France

6. Title

Reducing the Burden on the Dismounted Soldier

7. Presented at/Sponsored by

Final Report of RTG HFM-238.

8. Author(s)/Editor(s)	9. Date
Multiple	March 2021
10. Author's/Editor's Address	**11. Pages**
Multiple	234

12. Distribution Statement

There are no restrictions on the distribution of this document. Information about the availability of this and other STO unclassified publications is given on the back cover.

13. Keywords/Descriptors

Burden mitigation; Burden reduction; Load carriage; Load mitigation; Operational effectiveness; Reducing soldier burden; Soldier burden; Technological solutions; Warfighter

14. Abstract

Throughout history, the dismounted soldier has been required to carry heavy loads. Soldiers often need to march long distances carrying loads over demanding terrain and in extreme environmental conditions. Once they arrive at the enemy's location, whilst soldiers can remove their packs and much of their sustainment load, they must still be fit to fight whilst wearing assault or fighting loads. Loads currently carried by NATO soldiers are at record highs and anecdotal evidence suggests that, on occasion and for some roles, current combat loads may be approaching the soldier's own body mass.

NATO Human Factors and Medicine (HFM) Research Task Group (RTG) 238 "Reducing the Burden on the Dismounted Soldier" was established to develop an international consensus on the best approach to address the systemic problem of soldier burden. The specific objectives of this RTG were to: Define the burden; Identify factors known to influence the size and nature of the burden; Identify strategies to mitigate the threats in order to maintain operational effectiveness; and Identify an exploitable strategy for burden reduction.

This report details the outcomes, findings and recommendations for strategies to mitigate soldier burden.



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ISBN 978-92-837-2274-8