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Load Carriage Capacity of the Dismounted Combatant - A Commander's Guide

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ABSTRACT

There is a universal requirement for military personnel to carry an external load. The load of military personnel is typically comprised of clothing, protective ensemble (i.e. body armour, helmet), combat equipment (i.e. webbing, weapon systems, ammunition, power sources, radio) and sustainment stores (i.e. food and water). In addition, military operations often requires dismounted personnel to move, on foot, through various climates and terrains for long and continuous periods. The total load varies dependant upon factors such as mission requirements and threat profile. Recent evidence suggests that the individual's load is increasing with advancing technologies and personal protective equipment. Excessive external load may adversely impact upon an individual's physical capability (e.g. mobility, lethality) and health (e.g. survivability, thermal burden). It is therefore important we consider (likely) individual load carriage capacity in mission planning. 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, gender, age, injury profile, load carriage experience), 2) task characteristics (e.g. total external load, distribution of load, load carriage equipment design, movement speed, march duration, work to rest ratio) and 3) environment (e.g. terrain, heat, humidity, altitude) in which the task is performed. Some of these factors may in some situations be controlled (e.g. marching speed) whilst others are not (e.g. ambient temperature). There is a dynamic interaction between these factors which ultimately impact on an individual's load carriage capacity. When undertaking mission planning it is important for commanders to consider the factors influencing load carriage capacity and identify the likely burden. *Abstract cont'd over the page*

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Such information will guide amongst other things, duration of operations, work to rest schedules, total load limits, replenishment and logistical support requirements. This planning is critical to the maintenance of dismounted personnel's operational effectiveness, battlefield performance and ultimately mission success. This document reviews existing scientific literature and established work physiology models for the development of evidence-based load carriage guidelines. These guidelines will place emphasis upon critical task elements and human factors with the intent of assisting commanders' in making decisions about tasks involving load carriage. It is important to understand however that load carriage guidelines are not definitive nor can they be generically applied to all load carriage scenarios, rather they establish general principles to assist the commander in mission planning. Furthermore setting maximum absolute load limits or maximum intensity limits may be difficult to implement in the field and may not always be operationally possible. It is understood that mission requirements, operational constraints and threat profile dictate load carriage requirements. However mission planning needs to balance, to some degree, the requirements of the operational environment against the various physical considerations of personnel load carriage ability. Therefore, mission planners and commanders alike need to understand the impact of various load carriage variables on an individual's load carriage capacity and operational effectiveness.

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Load Carriage Capacity of the Dismounted Combatant - A Commander's Guide

Executive Summary

There is a universal requirement for military personnel to be capable of moving their body mass plus an external load. The load carried by military personnel is typically comprised of clothing, protective ensemble (i.e. body armour, helmet), combat equipment (i.e. webbing, weapon systems, ammunition, power sources, radio) and sustainment stores (i.e. food and water). In addition, the diversity and complexity of military operations often requires dismounted personnel to carry mission-specific equipment and move, on foot, through various climates and terrains for long and continuous periods.

The total load varies dependent upon factors such as mission requirements and threat profile. While the equipment carried is often crucial for mission success and survival, there are numerous examples through history demonstrating the adverse effect of heavy load carriage on soldier performance and operational success. Recent evidence suggests that the individual's load is increasing with advancing technologies and personal protective equipment. During current operations in Afghanistan anecdotal reports suggest that 50 kg is a common load carried by dismounted personnel whilst patrolling. Excessive external load may adversely impact upon an individual's physical capability (e.g. mobility, lethality) and health (e.g. survivability, thermal burden). It is therefore important we learn the lessons of the past and duly consider load carriage in mission planning involving dismounted personnel.

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, gender, age, injury profile, load carriage experience), 2) task characteristics (e.g. total external load, distribution of load, load carriage equipment design, movement speed, march duration, work to rest ratio) and 3) environment (e.g. terrain, heat, humidity, altitude) in which the task is performed. Some of these factors may in some situations be controlled (e.g. marching speed) whilst others are not (e.g. ambient temperature). There is a dynamic interaction between these factors which ultimately impact on an individual's load carriage capacity. When undertaking mission planning it is important for commanders to consider the factors influencing load carriage capacity and identify the likely burden. Such information will guide amongst other things, duration of operations, work to rest schedules, total load limits, replenishment

and logistical support requirements. This planning is critical to the maintenance of dismounted personnel's operational effectiveness, battlefield performance and ultimately mission success.

The purpose of this document is to review existing scientific literature and established work physiology models for the development of evidence-based load carriage guidelines. These guidelines will place emphasis upon critical task elements and human factors with the intent of assisting commanders' in making decisions about tasks involving load carriage. It is important to understand however that load carriage guidelines are not definitive nor can they be generically applied to all load carriage scenarios, rather they establish general principles to assist the commander in mission planning.

An established predictive model has been used throughout this document to predict the physiological burden (i.e. energy cost) of representative load carriage scenarios. As a general guide this model indicates that a 10 kg increase in external load is metabolically equivalent (i.e. energy cost) to an increase in walking speed of 0.5 km/hr or a change in terrain gradient from level to 1%. An additional model provides commanders with guidance as to how long a continuous load carriage task can likely be sustained. As an example, it predicts that an average soldier can carry 40 kg at 5.5 km/hr over hard flat terrain for approximately 14 km. If that external load is increased to 50 kg the distance decreases to 9 km. If the walking speed is increased to 6.5 km/hr (from 5.5 km/hr) the likely distance the task can be sustained for decreases to approximately 6 km. This guidance highlights that total external load may at times be over-emphasised, to the detriment of other important factors e.g. walking speed. Commanders and mission planners therefore need to consider (at the very least) walking speed in conjunction with total external load given the potential for walking speed to illicit larger increases in energy cost for a load carriage task.

The multi-factorial nature of human load carriage capacity makes it difficult to set maximum load limits. Furthermore setting external load and/or intensity limits may be difficult to implement in the field and may not always be operationally possible. It is understood that mission requirements, operational constraints and threat profile dictate load carriage requirements. However mission planning needs to balance, to some degree, the requirements of the operational environment against the various physical considerations of personnel load carriage ability. Therefore, mission planners and commanders alike need to understand the impact of various load carriage variables on an individual's load carriage capacity and operational effectiveness.

This report has been divided into two parts; Part A discusses in detail the scientific aspects of load carriage while Part B provides a brief summary of scientific findings and guidance to commanders for tasks requiring load carriage. Within Part A, Section 2 outlines the methods applied to assess the physiological demand of load carriage. Sections 3 to 6 outline the physiological and biomechanical considerations of load carriage, the potential adverse health outcomes and the impact on tactical performance of the dismounted combatant. Within Part B, Section 7 provides a brief summary of science relating to military load carriage and highlights key areas of consideration for the commander. Section 8 identifies strategies to mitigate the impact of load carriage. Section 9 brings together all key physiological considerations to assist commanders in

a) understanding the burden of load carriage, and b) planning a load carriage task. This information has been packaged in a table (Table 6), which provides commanders with an appreciation for the ability of individuals to (continuously) sustain a given load carriage task, under various operationally relevant parameters. It is important to understand that continuous work sustainment time does not consider other factors such as muscle discomfort and muscle fatigue, load carriage equipment integration and load carriage conditioning. These factors are known to reduce load carriage capacity before physiological factors (e.g. energy depletion), under certain conditions.

Finally, this guide is then distilled into an overview of key considerations for the management (i.e. preparation, execution and recovery) of personnel undertaking repeated load carriage tasks.

Authors

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Jace graduated from Australian Catholic University with a BExSci (2002), then completed a B.AppSci (Honours) (2003) and a PhD in Exercise Physiology (2009) at Deakin University. Since joining DSTO in January 2010, Jace's work effort has primarily been divided between the Physical Employment Standards (PES) project and soldier physical mobility/load carriage tasks. Jace has taught Exercise Physiology and related subjects at tertiary level for over 8 years and has considerable experience in exercise physiology research.

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LT Orr enlisted in the Australian Regular Army in 1989 and was posted to the Royal Australian Infantry Corps before transferring to the Physical Training Instructor stream (1995-2005). Commissioned in 2006, he served as both a clinical physiotherapist and as a human performance officer. In this latter role Rob has undertaken physical conditioning reviews of selection, conditioning and rehabilitation programs and processes for the Army Recruit Training Centre (2006), Royal Military College (2007-2010), and Special Operations Headquarters (2011-). Transferring to the Army reserve and taking up an appointment with Bond University in 2012, Rob's academic qualifications include a Bachelor of Further Education and Training (2002) and a Masters of Physiotherapy Studies (2006). He has recently (2012) submitted his doctoral thesis on soldier load carriage.

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Renée Attwells completed a BAppSc (Ex&SportSc) with honours in Biomechanics at the University of Sydney in 1999. For the next two years she worked in clinical and sports biomechanics laboratories in Sydney before moving to the United Kingdom. During the period 2002–2005 Renée was employed by Loughborough University supporting Dstl on its programme to enhance soldier mobility and load carriage. Renée joined DSTO in 2006 in the Human Performance area and has been involved in *support to Land 125, DMO and the Physical Employment Standards project. Renee was awarded an MPhil in 2008 from Loughborough University. The thesis was entitled "Military Load Carriage: The effect of increased load, gender and load carriage duration on gait and posture". Renee is currently the DSTO S&T Officer for Diggerworks*

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Daniel Billing completed a Bachelor of Applied Science (Human Movement) at the University of Ballarat in 1999 and was then employed by the Victorian (VIS) and Tasmanian (TIS) Institutes of Sport over a period of 6 years working in a number of scientific disciplines including biomechanics, physiology and physical preparation. Daniel then completed a PhD and Postdoctoral Fellowship in the area of human performance monitoring with Swinburne University of Technology, the Cooperative Research Centre (CRC) for micro Technology and the Australian Institute of Sport (AIS). Dan joined DSTO in 2006 as the lead for the Physical Employment Standards (PES) research programme. In addition to the PES research programme, Daniel now leads a broad range of human performance research activities.

Contents

ABBREVIATIONS/ ACRONYMS

ADF	Australian Defence Force
AIRN	Army individual readiness notice
BM	body mass
hr	hour
kJ	kilojoule
kJ/hr	kilojoule per hour
kg	kilogram
km	kilometre
km/hr	kilometre per hour
L/hr	litres per hour
L/min	litres per minute
m	metre
min	minute
NATO	North Atlantic Treaty Organisation
U.S.	United States of America
VO_2	oxygen uptake
VO_{2max}	maximum pulmonary oxygen uptake
VO_{2peak}	peak pulmonary oxygen uptake
°C	degrees Celsius
$>$	greater than
$<$	less than
$\leq$	equal to or less than

1. Introduction to Military Load Carriage

There is a universal need for military personnel to be capable of moving their body mass plus an external load both administratively over a prolonged duration and tactically at high speed. The load of military personnel is typically comprised of clothing, protective ensemble (i.e. body armour, helmet), combat equipment (i.e. webbing, weapon systems, ammunition, power sources, radio) and sustainment stores (i.e. food and water). In addition, the diversity and complexity of military operations often requires dismounted personnel to carry mission-specific equipment and move, on foot, through various climates and terrains for long and continuous periods. The total load varies dependent upon factors such as mission requirements and threat profile. The U.S. Army have classified combat loads accordingly as either fighting load (21.7 kg), approach march load (32.7 kg) and emergency approach march load (> 32.7 kg) (van Dijk, 2007). The Australian Army generally defines combat loads as patrol order, marching order (light), and marching order (heavy) which are intended for operations up to eight, 24 and 72 hours respectively. Whilst the combat load terminologies and exact loads may vary between the coalition armies, the classification, purpose and constituents of the load are similar.

While the equipment carried is often crucial for mission success and survival, its weight, when in excess, has led to combat deaths (Marshall, 1980, Mayville, 1987, Schwendiman, 2008). In the Great War, heavy loading of the foot soldier reduced marching ability and was claimed to have altered the tactics of war (Lothian, 1921). During the Second World War heavy loads were attributed with causing deaths of American troops in the water during the D-Day landings at Omaha Beach (Mayville, 1987). There are numerous other examples through history demonstrating the adverse effect of heavy load carriage on soldier performance and operational success.

Recent evidence suggests that the individual's load is increasing with advancing technologies and personal protective equipment. In East Timor, on Operation CITADEL, it was reported that Australian soldiers carried loads in excess of 45 kg, with gunners and signallers carrying loads in excess of 50 kg. The load of their webbing and body armour were thought to hinder

Australian soldiers chasing fleeing militia (Breen, 2000). During current operations in Afghanistan it has been suggested that 50 kg is the typical load carried by dismounted personnel (Dean, 2004). Excessive external load may adversely impact upon an individuals' physical capability (e.g. mobility, lethality) and health (e.g. survivability, thermal burden). It is therefore important we learn the lessons of the past and duly consider load carriage in mission planning involving dismounted personnel.

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, gender, age, injury profile, load carriage experience), 2) task characteristics (e.g. total external load, distribution of load, load carriage equipment design, movement speed, march duration, work to rest ratio) and 3) environment (e.g. terrain, heat, humidity, altitude) in which the task is performed (Figure 1). Some of these factors may in some situations be controlled (e.g. marching speed) whilst others are not (e.g. ambient temperature). There is a dynamic interaction between these factors which ultimately impact on an individual's load carriage capacity. When undertaking mission planning it is important for commanders to consider the factors influencing load carriage capacity and identify the likely burden. Such information will guide amongst other things, duration of operations, work to rest schedules, total load limits, replenishment and logistical support requirements. This planning is critical to the maintenance of dismounted personnel's operational effectiveness, battlefield performance and ultimately mission success.

The purpose of this document is to review existing scientific literature and established work physiology models for the development of evidence-based load carriage guidelines. These guidelines will place emphasis upon critical task elements and human factors with the intent of assisting commanders' in making decisions about tasks involving load carriage. It is important to understand however that load carriage guidelines are not definitive nor can they be generically applied to all load carriage scenarios, rather they establish general principles to assist the commander in mission planning.

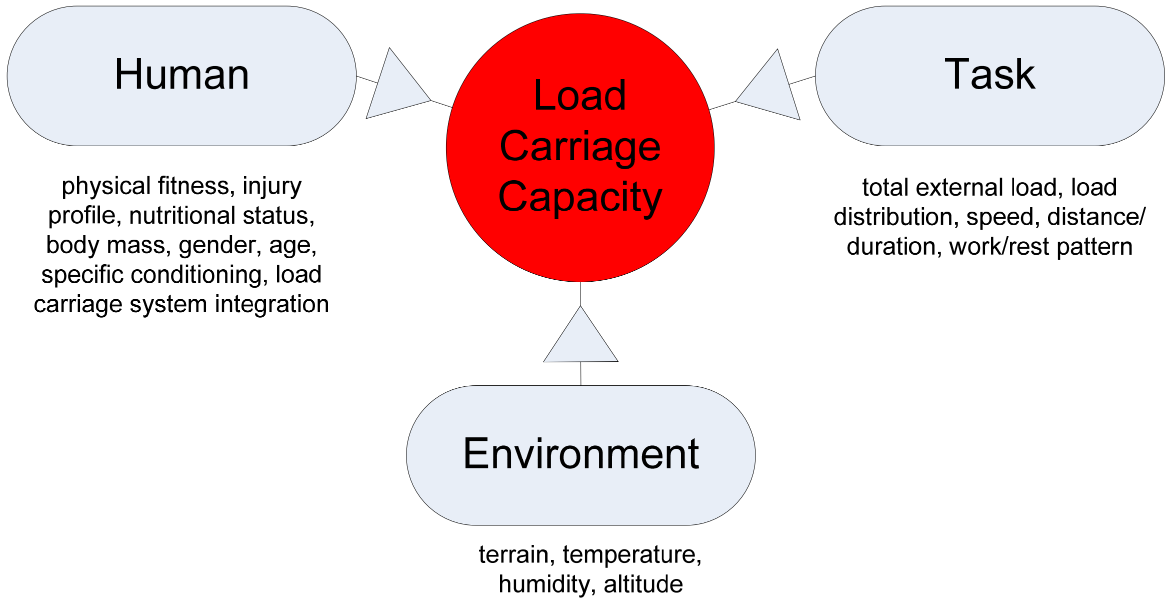

Figure 1 Factors influencing individual load carriage capacity

This report has been divided into two parts; Part A discusses in detail the scientific aspects of load carriage while Part B provides a brief summary of scientific findings and guidance to commanders for tasks requiring load carriage. Within Part A, Section 2 outlines the methods applied to assess the physiological demand of load carriage. Sections 3 to 6 outline the physiological and biomechanical considerations of load carriage, the potential adverse health outcomes and the impact on tactical performance of the dismounted combatant. Within Part B, Section 7 provides a brief summary of science relating to military load carriage and highlights key areas of consideration for the commander. Section 8 identifies strategies to mitigate the impact of load carriage. Section 9 brings together all key physiological considerations to assist commanders in a) understanding the burden of load carriage, and b) planning a load carriage task. This guide is then distilled into a practical overview for commanders to assist in preparing, executing and recovering from load carriage tasks.

PART A: SCIENTIFIC FOUNDATIONS OF LOAD CARRIAGE

2. Methods for Assessing the Physiological Demands of Load Carriage

2.1 Energy Cost

The energy cost associated with load carriage can be reported in a variety of forms. The rate of kilojoule (kJ) expenditure per unit of time (e.g. minute, hour) or oxygen uptake (VO_2) are the most common means for reporting the energy cost of a task. Throughout this report the energy cost of load carriage will be expressed as kilojoule per hour (kJ/hr) however this approach is for consistency and is not intended to indicate superiority of one unit of measurement over another.

2.2 Predicting Energy Cost

Undertaking well-controlled scientific research can be a long and resource intensive process. Under certain circumstances it may be appropriate for researchers to develop models, based on well-established scientific principles that allow for the accurate prediction of real-world outcomes. Pandolf and colleagues (Pandolf et al., 1977) developed a model to predict the energy cost of loaded walking (up to 50 kg) on level and graded terrain up to a speed of 7.9 km/hr. This equation has been further validated across a range of gradients (0-10%), external loads (4.1 to 40 kg) and walking speeds (3.2-6.0 km/hr) (Duggan and Haisman, 1992, Pimental and Pandolf, 1979). Total external load is not the only consideration for load carriage capacity. Speed of movement, terrain surface and gradient of the terrain are also important factors determining the physiological cost of load carriage and have been included in the model developed by Pandolf and colleagues. This equation has been applied to representative load carriage scenarios throughout this document to predict the physiological burden of load carriage. However it must be noted that the Pandolf equation does not take into consideration factors such as muscle discomfort/fatigue or injury which may reduce mechanical efficiency and consequently increase energy cost.

The predictive equation is;

$$M = 1.5\,W + 2.0\,(W + L)(L/W)^2 + \eta(W + L)[1.5\,V^2 + 0.35\,VG]$$

Where M = metabolic rate, watts; W = subject weight, kg; L = load carried, kg; V = walking speed, m/s; G = grade, %; η = terrain factor (terrain factors: 1.0; asphalt, 1.1; dirt road; 1.2, light brush, 1.5; heavy brush, 1.8; swampy bog, 2.1; loose sand).

2.3 Estimating Sustainment Time

The capacity for personnel to maintain a given work intensity, or "sustainment time", is particularly relevant to commanders and mission planners making decisions about tasks involving load carriage. Energy cost is one means for reporting the physiological burden of a load carriage task. The percentage of an individuals' maximum aerobic capacity (VO_{2max}) demanded is another means for reporting the physiological burden and understanding sustainment time. The tolerable duration for which personnel can sustain a load carriage task is primarily determined by the %VO_{2max} that the task demands and the duration of the activity (Figure 2). Current guidelines suggest that the average person can likely sustain 30-40% VO_{2peak} for an 8-hour period, 50% for 3-4 hours, 60% for 2 hours, 70-75% for 1 hour and 100% for several minutes (Astrand et al., 2003, Bink, 1962, Saha et al., 1979, Wu and Wang, 2002). This inverse relationship between task duration and intensity forms the basis for the sustainment time model (Figure 2). The sustainment time model is based on a series of predictions/estimations, and allows for the estimation of performance in both prolonged and short-duration tasks. The maximum aerobic capacity (i.e., VO_{2peak}) is predicted from beep test performance (Léger and Lambert, 1982) whilst the energy cost (VO_2) of marching is estimated using an established (Pandolf et al., 1977) and independently validated (Duggan and Haisman, 1992) model. This allows the estimation of relative work intensity of given a task (i.e., %VO_{2peak}). The relative task intensity is then utilised to estimate the maximum tolerable duration that a work intensity can be sustained (i.e., sustainment time) based on previous research (Astrand et al., 2003, Saha et al., 1979, Wu and Wang, 2002) (Figure 2). The energy cost and sustainment time models have been utilised to assess load carriage burden and predict load carriage performance. The information gained from these models is distilled in Section 8 with the provision of practical guidelines and tables to assist commanders in the planning and preparation for load carriage tasks.

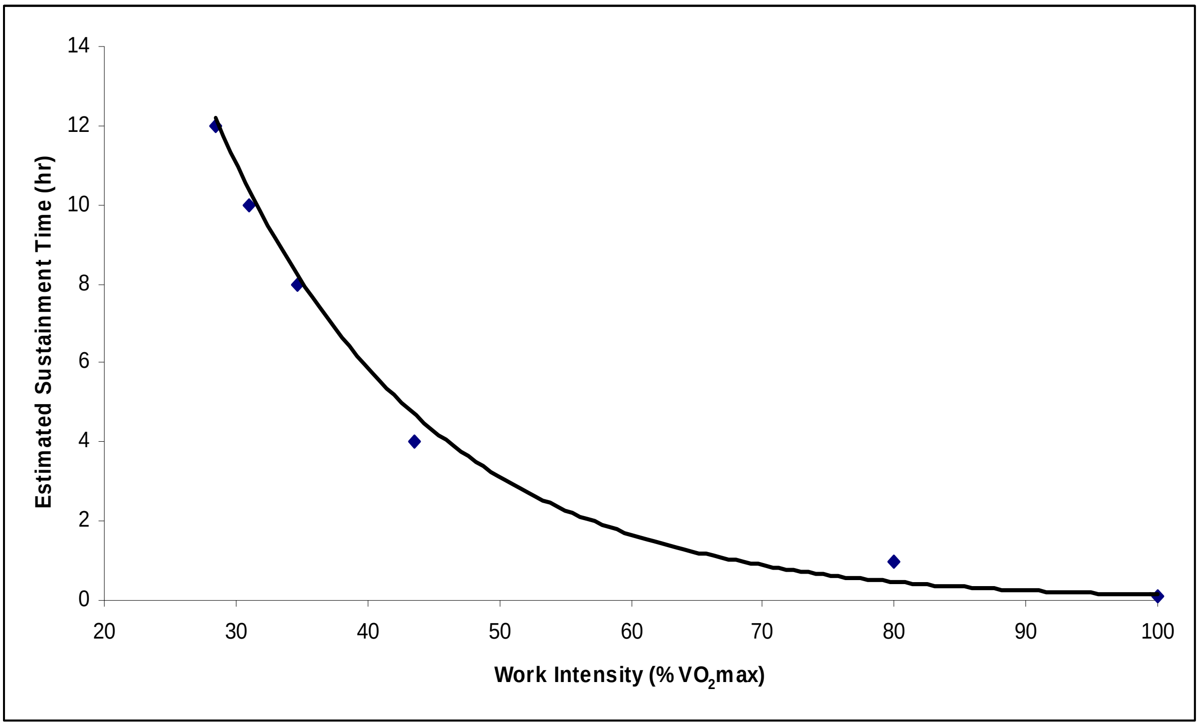

Figure 2 Estimated sustainment time based on results from Wu and Wang (2002), Astrand et al. (2003) and Saha et al. (1979).

2.4 Literature Search Criteria

The review of literature investigating load carriage was limited to studies published in peer-reviewed journals and reports produced by military labs (e.g. US Army Research Institute of Environmental Medicine). Load carriage has been widely investigated in a number of different contexts (e.g. military, hiking, firefighters, Nepalese porters) however studies were limited to research that either investigated military populations or research with direct application to the military context.

3. Physiological Considerations of Prolonged Load Carriage

Prolonged load carriage is typically undertaken at low to moderate intensity (e.g. 2 - 6 km/hr) over distances of 5 to 20 km (e.g. patrolling, administrative marches. The loads carried by personnel during prolonged marches may range from 20 kg to in excess of 50 kg. Under these load carriage conditions physical stress can manifest in a variety of forms, and the main physiological factors influencing load carriage capacity are discussed below.

3.1 Total External Load

It is well-established that as external load increases the energy cost of load carriage in standing, walking, running and stair climbing also increases (Beekley et al., 2007, Crowder et al., 2007, Pandolf et al., 1977, Quesada et al., 2000) (Figure 3). Numerous studies (Bastien et al., 2005, Beekley et al., 2007, Christie and Scott, 2005, Crowder et al., 2007, Quesada et al., 2000) have described a linear increase in energy cost with increased pack weight. Regardless of the precise nature of this relationship, a weight load threshold exists beyond which load carriage capability is significantly degraded (Haisman, 1988). Where this threshold (or "tipping point") lies for each individual is unknown. Epstein et al. (Epstein et al., 1988) suggest that maximal load carriage efficiency (as determined by energy expenditure) is achieved at 4.5-5.0 km/hr walking speed with a load weighing 40-50% of body mass (e.g. 32 to 40 kg for an 80 kg soldier). Whereas Harman et al. (2000) recommend that personnel should avoid walking faster than 4.8 km/hr with external loads approaching 47 kg.

March performance (i.e. time to complete distance) has been shown to diminish with increasing external load (Derrick et al., 1963, Harman et al., 1999, Harper et al., 1997, Knapik et al., 1997). Knapik et al. (Knapik et al., 1997) showed that U.S. special forces soldiers decreased walking speed during a maximal effort 20 km road march with increasing external loads (34 to 61 kg). Interestingly, the decrease in walking speed with increasing external load resulted in reduced energy expenditure. This would indicate that energy expenditure is not the sole determinant of self-selected work intensity (i.e. walking speed), and other factors (e.g.

shoulder discomfort, pack pain) may become more important with increasing external loads (Knapik et al., 1997, Myles and Saunders, 1979).

Such guidelines, whilst informative, must be interpreted with caution. The interaction between soldier characteristics, task characteristics and environment (Figure 1) determine this limit to individual load carriage capacity and the relationship between these variables mean that generic guidelines cannot be applied. Walking speed, surface gradient and walking surface characteristics (e.g. asphalt, loose sand) together with external load, predominantly determine the energy cost of load carriage (Pandolf et al., 1977). For example, the energy cost of marching with a 35 kg load at 3.5 km/hr was shown to be same as marching with 20 kg load at 4.5 km/hr for a group of South African soldiers (Christie and Scott, 2005). As a general guide the energy cost associated with a 10 kg increase in external load is equivalent to an increase in walking speed of 0.5 km/hr (Figure 3). Commanders therefore need to consider walking speed in conjunction with total external load during mission planning given the potential for walking speed to illicit larger increases in energy cost for a load carriage task.

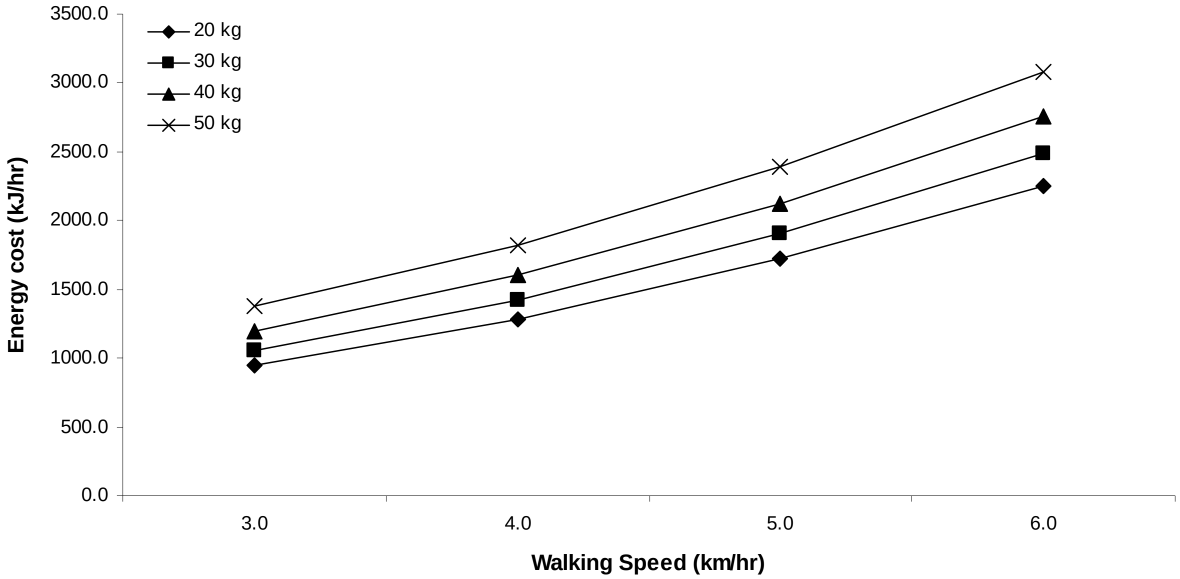

Figure 3 Energy cost of load carriage with increasing external load as predicted using the equation of Pandolf et al.(1977).

3.2 Load Distribution

For dismounted personnel, load may be distributed to the head (helmet, night vision goggles), trunk (webbing, pack, body armour), hips/thigh (webbing), hands (weapon) and feet (boots). With this in mind, the distribution of external load has been shown to influence energy cost and load carriage capacity. It is well established that loads distributed close to an individual's centre of mass minimises postural disturbances and results in decreased energy expenditure (Knapik et al., 2004, Legg et al., 1992, Ramanathan and Datta, 1971). For loads carried within a backpack or webbing load carriage system, load placement should be low to mid-back when crossing elevated and/or uneven terrain in order to improve balance. Conversely, when walking on flat terrain, heavier loads should be placed higher on the back to reduce the energy costs of carrying the load (Knapik et al., 2004). Whilst laboratory studies (Abe et al., 2004, Stuempfle et al., 2004) have observed a reduction in energy cost with high load placement (compared to low) when walking on a level treadmill with 15-25% body mass, these results must also be balanced against accessibility of stowed items. Regardless of terrain and vertical load distribution, the load should be balanced across the back, i.e. right to left side (Watson et al., 2008).

For loads carried around the body, evidence shows that the feet and hands are the least efficient location for load carriage (Soule and Goldman, 1969, Taylor et al., 2011). It has been shown that every 1 kg added to the foot increased energy expenditure by 7-10% and that every 1 kg added to the thigh increased energy expenditure by 4% (Knapik et al., 2004). Likewise load in the hands results in increased energy expenditure compared to torso load carriage (Datta and Ramanathan, 1971, Knapik et al., 2000). Modifications to equipment and/or redistribution of weight around the bodies' centre of mass are potentially important for the individual warfighter. However, perhaps more importantly Commanders and subordinates need to carefully consider whether the benefit of the additional external load outweighs the associated increase in energy cost when making decisions about equipment taken on missions and how and where it is carried.

3.3 Movement Speed

For dismounted personnel, the speed of load carriage (marching speed) is largely dictated by mission requirements. Administrative (i.e. non-tactical) tasks are typically undertaken at a moderate pace (e.g. 3.0-6.0 km/hr) whilst tactical tasks may involve movement at various speeds from slow walking to sprinting. An increase in marching speed for a given load will increase the energy cost of the activity (Abe et al., 2004, Bastien et al., 2005, Christie and Scott, 2005, Soule and Goldman, 1969, Soule et al., 1978). Furthermore when all other variables are held constant, an increase in walking speed is likely to cause a greater increase in energy cost than increases in external load (Charteris, 2000, Christie and Scott, 2005, Pal et al., 2009, Soule et al., 1978). The well-established model (Pandolf et al., 1977) shows that the energy cost associated with a 2.0 km/hr increase in walking speed (from 3.0 km/hr) elicits a 54 % greater energy expenditure than a 20 kg increase (from 20 kg) in external load (Table 1).

Table 1 Relative (percent) increase in energy cost associated with increases in either external load or marching speed predicted using the equation of Pandolf et al. (1977; based on average soldier body mass of 80.0 kg).

Reference marching condition; 20 kg, 3.0 km/hr, flat dirt road	
Load and increase (%) in energy cost	**Speed and increase (%) in energy cost**
30 kg; ↑ 12%	4.0 km/hr; ↑ 36%
40 kg; ↑ 28%	5.0 km/hr; ↑ 82%
50 kg; ↑ 50%	6.0 km/hr; ↑ 139%

When marching speed and external load combinations are categorised according to energy cost (Table 2) the results suggest that personnel may be able to tolerate heavy external loads if marching speed is appropriately reduced, consequently defining a maximum load is not a straightforward activity. On the other hand, a relatively light load (e.g. 25 kg) can be too heavy if marching speed is too fast. This observation is based upon metabolic (energy) cost only and does not take into consideration other important factors such as muscle discomfort and altered biomechanics during prolonged and/or heavy load carriage tasks which are discussed in later sections.

In addition to the speed of movement, the nature of the marching speed should also be considered, i.e. "set" speed and 'self-selected' (or self-paced) speed. Studies have observed that individuals tend to self-select a reduced marching speed with increasing external load (Hughes and Goldman, 1970, Knapik et al., 1997). When allowed to self –regulate walking speed during prolonged load carriage with varying external loads, individuals appear to often (Hughes and Goldman, 1970) but not always (Knapik et al., 1997) adjust speed to maintain a relatively constant work rate (i.e. energy expenditure) . Individuals typically undertake load carriage at a set speed (e.g. marching in formation) rather than at self-selected speeds (e.g. roving sentry). However there may be advantages in some situations (e.g. administrative movements, load carriage training) to allow personnel to move at a self-selected pace (whilst remaining within required deadlines) during heavy load carriage.

Table 2 Workload classification based on energy cost of different external load and marching speed combinations. Workload categories taken from Sharkey et al. (Sharkey and Davis, 2008) and based on predicted energy cost (light < 1296 kJ/hr, moderate 1296-1852 kJ/hr, heavy 1852-2408 kJ/hr, very 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
	3.0 km/hr	Light	Moderate

40 kg	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

3.4 Distance and Duration

The duration of load carriage can range from minutes to hours, potentially over consecutive days. The combination of duration or distance of load carriage along with marching speed and total external load primarily influence an individuals' load carriage sustainment time. Climate, terrain and individual characteristics also contribute to load carriage capacity. It is important to understand the inverse relationship between task duration and task intensity i.e. the harder personnel work the shorter the duration the task can be sustained. If the demands (i.e. external load, environment) of a mission cannot be altered, the use of rest breaks may assist in delaying and/or preventing fatigue and possible decrements in personnel performance.

Some studies (Blacker et al., 2009, Blacker et al., 2011, Epstein et al., 1988, Patton et al., 1991) but not all (Quesada et al., 2000, Sagiv et al., 1994) have shown that the energy cost of load carriage progressively increases during prolonged (i.e. ≥ 120 min), constant load marching. A similar increase in the cardiovascular demands during prolonged exercise (known as "cardiovascular drift") is well described (Coyle and Gonzalez-Alonso, 2001). It appears that heavier external loads and/or faster marching speeds augment the progressive increase in energy cost during prolonged load carriage (Blacker et al., 2011, Epstein et al., 1988, Patton et al., 1991). An increase in the energy cost of constant load marching is attributed, at least in part, to decreased mechanical efficiency due to altered biomechanics (Patton et al., 1991).

During self-paced prolonged load carriage (all other variables held constant), walking speed has been shown to decrease over time due to increasing energy costs (Hughes and Goldman, 1970, Knapik et al., 1997). It is suggested the decrease in walking speed offsets the progressive upward drift in energy cost of load carriage to maintain a constant work intensity (i.e. % maximal oxygen uptake, VO_{2max}). Furthermore it is suggested that under prolonged load carriage conditions torso and/or upper body muscle fatigue and localised discomfort become more important limiting factors than metabolic and cardiovascular influences (Knapik et al., 1997, Koerhuis et al., 2009).

3.5 Terrain

Personnel may be required to carry loads in a variety of environments (jungles, hills, deserts) which may influence load carriage capacity. The gradient (e.g. flat, incline, decline) and surface characteristics (e.g. bitumen, sand, swamp) of the terrain are important factors when considering load carriage capacity and energy cost.

It is well established that the energy cost of load carriage increases when walking up inclined terrain, compared to flat walking (Crowder et al., 2007, Knapik et al., 2004, Sagiv et al., 2000, Santee et al., 2001). It has been shown that the energy cost of load carriage when marching with a 25 kg load at between 5 and 5.6 km/hr at a 5% and 10% gradient increases approximately 45 and 108% respectively compared to flat marching (Crowder et al., 2007, Sagiv et al., 2000). As a guide a 1% increase in surface gradient increases energy expenditure equivalent to a 10 kg increase in external load (Pandolf et al., 1977). Unlike inclined terrain, the energy cost of downhill walking is decreased compared to level walking (Blacker et al., 2009, Santee et al., 2001). Downhill walking however, does not demonstrate a linear relationship with energy cost. The energy cost of downhill walking appears to reach a minimum at -8%. Beyond this point energy cost begins to increase, compared to less severe downhill gradients, due to the work required to maintain stability (Santee et al., 2001).

With respect to surface characteristics of the terrain, Soule and Goldman (Soule and Goldman, 1972) developed coefficients indicating the relative energy cost of walking across various terrains with loads ranging from 10 to 40 kg. The order of least to most demanding walking surfaces is as follows; blacktop (asphalt), dirt road, light brush, heavy brush, swampy bog, loose sand and soft snow. The predicted energy cost of load carriage would increase almost 50% if the surface changed from a dirt road to loose sand if all other variables (walking speed, load and gradient) were held constant (Table 3).

Table 3 Relative (percent) increase in energy cost of altered load carriage conditions (compared to reference marching condition) predicted using the equation of Pandolf et al. (1977).

Reference marching condition; 20 kg, 3.0 km/hr, flat dirt road			
Load	**Speed**	**Gradient**	**Terrain**
30 kg; ↑ 12%	4.0 km/hr; ↑ 36%	1 %; ↑ 13%	Light brush; ↑ 4%
40 kg; ↑ 28%	5.0 km/hr; ↑ 82%	2 %; ↑ 26%	Heavy brush; ↑ 17%
50 kg; ↑ 50%	6.0 km/hr; ↑ 139%	5 %; ↑ 65%	Sand; ↑ 42%

3.6 Climate

The negative impact of hot and cold conditions on military operations is well documented (Astrand and Saltin, 1961). With this in mind, climactic conditions (e.g. temperature, humidity, rainfall, snow) can impact significantly upon the physiological burden of load carriage. High ambient temperature and/or humidity can increase the thermoregulatory stress associated with work (i.e. load carriage) and reduce work capacity. Work in hot environments may also increase dietary carbohydrate and/or fluid requirements however this is largely dependent upon work duration and intensity. The metabolic heat generated during load carriage in a thermo-neutral environment can be sufficient to cause considerable heat stress. Therefore undertaking strenuous work in hot and/or humid conditions can augment the thermal burden associated with load carriage tasks. Counter-measures such as decreased work-rates and/or increased rest periods may be required to prolong work and decrease the risk of thermal injury. Refer to Army work-rest tables for further guidance (Department of Defence, 2007).

Dehydration can further impair both physical performance and tolerance to hot environments, consequently regular consumption of water to replace lost fluids is vital. Therefore when undertaking load carriage tasks in hot and/or humid conditions it becomes increasingly critical that work-rest tables (Department of Defence, 2007) are closely monitored and fluids are consumed regularly. However it is equally important to ensure that fluid consumption does not exceed sweat loss. Over consumption of water can lead to a potentially fatal condition known as hyponatraemia, which has been reported in soldiers undertaking basic training and during prolonged marching (Galun et al., 1991, Garigan and Ristedt, 1999).

During cold stress, basal metabolic rate can increase to intensities equivalent to approximately 40% VO_{2max} due to shivering thermogenesis (Eyolfson et al., 2001). The energetic cost of maintaining thermal balance in a cold environment can represent a considerable additional metabolic load on the body (Cheung, 2010). Furthermore an increase in heat production through shivering can accelerate the depletion of carbohydrate stores (Haman et al., 2005). Shivering during load carriage is unlikely due to the metabolic heat production associated with marching. However, conducting slow deliberate patrols with frequent stops may be sufficient to induce shivering. Cold weather and rainfall can also impact on the energy cost of load carriage and load carriage capacity of dismounted personnel. Rainfall and snow can alter the surface characteristics of the terrain (e.g. mud, water, snow) and increase the clothing and equipment burden. Studies investigating energy requirements in military populations have suggested increased energy requirements during cold conditions (Johnson and Kark, 1947, Swain et al., 1949, Tharion et al., 2005). An increase in the weight and/or bulk of clothing and equipment carried by dismounted personnel and winter terrain (e.g. snow, mud) can also increase energy expenditure (Gray et al., 1951, Soule and Goldman, 1972). Two studies investigating energy expenditure in moderately active soldiers in cold environments (mean temperature -18°C to -22°C) have shown similar findings, with energy expenditure found to be approximately 18,000 kJ per day (Jones et al., 1993, King et al., 1993). In line with these findings the current U.S. Military recommended dietary allowance for males in environments that are colder than 14°C is 18,900 kJ per day. Insufficient food intake may in fact be a greater issue for personnel in cold environments than increased energy requirements. Increased palatability of rations and/or supplemental ration packs may be options to ensure personnel are adequately nourished whilst on operations in cold environments.

3.7 Altitude

The atmospheric oxygen levels decline as one ascends in elevation above sea-level which may reduce physical work capacity. It is suggested this effect becomes more evident at elevations above 1500 m (Sharkey and Davis, 2008). Due to the decreased oxygen availability work rates should be adjusted (i.e. reduced). Repeated exposure to this environment will lead to physiological adaptations (acclimatisation) that improve an individual's ability to work at altitude. Increased aerobic fitness also increases an individual's ability to cope with work at altitude. Altitude can also increase fluid loss (compared to sea-level) so care must to taken to ensure adequate fluids are consumed.

3.8 Nutritional Requirements

Load carriage demands (i.e. external load, marching speed, march distance) together with environmental conditions (i.e. climate, terrain) largely influence the nutritional requirements of dismounted personnel. Individual characteristics such as body mass, lean body mass and gender also influence nutritional requirements. Studies have demonstrated that soldiers' daily energy expenditure can range from 12,000 kJ for sedentary occupations to 28,000 kJ for special forces selection (Forbes-Ewan, 1999). The upper end of this energy expenditure range is comparable to energy expenditures observed in elite endurance athletes (Rodgers and Spector, 1986, Sando et al., 1986). A number of studies that have measured energy expenditures of soldiers undertaking common dismounted tasks have observed average daily energy expenditures in the range of 15,000 to 19,000 kJ (Booth and Coad, 2002, Booth et al., 2001, Forbes-Ewan et al., 2008). Combat rations typically provide 15, 500 kJ (NATO, 2010) and these results suggest that this may be inadequate for some prolonged and/or intense tasks involving load carriage. Personnel may therefore require supplementation (e.g. emergency ration chocolate bars) to meet energy requirements under such conditions. Inadequate nutritional recovery from prior tasks may also decrease the work capacity of dismounted personnel and increase susceptibility to injury on subsequent days.

As previously mentioned regular consumption of fluid is critical to the health and performance of dismounted personnel. A decrease in fluids as little as 2% body mass can degrade both physical and mental performance and increase susceptibility to heat injury. Decreased attention and vigilance as well as decreased ability to perform complex mental processing tasks have also been observed with dehydration. Average sweat rates for infantry soldiers during operations in hot-dry and hot-humid conditions have been shown to be 1.0-1.7 L/hr (Amos et al., 1998, Forbes-Ewan, 1999). Based on these results the fluid requirements for personnel undertaking prolonged load carriage (e.g. 6-8 hr patrols) in hot and humid conditions (> 30°C) may approach 10 litres. Every kilogram of weight (1 litre of water = 1 kg) added to dismounted personnel increases the load carriage requirement. However the negative effects of dehydration (> 2% body mass) potentially outweigh the increased physiological burden of additional water supplies. Personnel should ensure that sufficient water is carried on operations and not sacrificed to reduce pack mass. With that in mind it is important that fluid consumption does not exceed sweat loss as over consumption of water can be equally harmful to an individual's health.

3.9 Personnel Characteristics

Evidence suggests certain physical characteristics are more favourable to load carriage performance. Body mass, fat free mass, absolute muscular strength and absolute VO_{2max} have been identified as predictors of load carriage capacity (Bilzon et al., 2001, Haisman, 1988, Lyons et al., 2005, Pandorf et al., 2002, Rayson et al., 2000, Ricciardi et al., 2007). Several studies have demonstrated superior performance in load carriage tasks in heavier individuals, when compared to lighter individuals (Bilzon et al., 2001, Harman et al., 2008, Harper et al., 1997). It is often observed that a larger body mass is associated with a larger muscle mass, greater absolute aerobic capacity and greater strength (Patterson et al., 2005). A fixed load would also represent a lower of percentage of body mass in heavier personnel when compared to lighter personnel. This is pertinent to gender differences in load carriage capacity as females have on average lower body mass and lower relative muscle mass compared to males. However this assumption should be used with caution as research suggests that the correlation between body composition (i.e. % fat free mass) and body mass is weak. Furthermore current evidence suggests that western societies are increasing in both body mass and body fat due to increased caloric intakes and reduced physical activity.

With regard to establishing maximum load limits it must be emphasised that operational loads should not be set as a percentage of body mass. Military load carriage studies frequently express external weight loads relative to body mass. This is useful in understanding the effect of external load on various physical parameters such as the external weight load threshold. However reporting external weight load as a relative rather than absolute weight is not relevant to military operations. Whilst there may be the capacity to share section equipment this distribution is influenced by various factors including occupational specialty and physical conditioning as well as body mass. Regardless there are minimum absolute external loads that personnel must carry during load carriage tasks and these minimum loads are not altered by body mass.

4. Biomechanical Considerations of Prolonged Load Carriage

As with physiological considerations, the biomechanical considerations of prolonged load carriage are affected by a multitude of variables (e.g. walking speed, distance, terrain surface and gradient, total load, load distribution, load carriage equipment, individual characteristics). Accordingly it is essential to appreciate how these factors can impact upon individual load carriage capacity. Short term (< 20 min) load carriage of up to 36 kg results in minimal change in posture and gait (Johnson et al., 2000, Martin et al., 1982, Orloff et al., 1999). Studies investigating more prolonged load carriage however have observed alterations in ground reaction forces, lower limb joint angles, increased forward lean, decreased stride length, increased stride frequency, increased duration of the double support phase and increased discomfort (Attwells et al., 2006, Harman et al., 2000, Knapik et al., 1992, Lloyd and Cooke, 2000, Polcyn et al., 2002). Similar to increased march duration, increased external load is also associated with increased forward lean, increased ground reaction forces and altered muscle activity (Attwells et al., 2006, Birrell et al., 2007, Cook and Neumann, 1987, Goh et al., 1998, Harman et al., 1992, Harman et al., 2000, Kinoshita, 1985, Martin and Nelson, 1986). It is also suggested as load increases so to does the risk of back injury (1992, Knapik et al., 1992). Changes in posture, joint angles, ground reaction forces and gait may increase fatigue and the risk of injury (Birrell et al., 2007, Goh et al., 1998).

Research indicates that load carriage exposure need not be prolonged to increase the risk of adverse health outcomes such as musculoskeletal injuries. During a two-legged drop landing task landing kinematics are altered and maximum ground reaction forces increase with the addition of body armour, helmet and weapon, compared to the unloaded state (Sell et al., 2010). Furthermore during short-duration load carriage (3 min) changes in forces exerted on the upper and lower back have been observed (Lafiandra and Harman, 2004) . These results indicate that carrying an external load increases stress on the body and the risk of injury during both prolonged (e.g. marching) and acute (e.g. exiting vehicles) load carriage tasks.

4.1 Load Carriage Equipment Integration

Poor load carriage equipment integration may be a major limiting factor in load carriage capacity. Blisters and back pain are commonly observed during military load carriage (Knapik et al., 1992, Reynolds et al., 1999). Discomfort associated with blisters or lower back pain can lead to postural and biomechanical alterations which can decrease gait efficiency (i.e. increase energy expenditure) and increase susceptibility to injury. Changes to the load distribution (e.g. backpack v. front-back pack) with heavy (61 kg) but not moderate loads (34 and 48 kg) have been shown to decrease blister likelihood (Knapik et al., 1997).

Large increases in subjective discomfort, particularly in the back, shoulder and neck region, have also been observed under prolonged load carriage conditions (Harper et al., 1997, Knapik et al., 1992, Knapik et al., 1997). Evidence suggests that upper body discomfort and muscle fatigue (e.g. rucksack palsy) may become a limiting factor during prolonged load carriage (Attwells et al., 2006). A decrease in grenade throwing performance following loaded marching has also been attributed, at least in part, to muscle (shoulder) discomfort. Muscle discomfort is caused not only by the magnitude of pressure associated with an external load but also the exposure time.

Load carriage equipment that transfers some of the load from the shoulders to the waist has been shown to reduce shoulder discomfort (pressure) and improve load carriage performance (Holewijn, 1990, Holewijn and Lotens, 1992, Lafiandra and Harman, 2004). It has been demonstrated (Lafiandra and Harman, 2004) that approximately 30% of the vertical force generated by a backpack could be transferred to the lower back/hips (from the shoulders) by using an external frame backpack with a hip belt.

Load carriage equipment integration is also a critical consideration for personnel not undertaking prolonged load carriage (i.e. marching) tasks. Evidence suggests that prolonged and/or repetitive wear of protective body armour can cause compression of nerves in both the upper extremity (e.g. brachial plexus) and lower extremity (e.g. lateral femoral cutaneous nerves). Nerve compression has been associated with pain and paresthesias, a skin sensation such as burning, prickling, itching, or tingling. Shoulder and upper extremity pain and paresthesias has been reported in soldiers wearing body armour weighing approximately 5 kg (Bhatt, 1990). Nerve compression in the legs has also been associated with body armour use in soldiers (Fargo and Konitzer, 2007). It was suggested that the lower edge of the body armour ensemble rests on the inguinal region leading to compression of the lateral femoral cutaneous nerves and subsequent pain and paresthesias in the legs. These symptoms are potentially aggravated by either prolonged standing (e.g. sentry/checkpoint roles) or sitting (e.g. mounted patrols).

5. Potential Adverse Health Outcomes of Load Carriage

The level of load carriage exposure and an individual's risk profile influence susceptibility to a load carriage injury. The risk of injury increases with the magnitude of load carriage exposure, i.e. compound effects of increased weight, increased march duration or increased frequency. With regards to the individual's injury risk profile, low or high levels of joint flexibility, low muscular strength or aerobic fitness, smoking and alcohol consumption are all linked with increased incidence of load carriage related injury (Deuster et al., 1997, Knapik et al., 2001). However, the primary risk factor for injury in both males and females is aerobic fitness (Bell et al., 2000, Deuster et al., 1997, Knapik et al., 2001). A lower level of aerobic fitness will place an individual under greater physiological stress (i.e. required to work at a greater relative percentage of maximum aerobic capacity) when compared to an individual with a higher level of aerobic fitness.

5.1 Acute Injuries

Weight load, march duration, load distribution, terrain and individual fitness levels together with load carriage equipment design contribute to the incidence of acute load carriage injuries (Bessen et al., 1987, Daube, 1969, Knapik et al., 1992). As mentioned previously, the most common acute injury whilst undertaking military load carriage is blisters (Knapik et al., 1992, Knapik et al., 1992, Reynolds et al., 1990, Reynolds et al., 1999). Knapik et al. (Knapik et al., 1997) observed 35% of the total injuries over a 20 km march with a 46 kg load were blisters. The cause is attributed to frictional forces between the socks/shoes and the skin. Blister incidence increases with load carriage duration; discomfort due to such an injury may result in gait compensation. Alterations in gait may change the direction and magnitude of ground reaction force, increasing a dismounted personnel's susceptibility to injury. Changes to gait may also decrease marching efficiency, increase energy cost, and thus impact upon load carriage sustainment time.

Acute back pain may also become limiting during load carriage tasks. In a study where infantry soldiers undertook a strenuous load carriage task (20 km with 46 kg load), 50% of the soldiers who were unable to complete the march cited back related problems (Knapik et al., 1992). The risk of back pain or discomfort as a result of prolonged load carriage appears to increase with increasing external loads and has been attributed to the amplified forces on the spine (Goh et al., 1998, Lafiandra and Harman, 2004, Reynolds et al., 1990). Beyond, increased trunk forward lean, increased ground reaction forces and altered walking gait (Attwells et al., 2006, Birrell et al., 2007, Goh et al., 1998, Harman et al., 2000, Polcyn et al., 2002) changes in spinal curvature in response to acute loaded carriage have also been observed (Fowler et al., 2006, Orloff and Rapp, 2004).

Brachial plexus palsy or "Rucksack palsy" is another acute injury associated with load carriage (Knapik et al., 2004). It is proposed that this injury is caused by traction and or compression of the C5 and C6 nerve roots of the brachial plexus by the load carriage system shoulder straps (Knapik et al., 2004). Typical symptoms include numbness, pain and weakness of the upper extremity. Weight of load, load carriage duration and terrain all increase the risk of this injury (Bessen et al., 1987, Daube, 1969, Lafiandra and Harman, 2004). Changes to equipment design, including adjustment of shoulder straps, horizontal sternum straps and the use of a hip belt, have been associated with a decreased incidence of this injury (Bessen et al., 1987, Makela et al., 2006).

5.2 Chronic Injuries

Evidence suggests the cumulative effect of heavy load carriage likely contributes to stress fractures of the lower limb and pelvis and intervertebral disc injury. A review by the Australian Defence Force Army Recruit Training Centre showed that lower limb stress fractures accounted for more that 50% of total time lost to injury in the period 2005-2007. Marching accounted for the greatest percentage of these lower limb stress fractures (Pope, 2007). Stress fracture injuries are multi-factorial and at present no definitive model exists to identify when a possible load carriage capacity has been reached. Susceptibility is greater in females, tall individuals and those of a white ethnic background (Knapik et al., 2004). However, a lack of physical conditioning appears to be the greatest risk factor as evidenced by the high incidence of lower limb stress fracture injuries amongst military recruits (Knapik et al., 1996, Reynolds et al., 1999).

The Repatriation Medical Authority (RMA) released a statement of principles that may link load carriage to intervertebral disc prolapse (RMA, 2007). Amongst other causative factors, including driving motor vehicles, smoking habits and penetrating injuries, cumulative load may be associated with disc prolapse. Cumulative load (or "load factor") is the product of, a) the weight of the load lifted or carried (kg); and b) the time the load was lifted or carried (hrs). The RMA report suggests that 150,000 is the minimum loading over the preceding ten years before it can be reasonably hypothesised that load carriage is linked as a causative factor of this type of injury. To put this into perspective, this equates to dismounted personnel carrying 30 kg for 5000 hours over a 10 year period. It is not unreasonable to suggest that an infantry soldier would potentially undertake 500 hours of load carriage/ manual handling per year.

Similar factors influence the incidence of both acute and chronic injuries. The level of load carriage exposure and an individuals' risk profile largely determine whether an injury occurs and the subsequent severity. Heavy load weight is a risk factor for both acute and chronic injuries, with risk increasing as load and/or exposure increases. Regardless of the load carriage scenario, certain individuals are at increased risk of load carriage injuries. Low or high levels of flexibility (Knapik et al., 2001), low muscular strength and/or endurance, smoking, alcohol consumption and gender are associated with increased injury incidence when carrying loads (Deuster et al., 1997). However, the primary risk factor for military training-related injuries in both males and females is a low aerobic capacity (Bell et al., 2000, Deuster et al., 1997, Knapik et al., 2001). Load carriage sustainment time is also largely influenced by aerobic capacity. The higher an individuals' aerobic capacity (i.e. VO_{2max}) the lower the relative task intensity (% VO_{2max}) compared to a less aerobically fit individual. This reinforces the need for personnel to undertake physical training that includes both general aerobic conditioning and loaded marching (see Section 7.1). As previously discussed (see Section 5.1) equipment design can also influence injury causation.

5.3 Mounted Patrols

Mounted personnel are not exposed to the chronic load carriage demands experienced by dismounted personnel however the weight of combat and protective equipment may nevertheless increase the risk of adverse health outcomes. It has been shown that landing biomechanics are adversely affected with the addition of an external load (body armour, helmet and weapon) (Sell et al.). Therefore exiting vehicles, a common task during mounted operations, when performed with an external load (e.g. body armour, helmet, weapon) is associated with an increased risk of musculoskeletal injury.

Mounted patrols may also increase the risk of musculoskeletal disorders due to exposure to whole-body vibration (WBV). Whole-body vibration such as that experienced by vehicle occupants can increase the risk for musculoskeletal injury, in particular the spine (Brinckmann et al., 1998, Makhsous et al., 2005, Seidel, 2005). Whole-body vibration exposure experienced by occupational drivers has been shown to lead to muscle fatigue and weakening of the lumbar musculature, resulting in decreased spinal support and increased risk of spinal injury (Pope et al., 1998, Seidel and Griffin, 2001).

Sitting in vehicles with an external load (e.g. body armour) may exacerbate the effects of WBV and the subsequent risk for musculoskeletal injury. Similar to mounted personnel, police officers from Northern Ireland were exposed to two types of spinal stress; WBV and shoulder loading. They were required to wear body armour weighing ~ 8 kg for the duration of their shift, which typically lasted eight to 12 hours. Results showed a trend for decreased height of lumbar vertebra which was statistically significant for the second lumbar vertebra. Furthermore, when sitting in vehicles with an external load (e.g. body armour) is combined with poor sitting posture, exposure to WBV may further increase risk of musculoskeletal injury (e.g. lumbar disc failure) (Pope et al., 1998). Whilst there is a lack of research in the military context, evidence strongly suggests there is the potential for mounted personnel to experience adverse health outcomes as a consequence of WBV exposure. These results reinforce the importance of equipment-personnel integration along with personnel-platform integration in performance and injury management of personnel. Therefore, whilst mounted operations may not have the obvious health risks associated with dismounted roles there is nonetheless increased risk of adverse health outcomes to personnel due to the external load carried and exposure to WBV.

5.4 Gender Differences

There are various physical and physiological differences between men and women. On average, males when compared to females have;

- Greater body mass (Plowman and Smith, 2003)
- Greater stature (Plowman and Smith, 2003)
- Lower body fat (Plowman and Smith, 2003)
- Greater muscle mass (McArdle et al., 2007, Plowman and Smith, 2003)
- Greater maximal ventilation (Schwartz et al., 1988)
- Greater cardiac output (McArdle et al., 2001)
- Higher concentration of haemoglobin (McArdle et al., 2001)
- Higher VO_{2max} (McArdle et al., 2007, Shephard et al., 1988)
- Greater absolute upper body strength (McArdle et al., 2001)
- Greater absolute lower body strength (McArdle et al., 2007)

These differences are typically manifested as reduced physical capacities in females (e.g. muscular strength, muscular endurance and aerobic capacity) when compared to males. Lifting or carrying the same absolute load will therefore represent greater physiological strain (i.e. greater percentage of maximum tolerance limit) for an average female, when compared to an average male. This potentially increases the onset of fatigue and the risk of adverse health outcomes.

The differences in physical capacity between males and females appear to be largely related to size and stature rather than gender per se (Taylor and Groeller, 2008). Whilst on average, women have a reduced load carriage capacity (compared to males) there are examples of females out-performing males (Patterson et al., 2005). When comparisons in strength and power are made relative to lean body mass or muscle cross-sectional area the gender differences largely disappear (Hurley and Hagberg, 1998, Miller et al., 1993). Therefore the principal reason for the discrepancy in performance capacity between men and women is that, on average, women have lower absolute body and muscle mass (Gallagher and Heymsfield, 1998) and a higher relative body fat mass. Whilst gender tends to confer certain physical attributes and capacities, these capacities (e.g. muscular strength and aerobic capacity) are highly trainable regardless of gender (Castro et al., 1995, Eddy et al., 1977, Staron et al., 1994).

Operational load carriage requirements are primarily influenced by mission requirements and environmental conditions. Therefore absolute physical capacities (e.g. muscular strength, muscular endurance, aerobic capacity) are essential to successful task performance. Despite potential gender-related differences in load carriage capacity between personnel, occupational role rather than gender will influence load carriage task requirements. Whilst understanding differences in physical capacities between males and females may have little operational relevance it likely has greater significance during load carriage conditioning and physical training. A number of key considerations include;

- Walking with load alters gait and biomechanics. Marching speed is the product of stride length and stride frequency. People of shorter stature often adopt shorter stride lengths and higher stride frequencies to maintain a given pace (Knapik et al., 2004) (Yamasaki et al 1991). Female participants have been shown to increase stride frequency rather than stride length in response to increased loads or marching speeds. Differences in gait patterns appear to be related to stature rather than gender (Yamasaki et al 1991). During prolonged load carriage tasks the average female, and men of smaller stature, will be at a distinct physical and physiological disadvantage relative to the average male. It is suggested that there is a point where stride frequency can no longer be increased, and further increases in speed must be facilitated by increases in stride length. In addition during marching tasks personnel are often forced to maintain a given pace, or "keep in step". This practice may limit an individuals' self-selected stride length and stride frequency. Shorter individuals (e.g. females) may therefore be required to stride at a length that is greater than their preferred and/or safe stride length. This "overstriding" can place additional shearing stress on the pelvis, leading to stress reactions or stress fractures in the pelvic bones (Pope, 1999).
- Females are also susceptible to nutritional deficiencies, menstrual dysfunction and overuse conditions when undertaking physical training. The load carriage conditioning program needs to include "de-loading" periods to allow adequate recovery. Supplementary aerobic conditioning and strength training should also be included in a load carriage training

program to maximise physical adaptations and subsequent load carriage capacity (Orr et al., 2010).

- A lack of consideration of female requirements in load carriage equipment design may contribute to reduced female load carriage performance (Harper et al., 1997) and increase risk of adverse health outcomes (Fullenkamp et al., 2008). Problems with pack fit, shoulder strap fit and position of the waist belt have been identified as common concerns with load carriage equipment by females (Harman et al., 1999, Knapik, 2000, Ling et al., 2004)

6. Impact of Load Carriage on Tactical Performance

Tactical load carriage, for the purpose of this discussion, is defined as short to moderate distance (i.e. < 5 km) and slow to maximal movement speeds (2 km/hr to sprinting). Whilst administrative movements could be described as aerobic activities, tactical movements can be aerobic and/or anaerobic activities, primarily dependent upon the level of enemy engagement. Tactical movements are typically completed in a fighting load ranging from 20-35 kg. Examples of these movements may include tracking and engaging the enemy and breaking contact.

Individual physical mobility limitations, more so than fatigue per se, are considered the main factors limiting tactical movement. The primary factors potentially contributing to reduced tactical movement capacity are discussed below. It must be emphasised however that we cannot discount physiological factors discussed previously with respect to administrative movements contributing to decreased tactical performance. For example the effects of prior tasks (e.g. prolonged load carriage) may deplete energy stores, induce muscle fatigue, increase heat storage or diminish cognitive performance, all of which can decrease physical (i.e. tactical) performance. In line with this, Lieberman et al. (Lieberman et al., 2002) demonstrated that a modest energy deficit over the course of a single day of combat training led to a significant decrease in cognitive performance. Similarly a 53 hr combat training exercise that combined sleep loss with physical, nutritional, psychological and heat stress demonstrated a substantial degradation of cognitive performance (Lieberman et al., 2005). The cognitive performance of dismounted personnel potentially impacts upon their physical mobility, lethality and survivability.

6.1 Mobility

As external load increases there is an associated decrease in mobility on the battlefield. In fact it is suggested that army tactics were changed during the First World War in response to a load induced reduction in soldier mobility (Lothian, 1921). Studies have shown that external load can affect performance of key military tasks and thus compromise mobility when compared to an unloaded state (Martin and Nelson, 1985). Holewijn et al. (Holewijn and Lotens, 1992) demonstrated that for every 1 kg external load, there was an average performance loss of 1% during tasks including jumping, sprinting and obstacle course completion. A recent investigation (Silk et al., 2010) demonstrated an average decrease of approximately 1.5% in soldier performance for every 1 kg increase in a load range of 19.1 to 29.2 kg across four mobility assessments. The assessment tasks included an agility course, sprinting, jumping and a simulated section attack.

Obstacle courses have also been used extensively within military performance studies, with a large number of studies showing an increased time to complete the course with increased load (Bassan et al., 2005, Harman et al., 1999, Hasselquist et al., 2008, Holewijn and Lotens, 1992, Martin and Nelson, 1985, Pandorf et al., 2002). A meta-analysis conducted by the U.S. Army Research Laboratory showed a significant linear relationship between total load and obstacle course completion time (Bassan et al., 2005). Every 1 kg increase in external load, in the range of 15-42 kg, increased completion time for the 500 m obstacle course on average 7.88 sec (Bassan et al., 2005).

Load distribution and physical mobility has been investigated with equivocal results. It is speculated that differences in total load, distribution of load and soldier conditioning together with differences in assessment methods may account, at least in part for this. Derrick et al. (Derrick et al., 1963) showed no significant difference between upper and whole torso load distribution on soldier mobility. In contrast, Holewijn and Lotens (Holewijn and Lotens, 1992) observed that weight distributed to the lower back, compared to the upper back, was more detrimental to performance across a series of physical mobility assessments. It should be noted that both load conditions (16 kg) decreased performance, compared to the reference (unloaded) condition, however the relative decrements in performance were consistently greater for the lower back load. The practical significance of the differences between upper and lower back load distribution are unknown.

Given many movements are performed prone and the fact that the overall dimensions of dismounted personnel tend to increase as a function of load this has the potential to impact on movement through confined spaces. The increased physical space resulting from an increase in load from 14 kg to 27 kg was associated with a two-fold increase in time to complete a 3.7 m crawl (Pandorf et al., 2002). It was suggested that the decreased crawling space and altered movement technique contributed to the reduced performance with the 27 kg load. The impact of increased load on physical space needs to be considered not only for obstacle negotiation, but negotiating smaller spaces in urban or ship environments and entering and exiting patrol vehicles.

The relationship between load carriage and physical mobility is complicated by the overall load, how it is distributed on the body and the physical space taken up by the load, the task being undertaken, and the physical characteristics of the individual. Therefore there is no means of providing single guidance of the impact of external load and distribution of load on physical mobility.

6.2 Lethality and Survivability

Load carriage activities may impact upon the lethality of dismounted personnel as it has been shown that marksmanship performance can decrease following load carriage tasks (Knapik et al., 1991, Tharion et al., 1993). A decrease in marksmanship following load carriage tasks may be explained by a reduced ability to stabilise the weapon when firing due to muscle fatigue, elevated respiration, elevated heart rate or increased hand tremors (Knapik et al., 1991, Tharion et al., 1993). It must be emphasised that these studies did not establish a direct cause and effect between load carriage per se and reduced marksmanship. It is possible that other activities that achieve similar levels of physical fatigue may result in similar decrements in marksmanship. Furthermore, not all studies have found a decrease in marksmanship following load carriage (Knapik et al., 1997, Patterson et al., 2005). The conflicting results between studies may be attributable to differences in time between the completion of a loaded march (pre-fatiguing task) and the commencement of the marksmanship assessment. Longer time periods between the march and firing assessments allow for greater recovery from the physiological stress associated with loaded marching (e.g. decreased heart rate and decreased hand tremors) (Leyk et al., 2007, Leyk et al., 2006). Some studies (Harper et al., 1997, Holewijn and Lotens, 1992), but not all (Knapik et al., 1991, Knapik et al., 1997) have demonstrated a decrement in grenade throwing performance (distance and/or accuracy) following load carriage activities. A direct causal effect of load carriage on grenade throwing performance has not been established.

Load carriage may also impact upon lethality and/or survivability through altered cognitive functioning. Mahoney et al. (Mahoney et al., 2007) observed that, when walking with a 40 kg load, vigilance decreased (when compared to an unloaded state). The decrement in vigilance task performance was further exacerbated when walking involved obstacle avoidance. The results also showed a greater decrement in vigilance task performance in response to tactile and visual stimuli compared to auditory. These results suggest that personnel, when carrying heavy loads, are more likely to overlook or misinterpret visual cues when patrolling and visually scanning for enemy and threats. More recently May et al. (May et al., 2009) investigated the impact of a backpack load (30% body mass) on decision making ability in response to auditory stimuli. The results demonstrated that a backpack load degraded mental processing as evidenced by increased reaction time and response error. Preceding load carriage tasks may also impact upon survivability through potentially diminished cognitive performance in tactical situations. Johnson and Knapik (Johnson et al., 1995) showed that in response to prolonged (20 km) load carriage, mental alertness diminished with increasing load (34 to 61 kg).

PART B: GUIDE TO MILITARY LOAD CARRIAGE

7. A Review of the Science

7.1 Introduction

All members of defence may, at some time be required to carry load. Whilst often this entails traditional webbing and back pack loads, the loads carried by defence members can take many shapes and forms.

Members from 1 Joint Public Affairs Unit Field Tam Iraq
Photo: Department of Defence

A sailor prepares to fight a potential fire aboard the ship whilst deployed on Operation HELPEM FREN
Photo: WO2 Gary Ramage

7.2 External Load

'I saw a rain and sweat drenched man in green, laden like a pack mule, aged 21 going on 50, cutting his way through the jungle by day to find and attack the enemy, then laying all night in paddy fields or on trails in ambush…'

Brigadier Colin Kahn, DSO, former CO of the 5 RAR
Dawn Service Address, 1987
detailing mental images that summed up Vietnam
quoted in Australia's Vietnam War by Doyle et al

Military personnel, regardless of service, may be required to carry loads as part of their vocation. These loads primarily serve four functions, these being; sustainment (e.g. food, water), protection (e.g. helmet, body armour), lethality (e.g. weapon, ammunition, grenades) and command and control (e.g. radio, battle management system). As the individual is asked to carry more, the load carried increases which in turn increase the energy requirements of the individual to carry the load. This increase in energy cost occurs regardless of whether personnel are standing, walking, running or climbing stairs.

Commanders and personnel conducting load carriage tasks need to carefully consider whether the benefit of any additional external load outweighs the additional energy cost and potential consequences associated with heavy load carriage (e.g. performance decrements in vigilance, responsiveness, decision-making, movement speed and marksmanship).

Based on predicted energy cost and sustainment time:

- An extra 10 kg carried will reduce marching speed by 0.5 km/hr to maintain the same energy expenditure.
- An extra 10 kg carried will reduce marching sustainment time from approximately 3 hrs to 2 hrs, assuming a base load of 40 kg and marching speed 5.5 km/hr over hard, flat terrain.

Picture thought to be of two infantry soldiers deployed to East Timor
Photo: Department of Defence

7.3 Load Distribution

'The soldier must be considered as an integrated system, rather than simply the aggregation of individual components'

COL J. Blain
Director Diggerworks

Generally, personnel have loads distributed around their bodies. Helmets and Night Vision Devices on the head; backpacks, webbing systems, and self-contained breathing apparatus suspended from the shoulders and distributed around the torso; weapon systems, mine sweeping wands and other stores in the hands; Pistols or Gas masks on the thighs; and boots on the feet.

A soldier of the First Mentoring Task Force on patrol in the Miribad Valley Region of Afghanistan. Photo: Department of Defence

Just as load weight impacts on the energy cost of carrying the load, so too does the distribution of load. Generally loads carried on the extremities are more costly than loads carried closer to the trunk. Optimal zones for load carriage are shown in Appendix A.

When moving across flat terrain and/or not likely to come under threat (i.e. agility unlikely to be required), optimal load placement is higher on the back, central and close to the trunk. This loading position will minimise the energy cost of load carriage. When crossing uneven terrain (cross country patrol), an unstable surface (ship boarding party) or likely to come under threat, loads should be placed centrally on the low to mid back and close to the trunk to improve balance and agility.

7.4 Movement Speed

'When you get shot at, you move as fast as you can…but it wasn't very fast. You are just tired. So tired.

Justin Kalentis, US Army, wounded in Afghanistan,
discussing the loads they were carrying
quoted in *The Seattle Times* (14 Feb 11)

As movement speed increases, the energy cost of carrying load increases. Some research even suggests that the speed of load carriage task is a more important factor than the weight of the load carried. As a general guide the associated energy cost of an increase in walking speed of 0.5 km/hr is equivalent to increasing external load by 10 kg.

Load and speed have a generally inverse relationship whereby increases in load reduce the speed at which load carriage tasks are completed. For example the energy cost of marching with a 35 kg load at 5.0 km/hr is similar to marching with a 50 kg load at 4.2 km/hr.

Based on predicted energy cost and sustainment time:

- By reducing marching speed from 5.0 km/hr to 3.5 km/hr you can carry an additional 15 kg for the same energy cost.
- Doubling external load from 20 to 40 kg whilst walking over hard, flat terrain at 3.0 km/hr will increase energy expenditure by ~ 29%. Doubling walking speed from 3.0 to 6.0 km/hr whilst marching with a 20 kg load over hard, flat terrain will increase energy expenditure by ~ 132%.
- Increasing marching speed from 5.0 to 6.0 km/hr with a 20 kg load over hard, flat terrain will decrease sustainment time from approximately 7 hrs to 3 hrs.

An Australian soldier struggles with his load in Somalia on Operation SOLACE
Photo: WO2 Gary Ramage

7.5 Distance and Duration

'…It was a series of forced marches, brief battles, consolidation and then further advances'

Captain Don Beard, RMO 3 RAR
discussing the pressure on soldiers over the
winter months during the Korean conflict
quoted in 'The Battle of Kapyong' by Breen.

As with speed of movement and load, there is an inverse relationship between task intensity and task duration. The harder the task (load or speed) the shorter the period in which the task can be sustained. In addition, as task duration increases, there is an increase in energy costs for maintaining the current effort. This occurs more readily with heavier loads or faster speeds of movement.

A potential means of limiting the impact of task duration on personnel load carriage ability is through the use of rest periods. Rest periods, are frequently used by Nepalese porters, allowing them to carry loads of over 100% body weight for long durations (work to rest ratio approximately 2.5:1).

Soldiers from the 1st Mentoring and Reconstruction Task Force's Combat Team Alpha, take a well earned rest after patrolling through the village of Sarab in Afghanistan.
Photo: CPL Rachel Ingram.

7.6 Terrain

'I have seen men standing knee deep in the mud of a narrow mountain track, looking with complete despair at yet another insurmountable ridge. Ridge after ridge, ridge after ridge, heart breaking, hopeless, futile country.

CAPT F Piggen, 3Bn,
in a letter to his headmaster
after reaching the end of the Kokoda trail
quoted in At the Front Line: Experiences of Australian Soldiers in World War II
by Johnston.

Defence personnel are required to negotiate various terrain types during load carriage tasks. From moving ship decks on small shipping vessels out at sea to land terrain in operational theatres that can vary from flat marsh lands to shale rocky hills in a single mission.

Terrains possess two challenges to load carriage tasks, there are terrain grade and terrain type. As the grade of terrain increases the energy cost of carrying a given load at a given speed increases. As a general guide 1% increase in surface gradient increases energy expenditure equivalent to a 10 kg increase in external load. Decline gradients have been shown to decrease energy cost, compared to walking over flat terrains. However, gradients beyond -8% begin to increase energy cost, compared to less severe downhill gradients, due to the increased work required to maintain stability.

Traversing harder, firmer surfaces (e.g. asphalt, dirt road), when compared to softer surfaces (e.g. swampy bog, loose sand), has been found to be more energy efficient when carrying a given load, at a given speed, over a given gradient (Figure 4).

Lower		ENERGY COST			Higher
Sealed Road	Dirt Path	Light Bush	Heavy Bush	Swampy bog	Loose sand

Figure 4. Scalar representation of energy costs associated with different terrain types.

Based on predicted energy cost and sustainment time:

- Marching through heavy bush, compared to a dirt road will increase energy cost by a similar amount to a 10 kg increase in load carried.
- Marching at 4.0 km/hr with a 40 kg load over hard terrain up a 2% gradient is equivalent to marching at 4.0 km/hr with a 60 kg load over hard, flat terrain.

Australian soldiers on an INTERFET patrol in East Timor on Operation ANNANDALE
Photo: WO2 Al Green

7.7 Climate

'A scorching day ahead. We do a route march through Durban and about 10 miles around it.

PTE Lynch
quoted in Somme Mud: The Experiences of an Infantryman in France 1916-1919
by Lynch (Edited by Davis)

Heat can impact on the load carrier through increasing thermal stress, and potentially lead to heat related injuries. In addition heat, through increasing fluid requirements, may increase the load an individual must carry. This increased load in turn, can have an additive effect and increase the risk of heat injury / illness.

In the cold, personnel use energy shivering and again may need to consume (and therefore carry) additional food supplies. Additional clothing to keep warm will increase total external load, which will increase the energy cost of load carriage.

Climate not only impacts on load carriage energy costs directly, but indirectly through changing terrain surfaces. For example, rain can increase an individual's load through the requirements to carry additional clothing and the additional weight of water laden equipment as well as through altering the surface of a dirt path to a muddy track, in turn increasing energy requirements to lift boots cacked in mud as well as to traverse a slippery path.

Based on predicted energy cost and sustainment time:

- Continuous marching at 5.5 km/hr with a 40 kg load over hard, flat terrain is sustainable for less than one hour in warm, dry conditions (30°C, 30% rh)
- Continuous marching at 5.5 km/hr with a 40 kg load over hard, flat terrain is sustainable for less than 30 min in hot, dry conditions (50°C, 10% rh)

A Special Operations Task Group member kneels in the snow of the Uruzgan mountains in Afghanistan.
Photo: Department of Defence

7.8 Altitude

At higher altitudes, generally above 1500 m, atmospheric oxygen levels decline. This in turn can reduce an individual's physical work capacity. However, repeated exposure to these higher altitudes will lead to physiological adaptations improving the individual's capacity to work at these levels. Thus highlighting the importance of pre-deployment acclimatisation and graduated in country preparation.

Soldiers from Bravo Company 4RAR patrol the high grounds in East Timor on Operation TANAGER.
Photo: WO2 Gary Ramage

Based on predicted energy cost and sustainment time:

- Based on continuous marching at 5.5 km/hr with a 40 kg load over hard, flat terrain the maximum march distances at sea level, 1500 and 2400 m are 14, 12 and 9 km respectively.

7.9 Hydration Requirements

'We were young and inexperienced with regard to Vietnam. This was Charlie's backyard and we were in it, plus all this weight, and it would be interesting to know how much weight we lost through sweat.'

SGT Frank Cashmore, SASR
quoted in SAS: Phantoms of War
by Horner

Load carriage demands, combined with environmental conditions, influence the member's nutritional requirements. Depending on the nature of the task, energy expenditure can exceed the energy provided in combat rations, increasing the need for dietary supplementation. The regular intake of fluids is vital to performance and illness prevention. Although water increases load weight, the increased external load needs to be balanced against the potential decrease in physical capacity associated with dehydration.

Commanders are to remain vigilant regarding the potential for heat injuries and illnesses and ensure they are well versed in supporting doctrine (Tri-service documentation is available on the Defence Occupational Health and Safety website under 'Heat Injury Management').

Based on predicted energy cost and sustainment time:

- Based on continuous marching at 5.5 km/hr with a 40 kg load over hard, flat terrain the maximum march distances whilst 0, 4 and 6% dehydrated are 14, 10 and 8 km respectively.

A solider from the Fourth Battalion Group stops for a drink while patrolling up the highest feature in East Timor to set up a retransmission station.
Photo: SGT William Gutherie

7.10 Mobility, Lethality and Survivability

> *'Ponk's men gave chase but they had no chance of catching up with the panicked militia who were unencumbered by the heavy webbing and flak jackets worn by their Australian pursuers.'*

quoted in Mission Accomplished: East Timor by Breen

Increases in external load weight, with its associated potential increase in physical load space, are associated decreases in mobility. Time to cover a given distance and the speed and ability to overcome obstacles are examples of these mobility limitations.

Heavy load carriage may lead to a degradation of marksmanship and grenade throw ability. Where possible, members should be provided with a suitable period of recovery (approximately 30 minutes) before taking on a task which may require application of weapon systems (eg. relief in place tasks).

A sailor from HMAS Toowoomba's boarding party prepares to enter the Rigid Hulled Inflatable Boat on Exercise TRITON STORM 2
Photo: Department of Defence

A soldier from the Reconstruction Task Force searches an abandoned building whilst on patrol north of Tarin Kowt, Afghanistan.
Photo: CPL Neil Ruskin

8. Strategies to Mitigate the Impact of Load Carriage

8.1 Physical Training and Load Carriage

Research has demonstrated that load carriage capacity can be enhanced with appropriate physical conditioning. Repeated exposure to walking with backpack loads has been shown to decrease the energy cost of load carriage (Knapik et al., 2004) and increase aerobic fitness (Rudzki, 1989). With respect to general physical training, programs that involve a combination of aerobic training (running) and strength training appear to be most successful in improving load carriage capacity, compared to training either component of fitness alone (Harman et al., 1997, Harman et al., 2008, Knapik et al., 2004). The improvement in load carriage performance from the combined training has been attributed to improvements in both upper body strength and aerobic fitness. The combination of loaded marching together with aerobic and strength training improves load carriage performance even further (Knapik et al., 1990, Knapik et al., 1996). With regard to the frequency of training sessions, evidence suggests that loaded marching should be undertaken two to four times per month under operationally relevant conditions (Knapik et al., 1990, Knapik et al., 2004, Orr et al., 2010, Visser et al., 2005). Both high-load-short-distance and moderate-load-long-distance training have been shown to improve loaded marching performance (Knapik et al., 1990, Orr et al., 2010, Visser et al., 2005). Load carriage training (e.g. load, speed, distance, frequency) should be progressive and consider individual characteristics and experience to mitigate the incidence of load carriage injuries (e.g. stress fractures) (Orr et al., 2010).

Whilst it is inappropriate to establish operational load limits as a percentage of the member's body mass, setting load as a percentage of body mass may be of use in the progressive physical conditioning of personnel for load carriage tasks. In a controlled training environment (e.g. Army Recruit Training Centre, Royal Military College - Duntroon) free from the influence of operational requirements, loads set as a percentage of body mass can be progressively increased towards an (operationally relevant) absolute end-point load. The Load Carriage Continuum Matrix for Single Service Training developed as part of the Royal Military College – Duntroon Physical Conditioning Optimisation Review (Orr, 2007) illustrates how loads set as a percentage of body mass can be used in the progressive load carriage conditioning of Army trainees (Table 4).

Table 4 Load Carriage Continuum Matrix for Army Single Service Training (SST) (adapted from Orr, 2007)

LOAD	SST1A	SST1B	SST2A	SST3A	SST3B
15% BM Under 60 kg = 8 kg Under 70 kg = 10 kg Under 80 kg = 11 kg 80+ kg = 13 kg	8 km Continuous marching Speed 5.5km/h Grade Flat to steep hills	15 km Continuous marching Speed 5.5km/h Grade Flat to steep hills			
27% BM Under 60 kg = 15 kg Under 70 kg= 17.5 kg Under 80 kg = 20 kg 80+ kg = 23 kg	5 km Continuous marching Speed 5.5km/h Grade Flat to mild hills	10 km Continuous marching Speed 5.5km/h Grade Flat to mild hills	12 km Continuous marching Speed 5.5km/h Grade Flat to steep hills	15 km Continuous marching Speed 5.5km/h Grade Flat to steep hills	
35% BM Under 60 kg = 20 kg Under 70 kg = 23 kg Under 80 kg = 26 kg 80+ kg = 30 kg		35% BM Patrol No faster than 5.0 km/hr 6 km per day maximum	8 km Continuous marching Speed 5.5km/h Grade Flat to mild hills	12 km Continuous marching Speed 5.5km/h Grade Flat to mild hills	15 km (CFA march)
47% BM Under 60 kg = 25 kg Under 70 kg = 30 kg Under 80 kg = 35 kg 80+ kg = 40 kg			47% BM Patrol No faster than 5.0 km/hr 6 km per day maximum	47% BM Patrol No faster than 5.5 km/hr 7.5 km per day maximum	
60% BM Under 60 kg = 33 kg Under 70 kg = 39 kg Under 80 kg = 45 kg 80+ kg = 50 kg				60% BM Patrol No faster than 4.5 km/hr 5 km per day maximum	

Understanding that external load, marching speed, marching surface and gradient collectively influence the energy cost of a load carriage task can assist in the load carriage conditioning of personnel. The energy cost of expected operational load carriage tasks can be replicated in training by manipulating one or more of the four load carriage factors listed above. It is suggested that where possible (and appropriate) external load remain unchanged, however marching speed, marching surface and surface gradient can all be manipulated to alter the intensity of a load carriage task and achieve equivalent energy cost. The reason for not altering operationally relevant loads is that, as discussed in Section 3.1, metabolic fatigue is not the only limiting factor during heavy and/or prolonged load carriage. Therefore load carriage training (or "work hardening") needs to simulate as much as possible the critical operational factors of load carriage tasks. Table 5 demonstrates how the energy cost of two representative operational load carriage tasks can be replicated during training simply by manipulating marching speed.

Table 5 Operational and In Barracks load carriage scenarios with equivalent energy cost, as predicted by the equation of Pandolf et al (1977).

Scenario 1		**Scenario 2**	
Operational example	**In Barracks training**	**Operational example**	**In Barracks training**
Undulating, dirt road Load: 25kg Marching speed: 4.0 km/hr	Flat, asphalt road Load: 25 kg Marching speed: 5.0 km/hr	Flat terrain, heavy scrub Load: 40 kg Marching speed: 3.0 km/hr	Flat, asphalt road Load: 40 kg Marching speed: 3.5 km/hr

Research clearly supports the conduct of specific physical conditioning and training prior to the operational requirement to undertake load carriage tasks (Orr et al., 2010). Progressive load carriage conditioning will improve performance and decrease the likelihood of adverse health outcomes (e.g. acute and/or chronic injury). For greatest benefit load carriage conditioning will reflect expected operational load carriage requirements, including the use of the specific equipment to be fielded on operations. A recent review (Orr et al., 2010) examining load carriage conditioning in the military context:

- Two to four evenly spaced load carriage sessions per month,
- Progressive increase in carried load, commencing with a light load and gradual increase towards military relevant load,
- Progressive increase in load carriage task duration/distance,
- Periods of recovery throughout the conditioning program to allow for recovery from the conditioning stimulus and consolidation of physiological adaptations,
- Supplemental physical training (i.e. aerobic training and strength training) to further improve load carriage capacity.

A soldier runs to the next obstacle during the Military Skills Competition in Timor Leste
Photo: AB Jo Dilorenzo

8.2 Command Strategies

Whilst formal Military load carriage limits may exist recent evidence suggests that they are not being adhered to and/or may not be viable. United States Army doctrine states that the ‘Fighting Load’ should equate to 22 kg, the ‘Approach March Load’ to 33 kg and the

'Emergency Approach March Load' between 55 and 68 kg (van Dijk, 2007). A field study of U.S. soldier loads in Afghanistan found that the soldier Fighting Loads and Approach March Loads were on average over 30% higher than doctrine recommended loads (Dean, 2004). Recent evidence suggests that Australian soldiers (i.e. Infantry, Combat Engineers and Artillery) involved in dismounted operations are regularly carrying loads in excess of 50 kg for prolonged periods, often in hot environments. To minimise the load carriage burden there are two key approaches available to the commander in preparation for a deployment: a) enhancing individual load carriage capacity and b) conducting mission specific planning (refer to Section 8). Further considerations for the commander that may assist in minimising load carriage burden are;

- Commanders should ensure that load carriage requirements are considered in conjunction with mission requirements, as opposed to as a separate entity or an after thought.
- Commanders should not rely on a generic "load list" for mission planning. Each individual mission should be planned and loads packed accordingly.
- Commanders need to avoid 'mission creep' and ensure only mission essential equipment/stores are carried in order to minimise loads carried.
- Educate personnel on appropriate methods of packing loads for optimal performance (refer Appendix A).
- Commanders should ensure load carriage equipment is functional, integrates with other combat equipment and is worn correctly. Poor load carriage equipment integration may be a limiting factor in load carriage tasks and/or battlefield performance.
- Acute injuries can significantly impact load carriage capability. Commanders are advised to keep close observation on personnel during load carriage activities, encourage buddy systems and reporting of potential injuries.
- The cumulative effects of load carriage can lead to injury. Commanders need to discriminate between necessary and unnecessary load carriage tasks.
- Where appropriate personnel should be provided with sufficient acclimatisation when moving into a new area of operations (e.g. hot and/or humid climate).

SGT Wagstaff, checks his pack before heading off on patrol in East Timor
Photo: CPL Chris Moore

9. Summary Guidelines

The multi-factorial nature of human load carriage capacity makes it difficult to provide definitive guidelines. Furthermore setting maximum absolute load limits or maximum intensity limits may be difficult to implement in the field and may not always be operationally possible. It is understood that mission requirements, operational constraints and threat profile dictate load carriage requirements. However mission planning needs to balance, to some degree, the requirements of the operational environment against the various physical considerations of personnel load carriage ability. Therefore, mission planners and commanders alike need to understand the impact of various load carriage variables on an individual's load carriage capacity and operational effectiveness.

Using the methods described in Section 2 and the physiological considerations contained in Section 3, a table (Table 6) has been developed to better guide commanders in assessing the physiological burden associated with load carriage tasks. Table 6 provides commanders with an appreciation for the ability of individuals to (continuously) sustain a given load carriage task, under various operationally relevant parameters. It is important to understand that continuous work sustainment time does not consider other factors such as muscle discomfort and muscle fatigue, load carriage equipment integration and load carriage conditioning. These factors are known to reduce load carriage capacity before physiological factors (e.g. energy depletion), under certain conditions. The information presented in Table 6 is also based on the assumption that individuals are adequately nourished, hydrated and rested prior to undertaking load carriage tasks.

Looking beyond the burden of a single load carriage task Figure 4 provides commanders with an overview of key considerations for the management (i.e. preparation, execution and recovery) of personnel undertaking repeated load carriage tasks.

Table 6 Estimated energy expenditure and continuous sustainment time for different loaded marching conditions. Each row demonstrates a change from the reference marching condition.

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.

Green	Ability to complete task and perform subsequent physically (aerobically) demanding tasks following march completion.
Yellow	Likely to complete march task but unlikely to be able to perform subsequent physically (aerobically) demanding tasks following march completion.
Red	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**	Green	1
Total external load	- 10 kg (30kg)	45	< 4.0 hr	15^{+} km	Green	1
	+ 10 kg (50 kg)	56	< 2.0 hr	9 km	Green	1
	+ 20 kg (60 kg)	63	< 1.0 hr	6 km	Yellow	1
Movement speed	Slow (2.5 km.hr-1)	21	> 12 hr	15^{+} km	Green	1
	Moderate (4.5 km.hr-1)	38	< 6.5 hr	15^{+} km	Green	1
	Fast (6.5 km.hr-1)	65	< 1.0 hr	6 km	Yellow	1
	Very fast (7.5 km.hr-1)	82	< 0.5 hr	2 km	Red	1
Terrain gradient	Uphill 1% Grade	56	< 2.0 hr	10 km	Green	1
	Uphill 3% Grade	67	< 1.0 hr	4 km	Red	1
	Uphill 5% Grade	78	< 0.25 hr	2 km	Red	1
	4% Downhill	46	> 3.0 hr	14^{+} km	Green	1, 2
Terrain surface	Medium-thick scrub	64	< 1.0 hr	6 km	Green	1

	Loose sand, 4.0 $km.hr^{-1}$	51	< 2.5 hr	10 km		1
	Soft snow 25 cm, 3.2 $km.hr^{-1}$	51	< 2.5 hr	8 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
Altitude	900 m	52	< 2.5 hr	13 km		1,46
	1,500 m	53	< 2.5 hr	12 km		1, 5-8
	2,400 m	57	< 2.0 hr	9 km		1, 5-8
Aerobic fitness *	Low VO_{2max} (3.23 $L.min^{-1}$)	60	< 1.5 hr	7 km		1
	High VO_{2max} (4.43 $L.min^{-1}$)	43	< 4.5 hr	15^{+} km		1
Body mass	Low body mass (71 kg)	47	< 3.5hr	15^{+} km		1
	High body mass(95 kg), low VO_{2max}	65	< 1.0 hr	5 km		1
	High body mass (95 kg),high VO_{2max}	47	< 3.5 hr	15^{+} km		1
Dehydration $^{\$}$	Minimal (2% body mass)	51	< 2.5 hr	12 km		1, 9, 10
	Significant (4% body mass)	52	< 2.0 hr	10 km		1, 9, 10
	Serious (6% body mass)	53	< 1.5 hr	8 km		1, 9, 10
+ 10 kg load, light scrub		60	< 1.5 hr	7 km		1
Low fitness, 4% dehydrated		60	< 1.5 hr	6 km		1
High body mass, low fitness		65	< 1.0 hr	5 km		1
Low fitness, 2400m altitude		68	< 1.0 hr	4 km		1

References: 1; Pandolf (Pandolf et al., 1977), 2:Santee (Santee et al., 2003), 3;Defence Safety Manual (Safetyman) (Department of Defence, 2007), 4; Terrados (Terrados and Maughan, 1995), 5; Faulkner (Faulkner et al., 1968), 6; Daniels (Daniels and Oldridge, 1970), 7; Sharkey (Sharkey and Davis, 2008), 8; Powers (Powers and Howley, 2009), 9; Caldwell (Caldwell et al., 1984), 10; Sawka (Sawka et al., 1985).

^ Based on Army continuous work table (Department of Defence, 2007) and Bureau of Meteorology prediction of wet bulb globe temperature (WBGT).

* The predicted VO_{2max} for an 83 kg soldier required to meet the Army Individual Readiness Notice (AIRN) pass standard for a male ≤ 25 years (11:18 min for the 2.4 km run) is 3.83 L/min, which is equivalent to a level 9-shuttle 8 beep test result. Low aerobic fitness is defined as a VO_{2max} of 3.23 L/min which is equivalent to a 13:10 min 2.4 km run time or a level 7-shuttle 8 beep test result for an 83 kg individual. A high aerobic fitness is defined as a VO_{2max} of 4.43 L/min which is equivalent to a 9:41 min 2.4 km run time or a level 11-shuttle 11 beep test result for an 83 kg individual.

$ Dehydration categorised according to National Athletic Trainers Association Position Statement: Fluid Replacement for Athletes (Casa et al., 2000Casa et al., 2000).

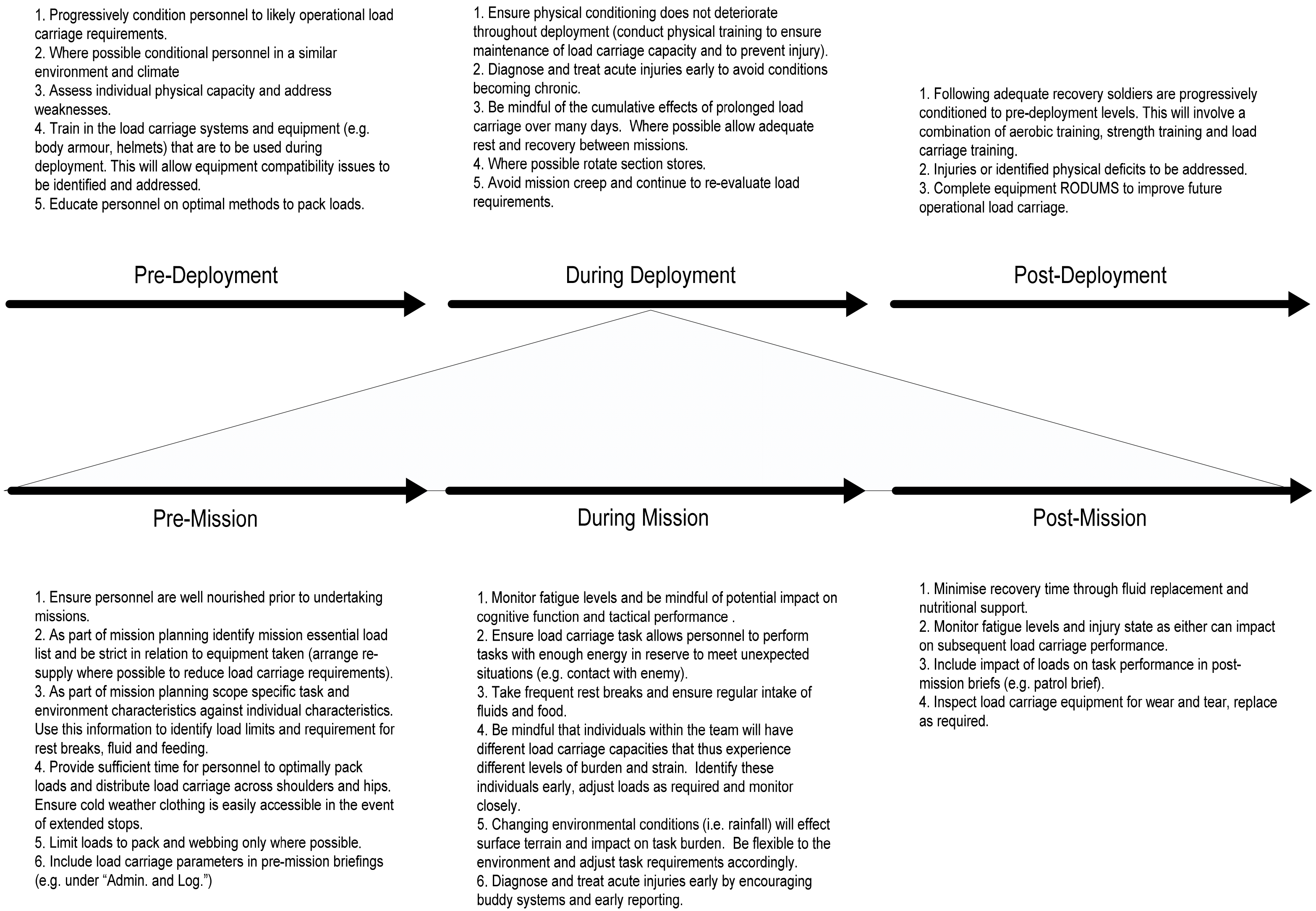

Figure 4 Load Carriage Planning and Management Cycle

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Appendix A: Guidelines for Pack Loading

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Load carriage, mission planning, physiological demands

19. ABSTRACT

There is a universal requirement for military personnel to carry an external load. The load of military personnel is typically comprised of clothing, protective ensemble (i.e. body armour, helmet), combat equipment (i.e. webbing, weapon systems, ammunition, power sources, radio) and sustainment stores (i.e. food and water). In addition, military operations often requires dismounted personnel to move, on foot, through various climates and terrains for long and continuous periods. The total load varies dependant upon factors such as mission requirements and threat profile. Recent evidence suggests that the individual's load is increasing with advancing technologies and personal protective equipment. Excessive external load may adversely impact upon an individual's physical capability (e.g. mobility, lethality) and health (e.g. survivability, thermal burden). It is therefore important we consider (likely) individual load carriage capacity in mission planning. 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, gender, age, injury profile, load carriage experience), 2) task characteristics (e.g. total external load, distribution of load, load carriage equipment design, movement speed, march duration, work to rest ratio) and 3) environment (e.g. terrain, heat, humidity, altitude) in which the task is performed. Some of these factors may in some situations be controlled (e.g. marching speed) whilst others are not (e.g. ambient temperature). There is a dynamic interaction between these factors which ultimately impact on an individual's load carriage capacity. When undertaking mission planning it is important for commanders to consider the factors influencing load carriage capacity and identify the likely burden. Such information will guide amongst other things, duration of operations, work to rest schedules, total load limits, replenishment and logistical support requirements. This planning is critical to the maintenance of dismounted personnel's operational effectiveness, battlefield performance and ultimately mission success. This document reviews existing scientific literature and established work physiology models for the development of evidence-based load carriage guidelines. These guidelines will place emphasis upon critical task elements and human factors with the intent of assisting commanders' in making decisions about tasks involving load carriage. It is important to understand however that load carriage guidelines are not definitive nor can they be generically applied to all load carriage scenarios, rather they establish general principles to assist the commander in mission planning. Furthermore setting maximum absolute load limits or maximum intensity limits may be difficult to implement in the field and may not always be operationally possible. It is understood that