THE UNIVERSITY OF QUEENSLAND
AUSTRALIA

Soldier Load Carriage: A Risk Management Approach

Lieutenant Robin Marc Orr

ADFPTI, BFET, MPhty

A thesis submitted for the degree of Doctor of Philosophy at

The University of Queensland in March 2012

School of Health and Rehabilitation Sciences

DECLARATION BY AUTHOR

This thesis is composed of my original work, and contains no material previously published or written by another person except where due reference has been made in the text. I have clearly stated the contribution by others to jointly-authored works that I have included in my thesis.

I have clearly stated the contribution of others to my thesis as a whole, including statistical assistance, survey design, data analysis, significant technical procedures, professional editorial advice, and any other original research work used or reported in my thesis. The content of my thesis is the result of work I have carried out since the commencement of my research higher degree candidature and does not include a substantial part of work that has been submitted to qualify for the award of any other degree or diploma in any university or other tertiary institution. I have clearly stated which parts of my thesis, if any, have been submitted to qualify for another award.

I acknowledge that an electronic copy of my thesis must be lodged with the University Library and, subject to the General Award Rules of The University of Queensland, immediately made available for research and study in accordance with the *Copyright Act 1968*.

I acknowledge that copyright of all material contained in my thesis resides with the copyright holder(s) of that material.

Robin Marc Orr
PhD Candidate

STATEMENT OF CONTRIBUTIONS TO JOINTLY AUTHORED WORKS CONTAINED IN THE THESIS

Orr, R., Pope, R., Johnston, V., & Coyle, J. (2010). Load carriage: Minimising soldier injuries through physical conditioning – a narrative review, *Journal of Military and Veterans' Health,* 18(3), 31-38.

> *Orr was responsible for the design of the study, data collection, data analysis, writing, editing, and submitting the article. Pope, Johnston, and Coyle supervised the design of the study, guided the data collection and analysis, reviewed progressive drafts of the paper, and provided detailed feedback.*

Orr, R., Pope, R., Johnston, V., & Coyle, J. (2011). Load carriage and its force impact, *Australian Defence Journal,* 185, 52-63.

> *Orr was responsible for the design of the study, data collection, data analysis, writing, editing, and submitting the article. Pope, Johnston, and Coyle supervised the design of the study, guided the data collection and analysis, reviewed progressive drafts of the paper, and provided detailed feedback.*

NOTE: This paper is currently being republished, with permission, in the *South African Army Journal.*

Orr, R., Johnston, V., Coyle, J., & Pope, R., (2011). Load carriage and the female soldier, *Journal of Military and Veterans' Health*, 19(3), 25-34.

> *Orr was responsible for the design of the study, data collection, data analysis, writing, editing, and submitting the article. Pope, Johnston, and Coyle supervised the design of the study, guided the data collection and analysis, reviewed progressive drafts of the paper, and provided detailed feedback.*

STATEMENT OF CONTRIBUTIONS BY OTHERS TO THE THESIS AS A WHOLE

Dr Rodney Pope, Dr Venerina Johnston, and A/Prof Julia Coyle assisted in the development of the research objectives, formulation of the research methodology and interpretation of the data. These members also provided thesis guidance through dedicated review of the manuscript, editorial assistance, and detailed comments.

Joan Rosenthal provided professional editorial services that included proofreading; review of grammar and syntax; sentence structure and voice; identification of ambiguity, jargon and repetition; and suggestions to improve brevity and clarity. Joan Rosenthal does not have academic expertise in the area of the thesis.

The candidate developed the research objectives, wrote the ethics applications, recruited the participants, conducted the research studies, conducted and interpreted the statistical analysis, and wrote and edited the thesis following feedback.

STATEMENT OF PARTS OF THE THESIS SUBMITTED TO QUALIFY FOR THE AWARD OF ANOTHER DEGREE

None

PUBLISHED WORKS BY THE AUTHOR INCORPORATED INTO THE THESIS

Orr, R. (2010). The history of the soldier's load, *Australian Army Journal*, *vii*(2), 67-88 – Incorporated in Chapter 3: A Historical Review of Soldier Load Carriage.

Orr, R., Pope, R., Johnston, V., & Coyle, J. (2010). Load carriage: Minimising soldier injuries through physical conditioning – a narrative review, *Journal of Military and Veterans' Health*, *18*(3), 31-38 – Incorporated in Chapter 2: Soldier Load Carriage: A Review of the Literature, and Chapter 6: Study C: Soldier Load Carriage and Physical Training.

Orr, R., Pope, R., Johnston, V., & Coyle, J. (2011). Load carriage and its force impact, *Australian Defence Journal*, 185, 52-63 – Incorporated in Chapter 2: Soldier Load Carriage: A Review of the Literature, Chapter 5: Study B: Load Carriage and its Associated Risks for the Soldier, and Chapter 9: Risk Treatments and Recommendations for Soldier Load Carriage.

Orr, R., Johnston, V., Coyle, J., & Pope, R. (2011). Load carriage and the female soldier, *Journal of Military and Veterans' Health*, *19*(3), 25-34 – Incorporated in Chapter 2: Soldier Load Carriage: A Review of the Literature.

Orr, R., Pope, R., Johnston, V., & Coyle, J. (2012). Load carriage and its force impact, reprinted *South African Army Journal (in press)* – Incorporated in Chapter 2: Soldier Load Carriage: A Review of the Literature, Chapter 5: Study B: Load Carriage and its Associated Risks for the Soldier, and Chapter 9: Risk Treatments and Recommendations for Soldier Load Carriage.

Poster presentations

Orr, R., Pope, R., Johnston, V., & Coyle, J. (2010). Load carriage: Minimising soldier injuries through physical conditioning – a narrative review, *PREMUS 2010, the Seventh International Conference on Prevention of Work-Related Musculoskeletal Disorders* in Angers, France (29 Aug 10 – 03 Sept 10).

Podium presentations

Orr, R., Pope, R., Johnston, V., & Coyle, J. (2011). Soldier Load Carriage: A Risk Management Approach, *Force Generation Lessons Board* in Sydney, Australia (10 Nov 11).

ADDITIONAL PUBLISHED WORKS BY THE AUTHOR RELEVANT TO THE THESIS BUT NOT FORMING PART OF IT

Drain, J., Attwells, R., Billing, D., & Orr, R. A Commander's guide to military load carriage, *Defence Science and Technology Organisation: Department of Defence* (under review).

Drain, J., Orr, R., Billing, D., & Rudzki, S. (2010). *Human Dimensions of Heavy Load Carriage.* Paper presented at the Land Warfare Conference 2010 in Brisbane, Australia 15 – 19 November 2010.

ACKNOWLEDGEMENTS

My principal advisor, Dr. Rod Pope: For mentoring me through this journey and both my personal and professional journeys with unfailing support and encouragement. You have given so much of your personal time and incredible knowledge with a patience bordering on the supernatural: I can only hope to emulate your example.

My principal advisor, Dr. Venerina Johnston: For trusting in my ability, encouraging me to expand my academic career, and reducing my stress immeasurably by taking the time and going the extra distance to help me through all the academic and administrative hurdles. Your wise counsel and the quiet chat we had in France opened my eyes to many possibilities. Thank you.

My associate advisor, A/Prof Julia Coyle: For teaching a high school drop-out English and for broadening my research horizons beyond my comfort zone. Your constant encouragement and words of wisdom kept me grounded and reminded me that there is an end – even if I could not yet see it.

Brigadier Simone Wilkie, FORCOMD: For undying support through my professional and academic pursuits over the last decade: You are a leader without measure, with a sense of humour to match.

Brigadier Stephen Rudzki, Joint Health Command: For invaluable assistance in encouraging and promoting my work. Your diversity and depth of knowledge and passion for improving the health of fellow soldiers is an inspiration.

Colonel Georgina Whelan, and Warrant Officer Class One Clayton Baker from FORCOMD and Warrant Officer Class One Andrew Cutts, 3 Brigade HQ: For tireless support in contacting (and re-contacting) units. Without you this work would never have been completed.

Major Anthony Watson, Land Warfare Development Centre: For your time and valued assistance in obtaining clearances for the release of the relevant defence doctrines.

Commanding Officers, Unit Coordinating Officers, officers and soldiers of the Australian Regular Army: For taking the time and making the effort to help me improve soldier load carriage. Your insights have expanded my knowledge and reminded me that there is still so much more to learn.

The Australian Defence Human Research Ethics Committee (ADHREC) and the University of Queensland Behavioural and Social Sciences Ethical Review Committee (BSSERC): For educating me in the world of research ethics and approving and supporting the research.

Dr. Asad Khan, University of Queensland and Dr. Michael Steele, Bond University: For your vital assistance in the general statistic appreciation.

Ms. Joan Rosenthal: For your dazzling editorial and linguistic skills. You preserved my sanity in the final hours.

My mother-in-law, Gaylynn and father-in-law, George: For your ongoing support and cheeky reminder to ‘get back into your study and do some work’ when distractions called to me.

My mother, Marilyn, and father, George: For giving me the passion to follow my dreams and the strength to never let obstacles stand in my way.

My wife, Andrea, and daughters, Samantha and Georgia: For support, love, and at many times, tolerance beyond measure: For the bacon and egg sandwiches in the mornings and coffees late at night and for the encouragement (and cuddles) when I was frustrated. To the three most beautiful women in my world, you are my inspiration and I am a better person because of you.

ABSTRACT

Soldiers must carry military equipment and move, on foot, over various terrains for long and continuous periods. While the equipment carried is often crucial to mission success and survival, its weight may be a source of risk to the soldier. Guided by the internationally recognised 5-step Risk Management Framework (RMF), a historical review and four cross-sectional studies were conducted to investigate the context of contemporary military load carriage within the Australian Regular Army (ARA), risks arising through load carriage, and current and potential risk management strategies.

The first RMF step is *establishing the context* in which risks take place. Following the literature review, a historical review explored the historical context of soldier load carriage through chronological narration spanning three millennia. Historical trends suggested that the *absolute* load carried by Australian soldiers, while commensurate with those of other nations, is increasing. Furthermore, history suggests that the ARA should not rely on changes in the nature of warfare or advances in technology to reduce the soldier's load.

Drawing the research into an Australian context, Study A investigated current ARA load carriage practices via an online survey. Distribution to key ARA units yielded 380 respondents who provided descriptive data on ARA load carriage practices. Loads carried by responding soldiers during physical training (PT), field training exercises, and military operations varied significantly in weight ($p<.01$) and in context. Mean ARA operational loads were reported as 28 kg in Patrol Order and 57 kg in Marching Order, again commensurate with other nations. Differences in loads and load carriage contexts between corps and genders were also identified.

The second RMF step is to *identify risks*. This requirement formed the basis of three distinct studies. Study B investigated injury and performance risks associated with the current ARA load carriage context. Self-reported injury and performance data were collected via the online survey used in Study A and injury surveillance data (2009 and 2010) were also collected through the Defence Occupational Health, Safety, Compensation and Reporting (OHSCAR) system. Within the surveyed population, 116 respondents (34%) reported sustaining an injury through load carriage and 218 (all respondents with operational experience) provided their perceptions of the impact of load carriage on operational task performance. In all, 1,954 OHSCAR load carriage injury data records were captured. The lower limbs were the most frequent site of injury, followed by the back. Fifty-one percent of respondents who reported suffering an injury while carrying load during initial training reported suffering additional load carriage injuries. Unexpectedly, a high frequency of heat illness was identified, with 31% of these injuries considered serious. On operational deployments, soldiers considered load carriage to negatively affect their performance in areas like attention to task, lethality and, most notably, mobility.

Study C examined the current load carriage PT undertaken by soldiers and units engaged in Studies A and B. Data were again gathered from online survey responses, as well as from the text of PT programs provided by units. The load carriage conditioning programs in training institutions and operational units, viewed through the lens of the F.I.T.T. (frequency, intensity, time and type of training) principle, achieved limited success in meeting established evidence-based guidelines for load carriage conditioning. Deficiencies were found across all four F.I.T.T. principle components in training institutions and operational units.

Study D reviewed the load carriage policies of the units engaged in Studies A to C and across the ARA in general. Data were gathered from responses to the online survey used in Study A, unit load carriage policies, and doctrinal texts. Textual data were analysed by content analysis. Shortfalls were identified in compliance with doctrine and unit policies and in the extent to which doctrine and unit policies met operational requirements. These discrepancies meant that many respondents were carrying loads heavier than doctrine or unit policy dictated.

As part of the third and fourth RMF steps, the risks identified through the above work were *analysed* and *evaluated.* Load weight was considered the primary risk factor associated with load carriage. In addition, the contexts in which the loads were carried were viewed as *risk modifiers* with the potential to influence *consequences* to *personnel* and *mission accomplishment* and their *likelihood* of occurrence. Following a *hierarchy of controls* model, potential *risk controls* were identified and considered to determine the extent to which they might reduce the risks posed by load carriage.

Constituting the fifth RMF step, *treating risks*, the risks requiring treatment were established and treatment options examined. These treatment options, comprising improved load carriage doctrine and policy controls, improved load carriage conditioning practices, and continued investment in soldier load reduction measures, were presented with short- and long-term options provided. Finally, transferability of this research to other vocational and recreational load carriers was discussed and further avenues of research were suggested.

KEYWORDS

load carriage, soldier, military, injury, training, risk management.

AUSTRALIAN AND NEW ZEALAND STANDARD RESEARCH CLASSIFICATIONS (ANZSRC)

110699 Human movement and sports sciences not elsewhere classified 100%.

AUTHOR'S CONFIRMATORY STATEMENTS

The opinions expressed in this study are those of the author and do not necessarily reflect those of the Australian Department of Defence or any extant policy.

The National Statement on Ethical Conduct in Human Research (developed jointly by the National Health and Medical Research Council, Australian Research Council and the Australian Vice Chancellors Committee, March 2007) has been adhered to during the conduct of this research.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS AND GLOSSARY OF TERMS

AAPOR	The American Association for Public Opinion Research
AC563	The notification and reporting form for all occupational health and safety incidents in the Australian Defence Force
ADF	Australian Defence Force
ADFA	Australian Defence Force Academy: a tri-service officer, initial training, university oriented, academy
ARA	Australian Regular Army
ARes	Army Reserve
CFA	Combat fitness assessment
CO	Commanding Officer
Doctrine	A concise expression of guidelines to meet conceivable military requirements
DRN	Defence Restricted Network
DSTO	Defence Science and Technology Organisation
F.I.T.T. principle	Acronym for frequency, intensity, time and type. The F.I.T.T. principle is used in the health and fitness industry to describe the principal requirements to be considered when determining a physical training dose
IET	Initial employment training: Trade training for enlisted soldiers following initial basic training
Injury	An injury, in the context of this program of work, occurs when a soldier is hurt in an incident not the result of enemy action (e.g. injured due to fall)
ISER	Institute for Social and Economic Research
JNCO	Junior Non Commissioned Officer. Ranks of Lance Corporal and Corporal (or equivalent in different corps)
JOFF	Junior Officer. Ranks of Lieutenant and Captain
LWD	Land Warfare Doctrine
LWP	Land Warfare Procedure
LTCOL	Lieutenant Colonel. The rank of the commanding officer of a unit
Marching Order (MO)	Marching Order is a form of military dress, generally for longer military operations (24 h +). MO configuration consists of Patrol Order and backpack. Additional components can include helmet, body armour, and personnel weapon system
MI	Military Instructor
MLW	*Manual of Land Warfare*
MOLLE	Modular Lightweight Load-Carrying Equipment
OC	Officer Commanding

OHS	Occupational health and safety
OHSCAR system	Occupational Health, Safety, Compensation and Reporting system
OR	Other Ranks. Private rank (or equivalent in different corps)
Pack or Ruck (U.S.)	A military-specific backpack forming part of a load carriage system
Patrol Order (PO)	Patrol Order is a form of military dress, generally for shorter duration military tasks (under 24h). PO includes fatigues, boots, and webbing. Additional components can include helmet, body armour, small patrol backpack, and personnel weapon system
PDF	Portable document format
PES	Physical Employment Standards. The standards required for a soldier to perform trade tasks for a given trade and across the ARA as a whole
POC	Point of Contact
Policy	In this instance, the collective term for Standing Operating Procedures, Standing Orders and Routine Orders
PT	Physical training
PTI	Physical Training Instructor
RMC-D	Royal Military College of Duntroon: An ARA officer training establishment
RMF	Risk Management Framework
SAID	Specific adaptations to imposed demands
SNCO	Senior Non Commissioned Officer. Ranks of Sergeant and Warrant Officer (or equivalent in different corps). Warrant Officer is the most senior non commissioned officer in the ARA
SNROFF	Ranks of Major and Lieutenant Colonel for this study
SPI	Serious personal injury
TOOCS	Type of Occurrence Classification System
Webbing	Webbing forms the basic component of a load carriage system. Fitted around the shoulders and waist or shoulders and chest, this system typically holds the more vital and used soldier stores (e.g. additional weapon ammunition)
Wound	A wound, in the context of this program of work, occurs when a soldier is hurt in an incident as the result of enemy action (e.g. gunshot wound)

1. INTRODUCTION

1.1. INTRODUCTION TO SOLDIER LOAD CARRIAGE

People undertake load carriage activities for a wide variety of reasons. Recreationally, hikers undertake walks with loads of up to 29% of their body weight (Lobb, 2004), over various distances,[1] terrains,[2] and elevations[3] for enjoyment or personal challenge. Conversely, as part of their activities of daily living and for survival, African women carry loads of up to 70% of their body weight on their heads (Charteris, Scott, & Nottrodt, 1989; Heglund, Willems, Penta, & Cavagna, 1995; Maloiy, Heglund, Prager, Cavagna, & Taylor, 1986). Vocationally, hired porters carry loads of up to 90% of their body weight along the Inca trails of Peru (Bauer, 2003) and up to a staggering 183% of their body weight in the Nepalese mountains (Bastien, Schepens, Willems, & Heglund, 2005; Malville, Byrnes, Lim, & Basnyat, 2001). Fire fighters carry loads made up of various forms of breathing apparatus, protective clothing, and fire fighting equipment (Park, Hur, Rosengren, Horn, & Hsiao-Wecksler, 2010). These loads of up to 37 kg are carried, often in environments of intense heat, while performing tasks that include stair climbing and dragging or carrying other people (Louhevaara, Smolander, Tuomi, Korhonen, & Jaakkola, 1985; Park, Hur, Rosengren, Horn, & Hsiao-Wecksler., 2008; Richmond, Rayson, Wilkinson, Carter, & Blacker, 2008; von Heimburg, Rasmussen, & Medbo, 2006).

Perhaps the most infamous load carrier of all is the foot soldier. From the ‘Marius mules’ of the Roman legions (Roth, 1998) to the ‘grunts’ of the American infantry (Melson, 1998), soldiers in the field typically carry loads for prolonged periods (Polcyn, Bensel, Harman, & Obusek, 2000) and cover long distances (Bigard, 2000). However, there is a risk to the soldier associated with carrying these loads. In excess, these loads have altered battle tactics (Lothian, 1921), reduced army size (Lothian, 1921), caused injuries (Lee, 2007), and resulted in soldier deaths in previous conflicts (Marshall, 1980). In more recent theatres of war, these loads have been imputed with reducing soldier effectiveness (Breen, 2000; McPhedran, 2009a), causing soldier injury (Lowell Sun, 2010) and, by reducing mobility while under enemy fire, causing combat wounds (Bernton, 2011a). On this basis, load carriage presents risks of both injury and reductions in soldier effectiveness.

---

[1] From a 6 km march between campsites to the total 440 km of the Hume and Hovell Trail as an example.

[2] From beach sands on the ‘Bay of Fires’ lodge walks in Tasmania to the dirt and mud tracks of the Kokoda trail.

[3] From the flat shores on the Bay of Fires’ lodge walks to the steep sections of the Machu Picchu trail.

Technology is often called upon to address these load carriage concerns and to address the negative consequences of heavy load carriage on the soldier. The use of technology in an attempt to reduce the soldier's load is not new and can be traced back to Assyrian soldiers who continually experimented with their shields in order to reduce their loads (Gabriel, 2002). Today, technology is expected to provide solutions to the soldier load problem, with 'soldier modernisation' programs being undertaken by numerous defence forces across the globe[4] (Baddeley, 2007; Basan, 2007; Bossi & Tack, 2000; Curlier, 2004; Jackson, 2004; Reid, Bryant, Stevenson, & Doan, 2000; Reid & Whiteside, 2000; Siebrand, 2002). These modernisation programs include focus on a range of issues that either directly (e.g. new load carriage systems) or indirectly (e.g. improving mobility or technological equipment integration) impact on the soldier's load carriage systems (Baddeley, 2007; Basan, 2007; Jackson, 2004; Reid, et al., 2000; Reid & Whiteside, 2000).

Unfortunately, modernisation programs often have countervailing effects where loads are reduced in one area only to be returned in another. For example, load reduction resulting from reducing the weight of combat body armour (Bernton, 2011a) is counterbalanced by the inclusion of batteries into body armour to power other systems (Kuchment, 2010). Whereas transport options may have reduced the soldier's load, signals equipment (e.g. AN/PRC 117F: 4.5 kg), Laser Range Finders (e.g. GVS-5: 2.3 kg) and body armour (e.g. Interceptor Body Armour with SAPI plates: 8 kg) have returned the weight to the soldier (Brown, Hobson, Kerr, et al., 2010; Mayville, 1987; Owen, 2008; Task Force Devil Combined Arms Assessment Team, circa 2003). In ways such as these, rather than technology improving the load carriage circumstance for the soldier, the opposite is occurring. That is, the soldier is considered to be '*overburdened with the weight of his technologies*' (Task Force Devil Combined Arms Assessment Team, circa 2003).

There is a range of proposed technological aids that are currently undergoing development to assist in reducing the soldier's load, including the Multifunction Utility/Logistics Equipment to carry the soldier's pack (Bachkosky, Andrews, Douglass, et al., 2007), unmanned aircraft systems that can drop additional stores to soldiers (Siuru, 2010), a lower body exoskeleton that attaches to the soldier (Pappalardo, 2004; Schiffman, Gregorczyk, Bensel, Hasselquist, & Obusek, 2008), and modifications to existing equipment, like a suspended load backpack system (Xu, Hsiang, & Mirka, 2009). However, such aids may not always be available or be a viable means of assisting the soldier in load carriage and, in the end, the soldier will have to carry heavy loads (Stringer, 2000).

---

[4] Examples of these defence forces (and programs) include: Australian (Land 125/project WUNDURRA), Canadian (IPCE), German (IdZ), Dutch (Dutch Soldier Modernisation Program), French (FELIN), Italian (Combattente 2000), Spanish (Combatiente Futuro), South African (African Warrior), British (FIST) and American (LAND WARRIOR and OBJECTIVE FORCE WARRIOR).

Moreover, contrary to design intent, these systems may in fact increase the soldier's energy requirements rather than decrease them (Gregorczyk, Hasselquist, Schiffman, et al., 2010). The load carriage system which the soldier uses to carry loads therefore becomes of increasing importance as it is within this system that the majority of the soldier's load will be carried (inside the soldier's backpack for example) (Task Force Devil Combined Arms Assessment Team, circa 2003).

Developing an effective load carriage system involves challenges, from applying the latest scientific knowledge regarding physiological and biomechanical factors affecting load carriage to integrating the system with other equipment. For example, research has found that shoulder straps in packs exert force on the neck, shoulders and upper back area, increasing skin pressure below the straps (Harper, Knapik, & de Pontbriand, 1997; Holewijn & Meeuwsen, 2000; Ling, Houston, Tsai, Chui, & Kirk, 2004), and increasing the potential for brachial plexus injury (Attard, 1985; Wilson, 1987). To mitigate these concerns, research has found that hip belt utilisation on a backpack can transfer some vertical load from the upper back and shoulders to the hips (LaFiandra & Harman, 2004; Reid & Whiteside, 2000). Hip belt utilisation also provides secondary benefits of requiring less trunk muscle activation, thereby facilitating improved gait pattern stability (Sharpe, Holt, Saltzman, & Wagenaar, 2008). Taking the need to transfer backpack weight from the shoulders to the hips into account, the *Modular Lightweight Load-Carrying Equipment* (MOLLE) was designed to replace the *All-purpose Lightweight Individual Carrying Equipment* (Lawson, 1998; Palmer, 1998). However, Harman, et al. (1999) found that while a person wore *Interceptor Body Armour* the MOLLE waist belt could not be cinched tightly enough to reduce weight on the shoulders. The Task Force Devil Combined Arms Assessment Team (circa 2003) found similar body armour and waist belt integration issues when reviewing the load carriage practices of U.S. soldiers during military operations in Afghanistan.

Apart from a loss of physiological benefits, integration problems have also affected soldier comfort and the utility of other equipment. Comparing two pack load carriage systems, Birrell and Hooper (2007) found that one backpack trial led, for a small number of participants, to the vest webbing cutting into the neck when they carried a 20 kg load. Likewise, Gourley (2003) found that once Interceptor body armour was donned, the combat fatigue pockets in the shirt become inaccessible. Finally, Harper et al., (1997) investigating gender differences in load carriage performance, found female soldiers reported more concerns than male soldiers with shoulder straps, pistol belts and backpack fit and stability. The authors go so far as to suggest that these equipment concerns may explain some of the differences in performance between genders. A potential cause for these integration and personal fit issues comes from the methods of design and modelling, which use, for example, a 50th percentile male manikin for studies (Reid, et al., 2000; Reid & Whiteside, 2000; Stevenson, Reid, Bryant, Pelot, & Morin, 2000). Thus, consideration of individuality is lost during the load carriage system design process. Although it may be argued that the load carriage system can be adjusted, there are often components, like the thickness of the shoulder straps, which are standardised and not adjustable. Observation by Sampson (2000), for example, suggested that the difficulties in donning the MOLLE experienced by subjects in his study may have come from individual anthropometric differences.

It is also important to acknowledge other factors, besides load itself, that impact on load carriage system development. The ability to disperse heat is of concern in the current operational environments of Iraq and Afghanistan, where temperatures are high and dehydration countermeasures demand that military personal carry additional water, and hence load. Unfortunately, while an internal frame allows a rucksack to be positioned nearer to the body's centre of gravity, an external frame is claimed to allow more heat and sweat to escape (Davies, 2000). This example highlights an instance where optimisation requirements (e.g. heat dispersion and optimal load positioning) may conflict with each other.

These examples demonstrate how technology alone will not provide the solution to reducing the soldier's load or its adverse impacts. O'Connor and Bahrke (1990) noted that technology is expected to reduce load carriage weight by only six per cent in total. Based on that figure, the average U.S. soldier carrying a load of 43 kg or a mean 55% of his or her body weight in Afghanistan would lighten the load by 2.6 kg and thereby reduce the *absolute* load to 40.4 kg or 51% of the body weight. This figure is still far short of the U.S. policy guideline which recommends a maximum 'Approach March Load'[5] of 32.7 kg (72 pounds) (Department of the Army, 1990). On this basis, further research into the loads and context of military load carriage is essential if alternative, viable, solutions are to be identified, implemented and evaluated.

1.2. MAJOR TOPICS FOR THE CURRENT RESEARCH

As noted in the preceding discussion, the adverse impacts of soldier load carriage on the soldier include causing injuries, wounds and mortalities and reducing their combat effectiveness. In addition, despite best efforts, technology should not be relied upon to reduce the loads carried by soldiers or their adverse impacts. On this basis, there is a vital need to explore solutions in addition to technological solutions if soldier loads or their adverse impacts are to be effectively reduced.

---

[5] Approach March Load is akin to Australian Marching Order (described in the Glossary and Annex A: ARA Load Carriage Systems Orders-of-Dress).

Prior to searching for these solutions, however, the load carriage context of the soldier must be fully examined. Failure to fully explore load carriage factors other than load weight could reduce the impact of any potential solutions. For example, it has been suggested that the speed at which loads are carried and the terrain traversed have a greater physiological impact on the carrier than the weight of the load being carried (Crowder, Beekley, Sturdivant, Johnson, & Lumpkin, 2007; Soule, Pandolf, & Goldman, 1978). Thus, reducing the soldier*'s load* alone might not provide the most effective solution to the problems associated with load carriage (like the aforementioned soldier injuries and mortalities and reduced soldier effectiveness). Conversely, if reducing the soldier*'s load* is not a viable option, manipulating other components of the load carriage context, like speed and terrain, could be potential solutions. Moreover, expanding examination of the current military load carriage context to include a historical review provides an opportunity to learn lessons from the past. In this instance, solutions that have been previously implemented to improve soldier load carriage, and the impact of these solutions, can be evaluated.

Once the wider load carriage context has been established, a detailed appreciation of the risks associated with the load carriage context and their impacts on the soldier must be developed. Physical injuries provide one source of risk to the soldier associated with load carriage. Injuries identified in the literature range from blisters, lower back injuries and knee and foot pain to stress fractures, meralgia and brachial plexus palsy (Charteris, 2000; Corkill, Liberman, & Taylor, 1980; Fargo & Konitzer, 2007; Greaney, Gerber, Laughlin, et al., 1983; Kelly, Jonson, Cohen, & Shaffer, 2000; Knapik, Reynolds, & Harman, 2004; Knapik, Reynolds, Staab, Vogel, & Jones, 1992; Makela, Ramstad, Mattila, & Pihlajamaki, 2006; Milgrom, Giladi, Stein, et al., 1985; O'Connor, 2000; Pester & Smith, 1992; Pope, 1999; Reynolds, White, Knapik, Witt, & Amoroso, 1999; Rudzki, 1989; van Dijk, 2009; Wilson, 1987). Another source of risk to the soldier is a reduction in military task performance. Loads carried by soldiers have been observed to impact on soldier mobility, marksmanship, grenade throw ability, general task performance and attention to task. (Frykman, Harman, & Pandorf, 2000; Harman, Frykman, Pandorf, et al., 1999; Harper, et al., 1997; Hendrick, Paradis, & Hornick, 2007; Johnson, Knapik, & Merullo, 1995; Knapik, Ang, Meiselman, et al., 1997; Knapik, Staab, Bahrke, et al., 1991; LaFiandra, Holt, Wagenaar, & Obusek, 2002; Leyk, Rohde, Erley, et al., 2007; Leyk, Rohde, Erley, et al., 2006; May, Tomporowski, & Ferrara, 2009; Pandorf, Harman, Frykman, et al., 2002; Park, et al., 2008; Perry, Kiriella, Hawkins, et al., 2010; Polcyn, et al., 2000; Ricciardi, Deuster, & Talbot, 2008; Rice, Sharp, Tharion, & Williamson, 1999; Shoenfeld, Shapiro, Portugeeze, Modan, & Sohar, 1977). These aforementioned risks must be identified and examined in the Australian Army load carriage context, if effective solutions to load carriage concerns are to be designed to minimise the negative impacts of load carriage on the soldier.

Physically conditioning the soldier to carry loads is one potential solution. Research suggests that low levels of fitness have been associated with an increased risk of injury during load carriage tasks (Jones, 1983; Knapik, 2000). On this basis, physical conditioning might be a feasible means of minimising the risks of injury associated with load carriage and might even improve load carriage task performance (Buckalew, 1990; Genaidy, Mital, & Bafna, 1989; Harman, Gutekunst, Frykman, Sharp, et al., 2008; Knapik, Reynolds, & Harman, 2004; Maurya, Singh, Bhandari, & Bhatti, 2009; Soule & Goldman, 1969; Williams & Rayson, 2006). The need to condition soldiers to carry load can be traced back as far as the Roman legionnaires (Renatus, 1996). Flavius Vegetius, in his work *Epitoma rei militaris* (Epitome of Military Science), recommended that recruits carry a load of up to 60 Roman pounds (19.6 kg) and march for five hours in order to condition the soldier to carry arms and rations during campaigns (Lothian, 1921; Renatus, 1996). However, although it appears from the literature that physical conditioning may help prevent load carriage injuries and improve load carriage task performance (Buckalew, 1990; Genaidy, et al., 1989; Harman, Gutekunst, Frykman, Sharp, et al., 2008; Knapik, et al., 2004; Maurya, et al., 2009; Soule & Goldman, 1969), the training stimulus would need to involve a sufficient training dose to produce the desired training response (Bompa & Haff, 2009; Rudzki, 1989). Conversely, a training dose that is too high could have a countervailing effect and increase the soldiers' risks of injury (Bompa & Haff, 2009). Therefore, for a viable solution for mitigating load carriage risks, the correct training dose needs to be ascertained and then compared to current soldier practice.

Although physical conditioning to improve soldier load carriage capability may provide a potential solution, this suggestion should be tempered by the reminder that the physical body can be conditioned to carry only a certain amount of weight (Porter, 1992). On this basis, setting ceiling limits on the amount of weight that a soldier carries (and defining the contexts in which different loads can be carried) might provide a potential solution to soldier loads and their adverse impacts, especially in instances where additional stores are carried 'just-in-case' (O'Connor & Bahrke, 1990). This, of course, entails the proviso that soldiers and their commanders comply with specified load limits. The U.S. *Field Manual 21-18 Foot Marches* states that the 'Fighting Load'[6] carried by a soldier should equate to 48 pounds and the 'Approach March Load'[7] to 72 pounds (Department of the Army, 1990). However, a recent field study of U.S. soldier loads in Afghanistan found that the average soldier's 'Fighting Load' and 'Approach Marching Load' were both over 30% heavier than prescribed by the manual (Task Force Devil Combined Arms Assessment Team, circa 2003).

---

[6] 'Fighting Load' is akin to Australian 'Patrol Order' (described in the Glossary and Annex A: ARA Load Carriage Systems Orders-of-Dress).

[7] 'Approach March Load' is akin to Australian 'Marching Order' (described in the Glossary and Annex A: ARA Load Carriage Systems Orders-of-Dress).

Not only do formal guidelines providing governance over soldier load carriage practices need to exist, but these guidelines need to be followed if the policies are to provide a feasible solution for mitigating soldier load carriage risks.

1.2.1. Research Aims and Research Questions

The issues discussed above were all considered during the process of designing and defining the aims of the current program of research. These aims were to:

1. investigate the full context of contemporary military load carriage, including factors like duration of load carriage tasks, and terrains over which load carriage tasks occur;
2. identify risks arising from contemporary military load carriage for the soldier; and
3. identify and evaluate risk management strategies.

To achieve these aims, key research questions were derived, these being:

1. What is the contemporary context of soldier load carriage and is the current context a typical representation of soldier load carriage?
2. What are the risks of contemporary military load carriage to the soldier?
3. What role does physical training play in load-carriage-related injury and task performance risks?
4. Can load carriage policy be enhanced to more effectively control load-carriage-related injury and task performance risks?

A detailed examination of load carriage was undertaken to address these research questions, utilising a risk management approach.

1.3. THE RISK MANAGEMENT FRAMEWORK AND THESIS OVERVIEW

1.3.1. Overview of the Risk Management Framework

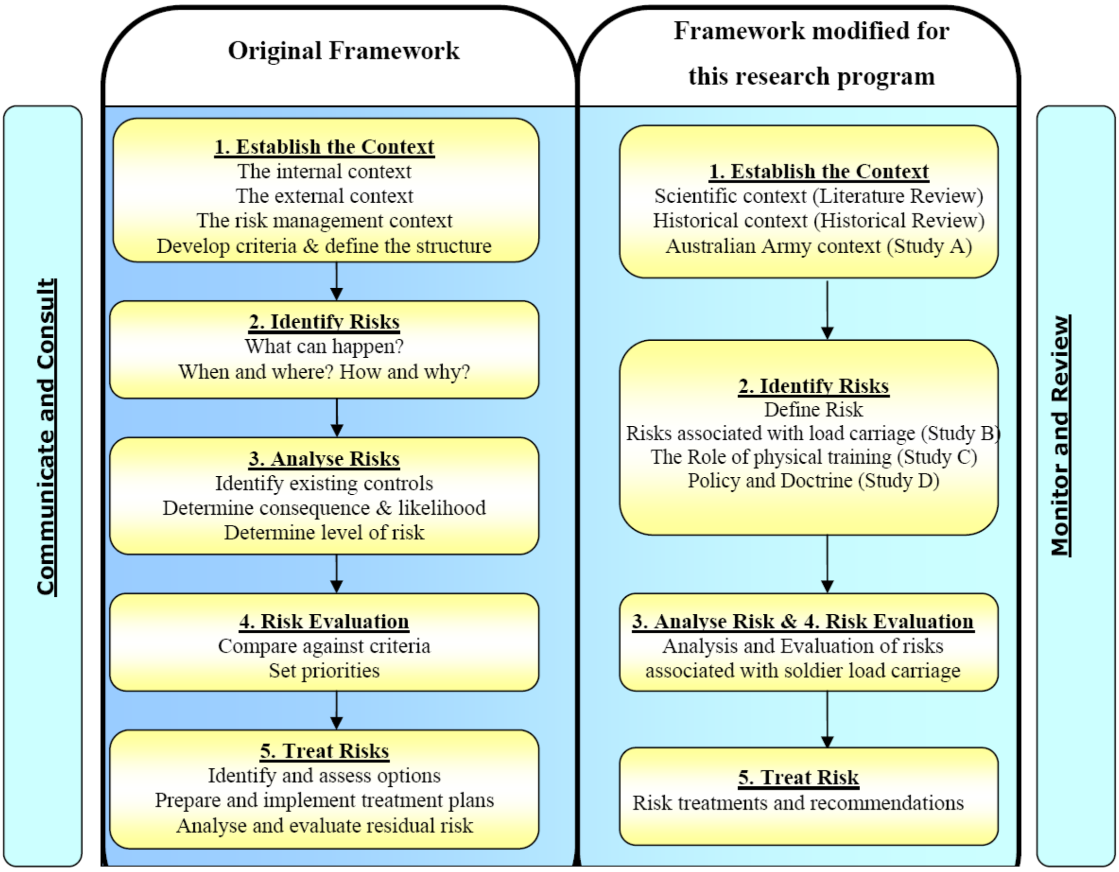
Risk can be defined as the chance of something happening that will have an impact on objectives (Standards Australia Working Group MB-002-01, 2004b) with, in this instance, objectives being the objectives of an event, or events. Often risk is portrayed in terms of an event (e.g. a load carriage march) and the consequences (typically unfavourable) that may flow from it (e.g. injury). Due to the multifaceted nature of the ‘event’ (soldier load carriage), a framework for the research that is capable of dealing with complex and diverse data and information in a systematic way was vital to the success of this research program. Furthermore, given that load carriage is a concern to the international defence community, the framework needed to be one that not only was internationally recognised but also met international standards. Finally, if the findings of the research program were to be implemented, a framework for the research was desirable which provided a ready mechanism for communication with military personnel and processes and which facilitated the translation of the research findings into practice. With these criteria in mind, the Risk Management Framework (RMF) was selected to guide this program of research.

The RMF, a nationally and internationally recognised framework (Australian Army, 2007a; International Electrotechnical Commission, 2009; Standards Australia, 2009; Standards Australia Working Group MB-002-01, 2004a, 2004b, 2004c), was selected as the framework within which the current research would be undertaken. The RMF was selected for the following reasons:

- the RMF is an internationally recognised framework;
- the RMF process allows the input, analysis, and evaluation of a high volume of contextual and risk information, including that derived from research, and provides outputs which can inform design of treatments for identified risks in a manner commensurate with the military approach to risk management (Australian Army, 2007a); and
- the RMF is closely aligned with, and can feed information directly into, the Military Risk Management (MRM) framework, which in turn guides the Military Appreciation Process (MAP), a process which guides military commanders and leaders to make well-reasoned and logical decisions (Australian Army, 2007a).

The RMF is essentially a five-step process, with two parallel processes continually feeding into these steps (Figure 1). Based on several key documents (International Electrotechnical Commission, 2009; Standards Australia, 2009; Standards Australia Working Group MB-002-01, 2004a, 2004b, 2004c), a brief overview of each step is given below.

Figure 1: The original risk management framework and the framework modified for this research program (modified from Standards Australia (2009) and Standards Australia Working Group MB- MB-002-01(2004b)).



The first step in the RMF is to *establish the context.* In this step the context in which the activity of interest (load carriage) is undertaken and in which associated risks are to be identified and must be managed is determined. Traditionally the fields that are explored in this step are (International Electrotechnical Commission, 2009; Standards Australia, 2009; Standards Australia Working Group MB-002-01, 2004a, 2004b, 2004c):

- *The internal context*: The organisation within which the activity occurs or is managed and through which the risk management process will be undertaken (e.g. culture, structure, internal stakeholders, capabilities, etc.).
- *The external context*: The environment in which the organisation operates (e.g. competition, financial and political environment, external stakeholders, key business drivers, etc.).
- *The risk management context*: The aim, objectives, strategies, scope, etc. of the organisation to which the risk management approach is being applied. These features are determined in order to ensure that the risk management approach is suited to the organisation and to the risks which are affecting achievement of the organisation’s objectives.

- *Develop risk criteria*: The criteria are determined against which the identified risks are to be evaluated in order to enable their categorisation by type and prioritisation for treatment. This process is potentially influenced by stakeholders, legal and regulatory requirements and perceptions, and determines the types and levels of risk that are important to the organisation in managing the activity or activities of interest.
- *Define the structure*: A logical framework and a plan for the specific risk management process are developed, ensure that relevant risks are not overlooked.

The second step is to *identify risks*. Here the risks that require management are identified. The sources of an identified risk are determined, with an attempt to establish the causal factors. The concepts of 'what can happen, where, when, why and how?' form the basis of this step (Standards Australia Working Group MB-002-01, 2004a, 2004b).

The third step is *risk analysis*. As the name suggests, the identified risks are analysed in order to develop an understanding of the likelihood that each risk will be realised and the types and severity of consequences that might result if the risks are realised (Standards Australia Working Group MB-002-01, 2004a, 2004b). This step usually culminates in an estimation of the level, or severity, of each identified risk by combining information regarding the likelihood and the consequence aspects of the risk, often through use of a risk matrix (Standards Australia Working Group MB-002-01, 2004a).

The fourth step is *risk evaluation*. Here decisions about the risk are made in order to categorise (by type) and prioritise the risks for treatment (Standards Australia Working Group MB-002-01, 2004a, 2004b). These decisions are based on the findings of the risk analysis and the risk criteria.

Risks are compared against evaluation criteria established in the first step of the RMF, and those risks requiring treatment are thereby identified and prioritised. If required, a decision to undertake further analysis of a risk can be made.

The fifth step is to *treat risks.* During this step, options to treat priority risks are identified and then assessed. Treatment plans are developed, taking into account proposed actions and timelines (Standards Australia Working Group MB-002-01, 2004a, 2004b). Proactive contingency planning can be developed to mitigate potential threats.

Two additional parallel and ongoing elements of the RMF exist. The first ongoing element is *monitoring and reviewing*. With the potential for change in the context, risks and causal factors during the course of the risk assessment process, ongoing monitoring and reviewing of these issues are essential. While seeking potential or evolving risks, this process can also be used to learn lessons from previous risk management strategies and to determine the success of any previously implemented risk treatment strategy (Standards Australia Working Group MB-002-01, 2004a, 2004b).

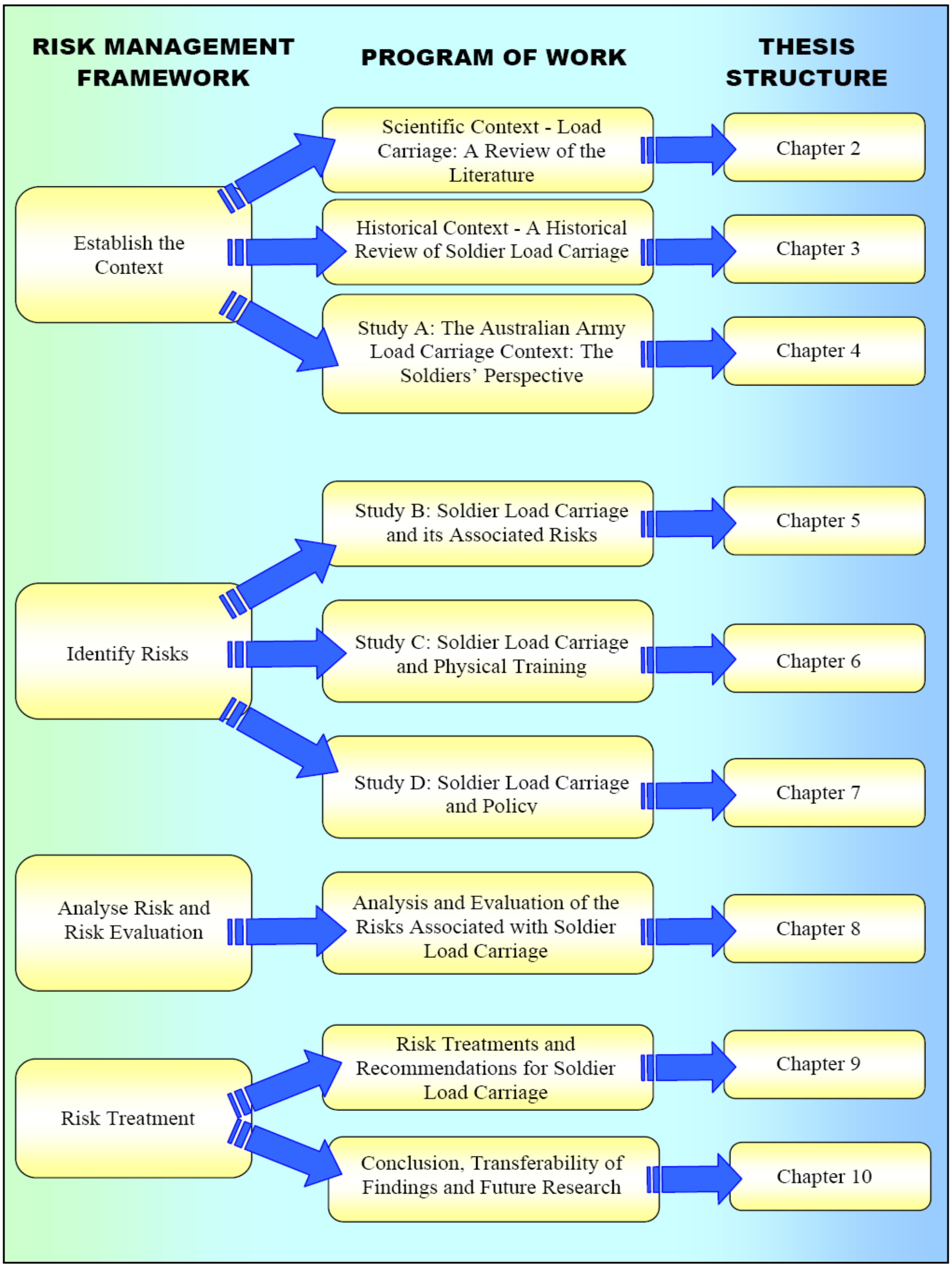
The second additional, parallel and ongoing element in risk management is *communication and consultation*. This parallel process allows for dissemination and gathering of information throughout the risk management process, thereby keeping internal and external stakeholders informed of each step and meeting the information requirements of each step. Moreover, the provision of rationales for decisions made is important not only for those with a vested interest in the outcomes but also for those who implement any risk treatment strategies.

Recently, the RMF standards framework (Standards Australia Working Group MB-002-01, 2004b) was updated by Standards Australia (Standards Australia, 2009). Although the overarching policy was updated, the structure and elements of the RMF itself remain the same in both the updated and superseded versions (Standards Australia Working Group MB-002-01, 2004b; Standards Australia, 2009). While acknowledging in this thesis that the 2004 RMF policy was superseded, the 2004 document and its supporting documents (Standards Australia Working Group MB-002-01, 2004a, 2004c) were retained for this program of research as these documents are still currently employed by the Australian Regular Army (ARA).

1.3.2. Use of the RMF for this Research and Thesis Overview

The steps and processes described above are standardised (ISO 30001), but the RMF does allow adaptability in its constructs to meet specific needs (Australian Army, 2007a). For this research, while the standard framework was employed, some nomenclature and foci were adapted in order to appropriately situate the framework within the current military research setting. These modifications were necessary to ensure that the required data were captured to answer specific research questions, as discussed below. Figure 2 represents an overview of the research reported in this thesis and its relationship to the RMF. Each part of the program of work is then discussed in further detail, to conclude this chapter and provide the reader with a clear overview of the program of research that was conducted to inform the thesis.

Figure 2: Overview of the program of work presented in this thesis and its relationship to the RMF.



Establishing the Context

To *establish the context*, three aspects of the load carriage context were explored: the current scientific context (the 'state-of-the-science' associated with load carriage), the historical context, and the current ARA load carriage context. Through these contextual aspects, the basic constructs of the risk management context and risk evaluation criteria were also established. These aspects of context were addressed in the following reviews and studies:

The Scientific Context – Soldier Load Carriage: A Review of the Literature (Chapter 2)

To establish the current scientific context or ‘state-of-the-science’ of contemporary military load carriage, a comprehensive review of load carriage literature was undertaken. This review focused on academic literature and professional knowledge in order to address four key areas:

1. the body’s physiological and biomechanical response to load carriage;
2. the influence of the carrier’s physical composition on load carriage;
3. the impact of load carriage on the soldier; and
4. the impact of load carriage conditioning on the soldier.

The Historical Context - A Historical Review of Soldier Load Carriage (Chapter 3)

A Historical Review of Soldier Load Carriage, continuing to *establish the context* of military load carriage, explored the history of the soldier’s load through a historical review. This review was designed to answer two key questions:

1. What historical trends in soldier load carriage can be identified from the literature?
2. What lessons can be learned from history to inform future soldier load carriage practices in Australia?

While several papers (Lothian, 1921: Knapik et al., 1989; 2000; 2004) and one text (Marshall, 1980) have briefly reviewed the history of soldier load carriage, this Historical Review is unique in that it not only provides a more rigorous approach to data capture, but it expands to consider the context in which soldier loads were carried (including the nature of warfare, distances marched, terrain and weather). Furthermore, unlike the previous papers identified above, this review included data of Australian forces.

Study A: The Australian Army Load Carriage Context: The Soldier’s Perspective (Chapter 4)

Study A (Chapter 4) finalised the process of *establishing the context* by examining the current context of military load carriage. The ARA (described in Appendix A) formed the setting in which this survey-based study was conceived and undertaken with the intention of answering key research questions:

1. What loads are currently carried by Australian Army soldiers, in training, during field training exercises activities and during military operations?
2. What are the characteristics (tasks, duration, terrain, etc.) that form the context of these load carriage activities?
3. Do the current load carriage weight and context vary with corps or gender?

Study A is significant in collecting not only Australian Army load carriage data weights and those of individual corps, but including the context in which these loads were carried (durations and terrain) and the nature of the load carriage activity (physical training, field training exercise or operations). Importantly, the results of this study provided an opportunity to compare current Australian Army load carriage practices with those of other international defence forces.

Risk Identification

The *Risk Identification* process of the RMF involves the identification and classification of risks associated with the activity or activities of interest and the determination of risk sources and mechanisms. On this basis, three key processes were established: Defining risk, identifying risks that exist, and determining sources and mechanisms of identified risk. These processes were addressed in the following reviews and studies:

Study B: Load Carriage and its Associated Risks for the Soldier (Chapter 5)

Study B (Chapter 5) employed a cross-sectional design using a survey of ARA personnel (the same survey as used in Study A) and data from ADF injury records to identify injuries that had occurred in a recent historical period, in order to inform the *Risk Identification* process of the RMF. This study identified risks associated with contemporary military load carriage in the ARA. Following provision of a definition of 'risk', the following research questions were addressed:

1. What are the frequencies, body sites, and mechanisms of load carriage injuries and what activities are commonly being performed at the times when these injuries occur?
2. What impacts do soldiers perceive load carriage has on their combat performance?
3. What are the consequences of injuries and performance impairments induced by load carriage on the soldier?

Study B was unique in that, unlike previous research investigating military injuries following a single load carriage marching event (Knapik, et al., 1992; Reynolds, et al., 1999), it provided insights into load carriage injuries sustained during a variety of military activities and spanned multiple load carriage events. Moreover, the study allowed the investigator to capture soldier perceptions of the impact of their loads on task performance while deployed on military operations.

Study C: Soldier Load Carriage and Physical Training (Chapter 6)

Study C (Chapter 6) examined the current programs of physical conditioning for load carriage undertaken by soldiers and units that participated in Study A. The physical conditioning programs were reviewed against best practice suggested by the literature (Chapter 2). This study focused on two research questions:

1. Does the load carriage PT currently undertaken in ARA training institutions and in operational units reflect evidence-based guidelines for optimal load carriage conditioning?
2. Is there a gap between current load carriage conditioning practices and load carriage requirements?

The cross-sectional research design once again gathered data from the responses provided through the online survey employed in Study A, as well as from the text of physical training programs provided by the selected units. Investigating load carriage conditioning practices of the Australian Army, Study C is original in its review of load carriage conditioning practices, both reported and programmed, against best practice guidelines developed in this study through interpretation of the available literature. In addition, the current reported load carriage practices of the Australian Army are compared to their training and operational requirements.

Study D: Soldier Load Carriage and Policy (Chapter 7)

Study D (Chapter 7) examined the load carriage policies of the units recruited in Study A and across the ARA in general. Overarching ARA policy doctrines were compared to unit policies and orders which were in turn compared to the practices reported by individual soldiers. From a strategic through to tactical level, this study focused on two key research questions:

1. What doctrines and policies detail the loads to be carried by Australian soldiers?
2. Do soldiers consider that the loads they carry meet with unit policies?

While one study (Task Force Devil Combined Arms Assessment Team, circa 2003) has compared current U.S. military load carriage practices against guidelines stipulated in policy, Study D is novel in that it not only compares Australian Army load carriage practices against policy during military operations, but also extends to examine the content of these governing doctrine and polices. Furthermore, the Australian Army soldier’s perceptions of compliance to these formal documents are also examined.

The results of the Literature and Historical Reviews (Chapters 2 and 3) and Studies A through D (Chapters 4 through 7) have formed the basis of papers published in the *Australian Army Journal*, the *Australian Defence Journal*, the *Journal of Military and Veteran's Health* and a text manual, *A Commander's Guide to Military Load Carriage*, to be published by the Department of Defence.[8] In addition, the work contained in this thesis has informed a joint conference paper with the Defence Science and Technology Organisation (DSTO) presented at the 2010 Land Warfare Conference, a poster presented at PREMUS 2010 (the Seventh International Conference on Prevention of Work-Related Musculoskeletal Disorders), and presentations for the Australian Army, the first of which took place at the Forces Command, Force Generation Lessons Board, in Nov 2011.

Risk Analysis and Risk Evaluation

In the risk analysis and risk evaluation steps of the RMF, the identified risks were analysed and evaluated against the risk criteria developed while *establishing the context* (Step 1 of the RMF). The risk analysis technique for this program of research revolved around a risk-ranking matrix, and was designed to estimate the levels of severity of each identified risk. Consequence scales and likelihood scales, based on the gathered evidence, formed the basis of the matrix. Employing a risk tolerance threshold, risks were prioritised and determinations then made regarding whether the risks required treatment and the priorities for treatment.

Analysis and Evaluation of the Risks Associated with Soldier Load Carriage (Chapter 8)

Chapter 8 draws together key findings from the entire program of research, in an overarching synthesis of those findings. Through the lens of the RMF, the consequences of load carriage risk to the soldier and the likelihood of these consequences occurring are discussed. Risk modifiers are drawn from the information provided in the preceding chapters and current risk control measures are considered. The chapter progresses to discuss risks that require treatment and treatment priorities.

Risk Treatment

In this step of the RMF, treatment plans to treat identified and prioritised risks are recommended (Standards Australia Working Group MB-002-01, 2004b, 2004c).

---

[8] Details of these works are provided on p. v.-vi.

Risk Treatments and Recommendations for Soldier Load Carriage (Chapter 9)

Chapter 9 presents three key risk treatment options that were identified through this program of research. These risk treatment options are discussed and the evidence supporting their use as soldier load carriage risk controls are presented. Framed through the use of short-and long-term targets, the risk treatment options are applied in a multifaceted approach to optimise their effectiveness and to provide collaborative support between options.

The results of this chapter informed a paper published in the *Australian Defence Force Journal* (currently being republished in the South African Army Journal) and form the basis of papers currently being prepared for both an internal military report and journal submission, and for formal presentations to senior military commanders and relevant Defence stakeholders. The first of these presentations took place at the Forces Command, Force Generation Lessons Board in Nov 2011.

Conclusion, Transferability of Findings and Future Research (Chapter 10)

Chapter 10 provides conclusions drawn from this program of research and considers limitations that influence the findings presented. The transferability of these findings to other occupational and recreational fields are discussed with international defence forces, protective services (police and fire departments) and recreational hikers and hiking companies examples of the other fields discussed. Finally, potential directions for future research are discussed, including formal trials of some of the proposed treatment strategies.

Additional RMF Processes

The additional RMF processes of *monitoring and reviewing* and *communication and consultation* were employed throughout the research process. Emerging literature and the ARA setting were continually monitored and reviewed to ensure that contextual changes were captured and the studies were informed by this process. Furthermore, once all research had been collected, new knowledge generated from this program of research was progressively disseminated to key stakeholders (Australian Department of Defence – Army) and the wider community. Collaborative consultation with stakeholders ensured that the knowledge was considered in emerging ADF projects and translated into practice as the research proceeded.

2. SOLDIER LOAD CARRIAGE: A REVIEW OF THE LITERATURE

2.1. A REVIEW OF THE LITERATURE

The health and safety of our military forces is essential to national security. On that basis, identification and management of risk factors that have the potential to degrade health and safety are important processes. Currently, there is a requirement for soldiers to manually carry loads (Knapik, et al., 2004). In excess, these loads have led to injuries and impaired performance (Knapik, et al., 2004). These adverse outcomes have eroded military force size and capability in previous (the beaches of Normandy as an example) and recent engagements (Afghanistan as an example) (Jordan, 2011; Lothian, 1921). As such, the risks of injury and performance impairment associated with contemporary military load carriage constitute risks to the generation and sustainment of military forces.

As discussed in Chapter 1, if risks associated with military load carriage are to be effectively addressed, a framework is needed which allows for the input, analysis, and evaluation of a high volume of diverse risk information, and which provides outputs that are not only applicable to treating the identified risks, but also commensurate with the military approach to risk management. The Risk Management Framework (RMF) (described in Chapter 1) is an internationally recognised framework that meets these needs (Australian Army, 2007a).

The first step in the RMF is to *establish the context* (Standards Australia Working Group MB-002-01, 2004a, 2004b, 2004c). This initial step must be thorough, as features of the contexts in which the risks exist (e.g. load weight) and the contexts that surround these risks (for example, how the load is carried) must be examined in order to assess the risks and the opportunities that might exist in these contexts (Australian Army, 2007a). For this body of research, the RMF step of *establishing the context* has been divided into three key elements. Discussed in detail in Chapter 1, these elements are:

a. The scientific context (or ‘state of the science’) of load carriage, addressed by review of pertinent research literature (this chapter);

b. The historical context of load carriage, addressed in the Historical Review of Soldier Load Carriage (Chapter 3); and

c. The ARA load carriage context, addressed in Study A (Chapter 4).

2.1.1. Review Methodology

The aim of this literature review was to seek out, draw together, critically evaluate and synthesise pertinent information from the various fields of load carriage research (physiology, biomechanics, injuries, performance, etc.) in order to establish the scientific context for load carriage. This review focused on academic literature and professional knowledge generated from previous research in order to inform the current body of research. In particular, the key topic areas addressed in the current review were:

1. the body's physiological and biomechanical response to load carriage;
2. the influence of the carrier's physical composition on load carriage;
3. the impact of load carriage on the soldier;
4. the impact of load carriage conditioning on the soldier; and
5. the impact of doctrine and policy on soldier load carriage.

Literature Search

Research papers and articles were gathered from numerous sources. Using databases as an initial starting point, key search terms were entered into MEDLINE (1950 to December 2010); PUBMED (1951 to December 2010); CINAHL (1982 to December 2010) and PROQUEST (Health and Medical Complete; Military Module) (inception to December 2010).[9] These key search terms were also entered into the Australian Defence Force intranet site (DEFWEB). The databases and key search terms, which varied slightly depending on the specifics of the databases' search engines, are detailed in Table 1. No language restrictions were applied and, where possible, searches were limited to 'human' participants. In an attempt to identify further research publications of relevance to this literature review, both military and civilian colleagues were contacted and requested to provide any load carriage texts available to them.

Table 1: The literature search: databases and search terms.

Database	Search terms
MEDLINE (Ovid)	load AND carr*; load AND march*; pack AND march*; endurance AND march*
PUBMED	load AND carriage; load AND carry; load AND marching; load AND march; pack AND march; pack AND marching; endurance AND march; endurance AND marching.
PROQUEST	load AND carriage; load AND carry; load AND marching; load AND march; pack AND march; pack AND marching; endurance AND march; endurance AND marching.
CINAHL	load AND carriage OR carry; endurance AND march OR marching; pack AND march OR marching; load AND march OR marching.
DEFWEB	load AND carriage; load AND carry; load AND marching; load AND march; pack AND march; pack AND marching; endurance AND march; endurance AND marching.

---

[9] Commencement dates for the search protocols were formed from the limitations within the specific database.

Once all initial papers were gathered, duplicate studies were removed and abstracts used to review and decide on inclusion of papers. The inclusion criterion was: papers reporting on load carriage in human subjects. The papers were then divided into three categories: original research papers and technical military reports, conference papers and abstracts, and secondary source articles[10] (e.g. books, scholarly articles, professional and trade journals). The reduced set of journal publications reporting original research, technical military reports, conference papers and abstracts was then subjected to more detailed scrutiny and the following key exclusion criteria:

a. age (outside of military service age of 17 – 55 years);
b. study included a form of mobility aid;
c. study included supplementation (e.g. vitamins);
d. study included medically unfit (e.g. obese) or diversified participants (e.g. idiopathic scoliosis);
e. study included components in an altered environment (e.g. micro-gravity);
f. study not published in English and not translatable by software (Babylon 9)[11] or by linguistic support available to the researcher (being Dutch, French and German);
g. studies which:
    - did not include a load carriage variable (dependent or independent);
    - were focused on generating or evaluating mathematical equations;
    - were not specifically related to a load carriage activity;
    - used manikins; or
    - involved no carriage of physical loads;
h. study addressed commercial interest (a certain brand of equipment) or focused on a specific piece of equipment (mountain carriage stretchers);
i. conference papers or abstracts printed in journals without full text; or
j. defence department documents rated above “unclassified”.

These exclusion criteria were implemented to remove potentially biased papers and studies in which the results might have questionable validity for application to the general military load carriage context (for example, a specific brand of equipment). The excluded papers and reasons for exclusion (based on the criteria above) are shown in Appendix B.[12] Although these articles were excluded from consideration in the review and in the results presented from the review, 24 of them, which were peer reviewed articles (denoted with an asterisk in Appendix B) were used to provide background information, expand on context, or provide supporting information. Once all the texts

---

[10] In this review secondary source articles are those that disseminate original research, typically for education (eg text book) or discussion (option piece in a military trade journal).

[11] ‘Babylon 9’ translation software and dictionary tool from Babylon Ltd.

[12] Defence papers rated above ‘unclassified’ are not listed.

meeting the inclusion and exclusion criteria were ascertained, bibliographies and reference lists of publications considered by these texts were reviewed to identify additional sources of information. All additional sources identified were reviewed and subjected to the same inclusion and exclusion criteria detailed above.

Data Extraction and Analysis

Each included paper was assessed using extracted data that defined the scope of the paper. These data were entered into an electronic Microsoft word (Microsoft, WA:USA, 2003) file with preformatted, investigator-designed fields. These fields captured participant characteristics (gender, age, background, etc.), a description of the study (loads, duration, speed, incline, study design), the outcome measures, the adopted level of statistical significance, perceived potential confounders and biases, and key findings. A blank copy of the electronic file format is in Appendix C. Once all papers had been reviewed, they were grouped by the focus of each paper (e.g. speed, load, terrain) into the key topic areas identified above (Section 2.1.1). When a paper presented with more than one focus, duplicates of the relevant electronic file were made, allowing the paper to be represented within all applicable topic areas. Papers with an injury focus were then further subdivided into either a group based on the injury region or, for more than one injury region, a multiple injury group. Strengths and weakness in the research methods were considered when reviewing each paper’s findings.

2.2. RESULTS

2.2.1. Literature search and selection

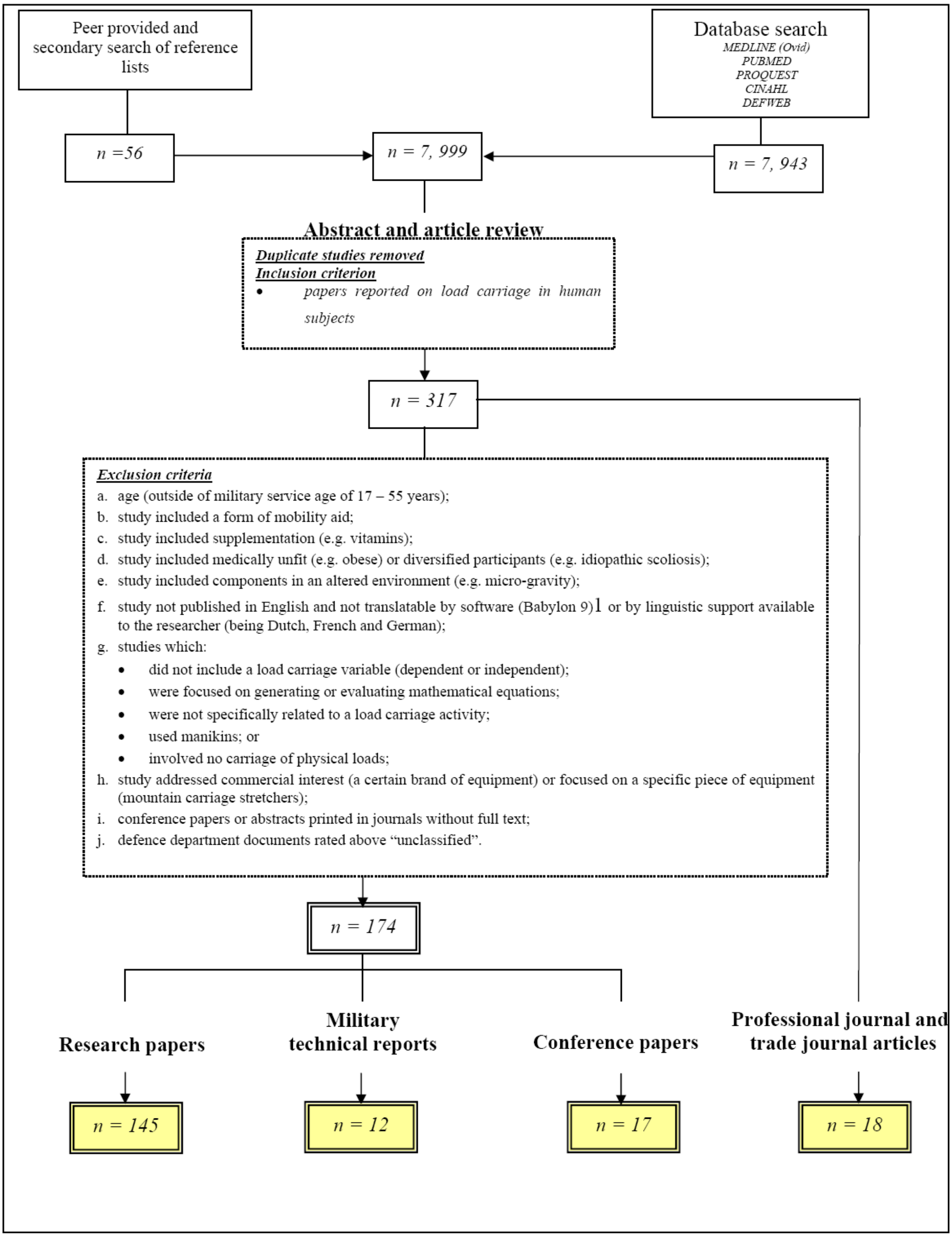
A total of 7,943 papers were identified from the initial search of the literature databases and 56 additional papers were gathered from colleagues and journal article reference lists. The initial exclusion of articles duplicated across databases and articles that did not meet the single inclusion criterion reduced the number of papers to 317.[13] From these papers, three full-text articles could not be obtained through library, peer, or military sources and were therefore also excluded (Appendix B). Judging from the article titles, it is highly unlikely that these papers would have met the inclusion criteria and they were therefore deemed non-critical. Following the implementation of the listed exclusion criteria, the number of original research papers and military technical reports of original research was further reduced to 157 papers (145 original research papers and 12 military

---

[13] A large volume of papers (approximately 5,000), captured primarily via Medline (Ovid) and Pubmed, were biomedical in nature (predominantly focussing on respiratory pathologies and viruses) and therefore excluded.

technical reports) and 17 conference papers.[14] [15]A complete overview of the literature review search and selection process is shown in Figure 3.

Figure 3: Flowchart of the literature search and selection process.



Duplicate studies removed

Inclusion criterion

- *papers reported on load carriage in human subjects*

Exclusion criteria

a. age (outside of military service age of 17 – 55 years);
b. study included a form of mobility aid;
c. study included supplementation (e.g. vitamins);
d. study included medically unfit (e.g. obese) or diversified participants (e.g. idiopathic scoliosis);
e. study included components in an altered environment (e.g. micro-gravity);
f. study not published in English and not translatable by software (Babylon 9)[1] or by linguistic support available to the researcher (being Dutch, French and German);
g. studies which:
    - did not include a load carriage variable (dependent or independent);
    - were focused on generating or evaluating mathematical equations;
    - were not specifically related to a load carriage activity;
    - used manikins; or
    - involved no carriage of physical loads;
h. study addressed commercial interest (a certain brand of equipment) or focused on a specific piece of equipment (mountain carriage stretchers);
i. conference papers or abstracts printed in journals without full text;
j. defence department documents rated above "unclassified".

---

[14] One conference paper (Visser et al., 2005), originally excluded, was re-included after the investigator contacted the authors who kindly supplied detailed conference presentation notes.

[15] Papers were divided into these categories to provide the reader a brief overview of their origins.

The final set of research papers (n=145) involved studies from 20 different countries: Australia (2 papers), Belgium (1), Canada (5), China (1), Finland (2), France (4), Ghana (1), Germany (2), India (6), Israel (4), Japan (5), Kenya (1), Korea (1), the Netherlands (2), New Zealand (2), Norway (1), Singapore (1), South Africa (7), the United Kingdom (26) and the United States of America (71). Participants for these studies came from both civilian (n=92) and military (n=54) backgrounds.[16] Civilian participants included volunteers from the general population as well as those required to conduct load carriage tasks as part of their occupation. Military participants came from the military forces of several nations, including; Australia (2 papers), Finland (2), Germany (2), India (2), the Netherlands (1), Singapore (1), South Africa (3), the United Kingdom (14) and the United States of America (35). The participants for these military studies included recruits, cadets, and fully trained military members employed in either a full-time or part-time or reserve capacity.

2.2.2. Review of the selected literature

The results of the review of the selected literature[17] are presented below in distinct categories in order to address the key topic areas identified above (Section 2.1.1). Before presentation of the review, the diverse variety in study foci (e.g. backpack, front pack, speed, weight, terrain) and outcome measures (e.g. heart rate, oxygen consumption, metabolic equivalent, etc.) must be mentioned, as these variations made direct comparison of findings between studies difficult. Finally, with only one article discussing load carriage doctrine (Task Force Devil Combined Arms Assessment Team, circa 2003)[18] captured during this literature search process, an alternate search strategy was employed. This alternate strategy, including a database search of the Australian Defence Electronic Library (ADEL) and use of subject mater experts in Army doctrines, and subsequent findings are discussed in Chapter 7 (Study D).

2.3. THE BODY’S RESPONSE TO LOAD CARRIAGE

Research suggests that when a person conducts a load carriage task both physiological and biomechanical responses occur (Knapik, et al. 2004). Examples of physiological responses of the body to load carriage tasks include changes to the load carrier’s aerobic capacity and heart rates (Knapik, et al. 2004; Blacker, et al. 2009). Examples of biomechanical responses include changes to the posture and gait kinematics of the load carrier (Knapik, et al. 2004).

---

[16] One paper included both military and civilian participants.

[17] Selected literature being all papers meeting the inclusion criteria (research papers, n=145, military reports, n=12, and conference papers, n=17) and the professional journal articles (n=18).

[18] A second article (Anonymous, 2004) was excluded from further review as it was a reiteration of the original article (Task Force Devil Combined Arms Assessment Team, circa 2003),

2.3.1. The Physiological Responses of the Body to Load Carriage

The physiological responses of the body to load carriage task vary. Not only has the weight of the load carried been found to elicit and influence the body's physiological responses to a load carriage task, but so too have elements of the context in which the load is carried (load position around the body, speed, terrain, duration, as examples) (Knapik, et al., 2004). The physiological responses of the body to load carriage and the influence of load weight carried and context are discussed in detail below.

The impact of load weight on the soldier conducting a load carriage task

Increases in load weight have been found to reduce endurance time (Koerhuis, Veenstra, van Dijk, & Delleman, 2009) and increase the energy cost of standing, walking (forwards and backwards, and up and down stairs), and running (Beekley, et al., 2007; Bhambhani, Buckley, & Maikala, 1997; Blacker, et al., 2009; Charteris, et al., 1989; Pederson, et al., 2007; Pimental, et al., 1982; Polcyn, et al., 2000).[19] Furthermore, not only does the amount of load carried on the person affect the energy cost of carrying the load but so too does the position of the load (Lloyd & Cooke, 2000b; Pederson, Stokke, & Mamen, 2007; Watson, Payne, Chamberlain, Jones, & Sellers, 2008) as will be discussed in detail later in this section.

For military soldiers, the impact of carrying loads during static standing is an important consideration, as training and combat duties can often include long periods of static standing. (Australian Army, 1986). Two examples of such tasks include controlling vehicle checkpoints and vital asset protection (e.g. guard duty). Five papers were identified in the current review which explored physiological correlates of static standing while carrying load (Anderson, Meador, McClure, et al., 2007; Holewijn & Meeuwsen, 2000; Maloiy, et al., 1986; Pandolf, Givoni, & Goldman, 1977; Pimental & Pandolf, 1979).

Four of these studies found increases in energy costs associated with increases in load weight during static standing trials (Anderson, et al., 2007; Holewijn & Meeuwsen, 2000; Pandolf, et al., 1977; Pimental & Pandolf, 1979). Pandolf, et al. (1977) and Pimental and Pandolf (1979) observed significant increases in energy costs as carried loads, presented in random order, increased from 20 kg to 50 kg while participants were static standing for periods of 20 minutes. Similar findings were reported by Holewijn and Meeuwsen (2000) without a load and with loads of 5.4 kg and

---

[19] The volume of evidence is provided in Appendix D

10 kg. While the above investigators found that the increased load had only a minimal effect on energy cost, they noted that heart rates increased significantly[20] by an average of nine beats per minute. The minimal increase in energy cost with these lighter loads could have resulted from increases in trunk muscle activation brought on by the need to compensate for body movements and to provide dynamic stabilisation, a requirement observed in the study by Anderson, et al. (2007). However, unlike military load carriage which has loads carried predominantly on the upper torso (LaFiandra, Lynch, Frykman, et al., 2003), Anderson, et al.'s (2007) results must be treated with caution as their participants carried loads of 14 kg and 20% in their hands at a measured elbow flexion strength at 90 degrees for trials of only six to 15 seconds. On this basis the transferability of these findings to contemporary military load carriage may be limited.

Maloiy, et al. (1986) presented the only included study that did not find an increase in energy cost associated with an increase in load weight while the carrier was static standing. Maloiy, et al. (1986) observed no significant effect on energy cost in quiet standing with a 34 kg load when compared to standing with no load. However, the value of that paper is questionable, with no details provided on the duration of the protocols, nor on the level of statistical significance achieved. Moreover, Maloiy, et al. (1986) had participants carry their loads on their heads and, as is discussed later in this review, the position of a carried load affects the energy cost of carrying the load.

Just as increases in load weight can potentially increase the energy cost of static standing, so can these increases in load increase the energy costs of walking (volume of evidence provided in Appendix D). Three studies suggest that these increases in energy costs associated with increases in load weight carried while walking may be linear in nature, with energy costs increasing in proportion to increases in loads (Crowder, et al., 2007; Gordon, Goslin, Graham, & Hoare, 1983; Quesada, Mengelkoch, Hale, & Simon, 2000). Two of these studies, employing within-subjects (repeated measures) designs, cited observations of such a linear relationship; approximately 0.2 mL/kg/min increase in oxygen consumption for every one per cent increase in backpack load (Crowder, et al., 2007), or an increase in energy cost of approximately five to six per cent for each 15% of body weight increase in load carried in a backpack (Quesada, et al., 2000). On this basis, the research cited suggests that a linear relationship between load weight (both absolute and relative weight) and energy costs exists.

---

[20] $p<0.05$

Contrary to these findings, studies by Holewijn and Meeuwsen (2000) and Robertson (1982), likewise employing within-subjects (repeated measures) designs, suggest that the increases in energy cost associated with increases in load may not be linear. Holewijn and Meeuwsen (2000) observed that the average energy cost per kilogram of added load in backpacks was not constant, with cost for the first 5.4 kg load lower than that for the unloaded state. Although this finding was observed by Holewijn and Meeuwsen (2000) it was not the focus of their study and hence no statistical comparison was performed, and these results should viewed with some caution. Robertson (1982) observed a significantly higher oxygen uptake cost ($p < 0.05$) when participant loads, carried around the waist, increased from 7.5% to 15% of body weight, compared to increases in loads from 0% to 7.5% body weight. Comparison of Robertson's (1982) results to the studies finding a linear increase in energy costs is tenuous as, in Robertson's (1982) research, loads were carried in a belt around the waist rather than on the back. Also, unlike the aforementioned studies reporting a linear increase in load carriage energy costs with increasing loads while walking, Robertson (1982) employed female rather than male subjects – perhaps suggesting possible gender differences. Finally, the two studies that failed to find a linear increase in the energy costs of carrying increasing loads while walking had smaller cohort sizes[21] and were therefore unlikely to find any linear relationship. On balance, the available evidence would suggest that the energy cost of carrying a load in a backpack increases in proportion to increases in load weight but it is not clear if the proportional increase is consistent across weights.

The impact of load position on the soldier conducting a load carriage task

For a soldier, load carriage is more than just a single load in a backpack.[22] Load carriage comprises loads carried on the head (helmet, night vision devices, radio headset), body (pack, webbing, body armour), thigh (pistol, protective mask), and feet (boots) and in the hands (personal weapon plus optical and targeting attachments).[23] As such, not only the load, but the distribution of load, and the impact of this distribution, are important considerations regarding the impacts of load carriage on the body and on performance.

In South America, Africa and Asia, load carriage by head pack and yoke is a popular means of load transport (Balogun, 1986; Legg, 1985) and is of relevance to the soldier who, as discussed above, may be required to carry loads on the head. Five studies (Datta, Chatterjee, & Roy, 1975; Heglund,

---

[21] Robertson (1982) n=7 female participants and Holewijn and Meeuson (2000) n=4 male participants compared to Gordon et al. (1983) n=10 male participants; Quesada et al. (2000) n=12 male participants and Crowder et al. (2007) n=14 male participants.

[22] See Figure A-1 in Appendix A for an example of load distribution around the body of an Australian soldier.

[23] See Figure A-1 in Appendix A for an example of load distribution around the body of an Australian soldier.

et al., 1995; Lloyd, Parr, Davies, Partridge, & Cooke, 2010; Maloiy, et al., 1986; Soule & Goldman, 1969) were identified in the current review to investigate the energy costs of head load carriage. Heglund, et al. (1995) observed that African women carrying a load either on the head or via a head strap could carry loads of up to 20% of their body weight with no increase in energy consumption, before energy costs began to increase as loads progressed up to 70% of their body weight. Although Heglund, et al. (1995) had a small sample size (n=2 for load carried on head strap across forehead and n=2 for load carried on top of their head), their findings are supported by the earlier work of Maloiy, et al. (1986) who reported similar trends when African women carried loads of 34 kg on their heads (61% of average BW). In contrast to these findings are the results of Soule and Goldman (1969) whose participants, carrying a load of 14 kg (20% of average BW) on their heads, reported around a 25% increase in energy cost when compared to an unloaded condition.

A potential cause of the differences in results can be found in the participants selected for the studies; the African women in the studies of Heglund, et al. (1995) and Maloiy, et al. (1986) were potentially more experienced at head load carriage than the 10 volunteers recruited in the United States by Soule and Goldman (1969). Therefore, unlike the African women, the participants in the Soule and Goldman (1969) study might have used additional energy to fixate the head and shoulders in order to avoid head movement. This theory is supported by Maloiy, et al. (1986), who acknowledged that untrained individuals might find head load carriage more difficult than individuals experienced in head load carriage. Opposing this ‘experience’ theory, Lloyd, et al. (2010) (study details are on the following page) observed no significant difference in the energy cost of head load carriage between experienced and inexperienced head load carriers.

Finally, on the basis of their studies of four manual labourers, Datta, et al. (1975) determined that a load of 30 kg would be the maximal recommended load to be carried on the head – a load equating to 59% of the groups’ average body weight. The generalisability of these results to the general population is limited, with the study cohort limited in size and participant demographics. With this in mind, and even though this suggested load exceeds the current helmet weight and helmet accessory load for a soldier, it is suggested that additional loads to the head should be avoided. Not only is there a potential for injury [see, for example, spondylosis findings in Ghanaians involved in head load carriage by Jumah and Nyame, (1994)], but more importantly for soldiers, loads carried on the head can increase the size of the soldier’s body signature[24] (Knapik, et al., 2004) which puts them at an increased risk of being seen or engaged with weapon fire by an adversary.

---

[24] The soldier’s body signature is the profile that their body creates or leaves behind. It can take many forms including physical (e.g size), and physiological (e.g thermal).

Comparisons of loads carried on the head and on the back have provided mixed results. In a combined study of both African women (study 1) and British women (study 2), Lloyd, et al. (2010) compared the energy costs of loads carried on the head with costs for the same load carried in a backpack. Both studies had participants carry loads of up to 70% of their body weight at self-selected speeds yet produced different results. A significantly greater ($p=.043$) energy cost was observed for loads carried on the head compared to loads carried on the back in study 1 (African women: 10.1 versus 8.8 ml.kg^{-1}min^{-1}), but no significant difference ($p=.081$) in energy costs were observed in study 2 (British women: 15.2 versus 14.2 ml.kg^{-1}min^{-1}). Differences in marching speed (Study 1; M=3.08 km.h-1: Study 2: M=4.33 km.h-1) may provide a potential reason for the difference in study findings as speed of march is known to influence the energy cost of a load carriage event (Christie & Scott, 2005). The findings in this latter study support previous findings by the authors (Lloyd, Parr, Davies, & Cooke, 2009, 2010) and other researchers (Das & Saha, 1966; Datta & Ramanathan, 1971), who reported no significant difference in energy cost or comfort rating between head load carriage and backpack load carriage.

As a final consideration, Lloyd, et al. (2010) observed a significant difference in the maximum amount of load that could be carried on the back versus on the head ($p = 0.014$). Whereas only two (of 24) of their participants were able to carry the maximum load of 70% body weight on their heads, seven were able to carry the same load on their back. Furthermore, the study by Lloyd, et al. (2010) had a higher number of participants than the previous head load carriage studies, and although they did not find any significant difference between head load and backpack load carriage in terms of energy cost, they did notice a high amount of variability in head load carriage efficiency, and claimed that this finding could have been the reason behind the ‘free ride’ findings of studies with smaller cohorts. Overall, the strength of the evidence available suggests that as loads carried on the head increase so too may the energy costs of carrying the load, especially when loads are over 20% of body weight.

Apart from carrying loads on the head and torso, soldiers are often also required to carry loads with, or on, the upper limbs. For instance when moving a large volume or weight of equipment, soldiers can carry loads on the shoulders, either via yoke systems or by resting the loads directly on the shoulders. Two studies have investigated the specific impact of shoulder load carriage, comparing the energy costs to loads carried on the back (Datta & Ramanathan, 1971; Legg, Ramsey, & Knowles, 1992). Datta and Ramanathan (1971) observed participants carrying loads of 30 kg in seven different modes, including on the shoulder and via a shoulder yoke. Following presentation of the loads in a random order, they found a significantly ($p<.001$) greater energy cost for carrying load on the shoulder (mean of 6.22 kcal/min) compared to carriage in a backpack (mean of 4.99 kcal/min). The study of Legg, et al. (1992) was more specific to military activity, with soldiers required to carry artillery shells (18.4 kg) and powder charges (7.6 kg) either on the shoulders or attached to a backpack frame while walking at 4.8 km/h on a treadmill. At gradients from flat walking to a 5% incline gradient, the energy cost of shoulder load carriage was found to be significantly higher (means of 2.4-2.6 $ml.min^{-1}kg^{-1}$; $p<.001$) than that for the same load carried on the backpack frame.

Although limited to only two studies, the evidence strongly suggests that the cost of carrying loads on the shoulders is greater than for carrying the same load in a backpack. Considering this finding, the cost of load carriage has been observed to increase further as load is moved down the extremities to the hands. Early work by Soule and Goldman (1969) found the cost of carrying a 7 kg load in the hands to be nearly twice that of carrying the load on the torso. Similarly, Datta and Ramanathan (1971), in the study mentioned in the paragraph above, also observed a significantly higher ($p<.05$) cost of load carriage in the hands (mean of 6.96 KCAL/min) than on the back (mean of 5.27 KCAL/min). Further, Knapik, et al. (2000), studying U.S. soldiers carrying a mannequin patient of 80 kg on a stretcher[25] utilising both hands at their sides, reported substantially higher cardiovascular (heart rate) stress ($p<.05$) for this activity when compared to other innovative stretcher carry methods which reduced direct hand load requirements. Whereas the innovative carrying methods were associated with heart rates increasing initially before reaching a steady state, the hand held load carriage method was associated with heart rates continuing to increase until the load carrier could no longer continue. As such, load carriage times were significantly shorter when loads were carried in the hands (81 – 88%; $p<.01$) when compared to the innovative methods. These results suggest that, not only may carrying loads in the hands be more energy costly than when these loads are carried on the body, but they may also limit load carriage performance.

A final consideration lies in the methods employed by soldiers to carry loads in the hands, as these loads are seldom equally distributed in both hands. Patrolling with a weapon held in the dominant or ‘master’ hand, a two-person store carry, and a four-person stretcher carry serve as examples of variations of load distributions in the hands. On this basis, unilateral hand loading requires consideration as unequal hand loading can increase hip muscle activity to twice that for the same load carried bilaterally (Neumann, Cook, Sholty, & Sobush, 1992), cause gait asymmetry (Zhang, Ye, & Wang, 2010) and potentially increase further energy expenditure (Datta & Ramanathan,

---

[25] Approximate carrying load was 45 kg based on loads at the front end (carried end) of the stretcher.

1971). Responses to unilateral load carriage may not be uniform and may be influenced by load characteristics and task requirements (Zhang, et al., 2010). The evidence provided strongly suggests that loads carried in the hands, which for the soldier would include their personal weapon[26] affixed with technological additions like infrared lasers, laser designators, night vision sights, and magnified sights (Eby, 2005), are more costly in terms of energy expenditure than the same load weight carried in backpacks.

With the intent of transferring backpack load weight from the shoulders to the hips, the U.S. *Modular Lightweight Load-Carrying Equipment* backpack replaced the *All-purpose Lightweight Individual Carrying Equipment* backpack (Lawson, 1998; Palmer, 1998). The rationale for this change to U.S. military packs was based on reports that waist or hip belts[27] added to backpack frames reduced shoulder stress by transferring load from the shoulders to the hips (Knapik, et al., 2004; LaFiandra & Harman, 2004; LaFiandra, Lynch, et al., 2003). While integration concerns raise questions as to whether these load carriage systems do transfer load from the shoulders to the hips (Harman, et al., 1999) soldiers may still carry loads around the hips and waist while wearing certain types of webbing. [28]

Ling, et al. (2000), comparing three load carriage conditions (backpack, over a shoulder, and around the waist) observed less deviations in normal gait patterns (measured by the difference in degrees of joint angles during the stance phase of gait) when participants carried their load (10 kg) around the waist. In this study, the waist carriage method was also subjectively rated as causing the lowest level of discomfort of the three conditions. Alternatively, when a backpack load of 35 kg was split equally between the backpack and a separate waist belt no significant differences in energy costs were found (Legg & Mahanty, 1985). This suggests that transferring a portion of the load from a backpack to the hips had no significant impact on energy cost of the load overall. On that basis, although hip belts that transfer load from the shoulders to the hips may reduce the risk of shoulder injury, they may not necessarily reduce the energy cost of load carriage. However, more research in this area is required.

---

[26] For example: 3.6 kg for a standard rifle (M16 Assault Rifle) up to 14.75 kg for a machine gun (M240B) loaded with a belt of ammunition (Task Force Devil Combined Arms Assessment Team. (circa 2003)).

[27] In the literature the terms ‘waist’ and ‘hip’ belts are used interchangeably even for the same brand of equipment (e.g. M.O.L.L.E. pack) and within the same study (LaFiandra et al., 2003). Where possible the exact term used in a given paper is used.

[28] See Figure A-1 in Appendix A for an example of load distribution around the body of an Australian soldier.

The soldier's lower limbs are not immune from the need to carry attached loads. Soldiers may be required to carry loads on the thigh (for example, pistols weighing approximately 1.2 kg[29] or gas protection devices weighing approximately 1.0 kg[30]), and in most instances are required to wear boots when performing load carriage tasks. Research on loads carried on the thigh suggests that oxygen consumption increases by up to 3.5% while running with a load of 0.5 kg per thigh (Martin, 1985). With that study limited to physically trained men running with loads of up to 1 kg fixed to their thighs, the generalisability of the findings to the overall load carriage population is limited. However, it is acknowledged that soldiers carrying a pistol or gas mask on the thigh might be required to run with the load and on this basis, the findings of that study warrant consideration.

Loads carried on the feet have generally been reported to incur the highest energy cost in both walking and running when compared to other modes of load carriage (Holewijn, Heus, & Wammes, 1992; Martin, 1985; Soule & Goldman, 1969). In an early study of the impact of boot weight on energy costs of performing tasks, Soule and Goldman (1969) observed increases in energy cost per kilogram of added boot weight that were up to four to six times those observed per kilogram of added body weight when boots weighing six kilograms were worn. These findings were supported by those of Holewijn, et al., (1992) who reported oxygen costs per added kilogram of boot weight to be approximately two to five times greater than those associated with a kilogram of additional body mass. Contrasting with these two findings are those of Strydom, et al. (1968) and Abe, et al. (2004). Strydom, et al. (1968) failed to observe significant differences in oxygen consumption in participants wearing boots weighing between 1.85 and 2.95 kg while walking at speeds of around 4.8 km/h and stepping up steps. Similarly, Abe, et al. (2004) only observed a significant ($p<.01$) difference in energy cost requirements between loads carried on the feet (weights affixed to ankles) and loads carried on the back when the loads on the feet reached 6 kg in weight.

Several factors might have led to the difference in findings between these studies. First, untrained participants have been reported to incur higher energy costs than more experienced participants when wearing boots (Jones, Toner, Daniels, & Knapik, 1984) and the two participants in the study of Strydom, et al. (1968), which failed to find a significant difference, were miners who were used to wearing boots daily. Second, Strydom, et al. (1968) employed only one walking speed whereas Holewijn, et al. (1992) and Soule and Goldman (1969) each employed three different speeds ranging from 4.0 to 6.5 km/h. Third, Strydom, et al. (1968) observed only two participants,

---

[29] Weight is for the M9 pistol with carrier and a magazine unloaded (Task Force Devil Combined Arms Assessment Team. (circa 2003)).
[30] Weight is for the M45 protective mask with carrier (Task Force Devil Combined Arms Assessment Team. (circa 2003)).

compared to the 10 participants in the studies of both Holewijn, et al. (1992) and Soule and Goldman (1969). A final consideration lies in the nature of the boots worn. Although Strydom, et al. (1968) did not mention the type of boots worn, mining boots do not necessarily have ‘uppers’ and may in fact be ankle boots only, whereas military boots usually have uppers, traditionally made of leather, and reach further up the lower limb (military boots were worn in both the Holewijn, et al. (1968) and Soule and Goldman (1969) studies). Stiff soles and uppers have been suggested to account for some of the increased energy cost of boot wearing by applying biomechanical limitations to movement (Jones, et al., 1984).

Finally, comparing athletic shoes to military boots, two studies by B. Jones, et al. (1986; 1984) found significant ($p<.05$) differences in the energy costs of wearing shoes versus boots when walking at speeds of above 4.0 km/h. Boots were reported to be associated with a greater energy cost than shoes, with the investigators suggesting that each 100 g increase in footwear weight (per pair) incurred a 0.7% to 1.0% increase in energy cost.

Two considerations of load position on soldier load carriage were beyond the scope of this research. These two considerations are the position of soldier loads within the backpack and the use of split load carriage systems in which loads are distributed between a backpack and a front pack. With the opportunity to capture information on the position of the soldier’s loads within a backpack and the type of load carriage system they were wearing (H-Harness with hip belt or chest webbing [and distribution of pouches and loads between front and rear]) not available to the researcher, these two considerations are explored only briefly in this review.

Just as the position of load around the body has the potential to affect the load carrier, so too does the position of a load within a pack. Different load positions within a pack have been observed to affect the energy costs of load carriage in static standing and while walking in some studies (Abe, Muraki, & Yasukouchi, 2008a; Knapik, et al., 2004; Stuempfle, Drury, & Wilson, 2004) but not in others (Bobet & Norman, 1984; Johnson, et al. 2000). Research also suggests that the position of load within a backpack affects both the postural balance (Schiffman, Bensel, Hasselquist, Norton, & Piscitelle, 2004) and the stability (Johnson, Pelot, Doan, & Stevenson, 2000; Knapik, et al., 2004; Qu & Nussbaum, 2009; Schiffman, et al., 2004) of the load carrier. The available evidence suggests that load placement may require a trade-off between energy efficiency and balance, with loads placed higher on the back potentially more energy efficient at the cost of stability, whereas loads placed lower on the back afford the carrier more stability but potentially increase the energy cost of carrying the load (Johnson, et al. 2000; Knapik, et al. 2004).

An alternative to backpack load carriage systems is a split pack system, with the load distributed between a backpack and a front pack. Strong evidence exists to suggest that these backpack and front pack systems may incur a lower energy cost (Datta & Ramanathan, 1971; Legg, 1985; Legg & Mahanty, 1985; Lloyd & Cooke, 2000b) and may be preferred by load carriers for comfort (Johnson, et al., 2000; Legg, 1985; Legg & Mahanty, 1985) when compared to backpack-only systems. Research has also identified potential concerns about implementation of these systems. These concerns include reducing soldiers' military skill performance (mobility), restricting soldiers' breathing capacity (through restricting their chest), reducing soldiers' view of the ground, and increasing soldiers' body signature (Johnson, et al., 2000; Knapik, et al., 1997; Knapik, Johnson, Ang, et al., 1993; Knapik, et al., 2004; Legg & Mahanty, 1985).

The impact of speed on the soldier conducting a load carriage task

The speed at which a soldier is required to carry load is predominantly dictated by mission requirements. Administration tasks could have soldiers move by foot, at a moderate pace, carrying heavy loads of stores and equipment across areas restrictive to vehicles, or have them move rapidly to a coordination point for an operation (Australian Army, 1984; Department of the Army, 1990). Operational tasks could range from spending long periods standing at vehicle checkpoints to conducting roving sentries, constantly walking around a vital asset (Australian Army, 1986). Patrolling, a key feature of military operations, involves a variety of speeds from static standing at short halts, to walking and running at paces dictated by the threat of enemy (Australian Army, 1986). The speeds at which the loads are carried will inevitably vary, and detailed examination of Australian soldiers' speeds of movement during load carriage tasks are beyond the scope of this research. However, an understanding of the complexities of the relationship between load carriage and speed is important in exploring the context of soldier load carriage. On this basis, the impact of speed of movement on the soldier conducting load carriage tasks is briefly reviewed.

In the literature reviewed it was widely acknowledged that as speed increases the energy cost of carrying a given load increases,[31] as does the carrier's perceived level of exertion (Robertson, Caspersen, Allison, et al., 1982). Furthermore, it was suggested that increases in speed may have a greater impact on energy expenditure than increases in load (Soule, et al., 1978). Thus the interaction between speed and load is important, with research indicating a potential inverse relationship whereby carriage of heavier loads requires slower marching speeds and carriage of lighter loads can be tolerated at faster marching speeds (Christie & Scott, 2005; Harper, et al.,

---

[31] The volume of supporting evidence is supplied in Appendix D.

1997). This relationship has been observed in load carriage studies where participants have been allowed to carry the load at a self-selected pace, and walking speeds have decreased as loads increased (Hughes & Goldman, 1970; Knapik, et al., 1997; Ralston, 1958). Thus, research suggests that reducing the speed at which the load carrier must complete a load carriage task may aid in mitigating the impact of the weight of the load. Conversely, reducing the load weight might allow the load carrier to complete a load carriage task at a faster pace.

The impact of the duration of a load carriage task on the soldier

Just as the weight of the load carried and the speed at which the load is carried must be appreciated, so too must the duration of the load carriage task. By way of contrasting examples, a soldier could be required to stand at a vehicle checkpoint in body armour, webbing, rifle, helmet, and boots for an hour, or leave on a three day reconnaissance patrol carrying the aforementioned equipment plus a backpack loaded with supplies to last the duration of the patrol (Australian Army, 1986). Distances that soldiers move under load could range from a 20 m walk across a compound to a march of over 120 km across enemy territory.[32] On this basis, the impacts of the duration of load carriage tasks must be considered, with longer durations potentially affecting the energy costs of carrying the load, the muscular demands of carrying the load and the hydration status of the body.

Seven research studies were found in this review which investigated the impact of load carriage duration on the physiological demands of load carriage tasks (Blacker, Fallowfield, Bilzon, & Willems, 2009; Epstein, Rosenbaum, Burstein, & Sawka, 1988; Holewijn & Meeuwsen, 2000; Patton, Kaszuba, Mello, & Reynolds, 1991; Sagiv, Ruddoy, Sagiv, Ben-Gal, & Ben-Sira, 2002; Schiffman, Chelidze, Adams, Segala, & Hasselquist, 2009; Scott & Ramabhai, 2000a). Four of these studies reported increases in the energy costs (per unit of time) of carrying a load as task duration increased (Blacker, et al., 2009; Epstein, et al., 1988; Patton, et al., 1991; Schiffman, et al., 2009). While these results were not always consistent, it is important to note that all four of these studies used a constant speed.

Whereas Patterson, et al. (2005) found the potential for energy expenditure to increase per unit of time by as much as 10 to 15% over durations of around 120 to 180 minutes while carrying a load of 27.5 kg, Schiffman, et al. (2009), who specifically studied the effects of increased load carriage durations, observed varied responses from their three subjects. The limitations of that study, which

---

[32] The march of the 45 Royal British Command Marines during the Falklands conflict serving as an example (Hastings & Jenkins, 1983; Stringer, 2000).

were a lack of assessment of statistical significance and small cohort size, were overcome in the studies of Patton, et al. (1991), Epstein, et al. (1988) and Blacker, et al. (2009). All three of these later studies reported significant (p<.05, p<.01 and p<.01 respectively) increases in energy cost per unit of time over long duration events (12 km and 120 minutes for the latter two studies respectively) while their participants carried substantial loads (49.4 kg, 40 kg and 25 kg respectively). However, of note, both Patton, et al. (1991) and Epstein, et al. (1988) did not find increases in energy costs per unit of time over events of the same durations when participants carried lighter loads.

Conversely, three studies failed to observe any differences in the energy cost of load carriage over time (Holewijn & Meeuwsen, 2000; Sagiv, et al., 2002; Scott & Ramabhai, 2000a). Holewijn & Meeuwsen (2000) observed no significant changes in energy cost per unit of time over a duration of up to 20 minutes with loads of up to 10.4 kg carried at a speed of 4.8 km/h. The findings of that study were limited by the short duration and lighter loads carried, especially in light of two of the above studies (Epstein, et al., 1988; Patton, et al., 1991) which, although observing increases in energy cost requirements over task duration with substantial loads, likewise failed to find significant changes in energy costs over the task duration with light loads. However, studies of a longer task duration with heavier loads found no significant increases in heart rates over events lasting for 180 minutes with a 40 kg load (Scott & Ramabhai, 2000a) and 240 minutes with loads of 38 and 56 kg (Sagiv, et al., 2002). The lack of a significant increase in heart rates over the duration of the event observed by Scott and Ramabhai (2000a) may have been attributable to participants working at a sub-maximal intensity or to the impact of 15-minute rest periods (taken after the first and second 60 minutes of walking). Conversely, Sagiv, et al. (2002) considered the backpack load carriage system that they employed in their study, which transferred load to hips and legs, to have possibly affected their findings. Furthermore, participants in the study of Sagiv, et al. (2002) might not have been working hard enough to become fatigued, as was evident from their ratings of perceived exertion scores (mean maximum rating of 12.9/20). Differences in fitness levels and military backgrounds were not considered, by the authors, to be an influencing factor in these nil-change findings, with highly endurance-trained participants and participants with a military background common to both the studies which found differences and those which failed to find differences.

Prolonged load carriage also has an effect on the muscular system as evidenced by results from electromyography and chemical marker studies (Bonato, Kothiyal, & Roy, 2000; Vaananen, Mantysaari, Pirkko, Komulainen, & Vihko, 1997). Bonato, et al. (2000) observed increases in the level of back muscle activation, measured via surface electromyography, when carrying 10% of body weight loads in the hands. These increases in muscle activation were considered, by the authors to be a possible means of compensating for increasing fatigue. Chemically, Vaananen, et al. (1997) observed an increase in serum creatine kinase (SCK) (400 to 650%) over a four-day marching period, carrying a minimum load of 10 kg and covering 42 to 50 km per day at speeds of between 5.0 and 7.0 km/h. While Vaananen, et al. (1997) cautioned against interpretation of the observed moderate increases in SCK as a serious pathophysiological indication of muscle damage, they also observed elevated subjective visual analogue scale ratings of perceived exertion for the duration of the event, with around 25% of the index score being from muscle soreness. Although the participants did not carry loads, Galun and Epstein (1984) likewise observed elevated levels of SCK which persisted for up to 72 hours following a 120 km marching event (pre-event mean of 97.6 µm/l: 72 hours post-event mean of 185.6 µm/l).

The impact of load carriage over time on hydration status of the load carrier may also be of concern. A study by Blacker, et al. (2009) not only found an increased oxygen consumption (means of 16.4 to 17.9 $ml.kg^{-1}.min^{-1}$) and heart rate response (means of 116 to 141 b.p.m.) to a load carriage event carrying 25 kg over a 120 minute period on flat ground but also an increase in the rate of sweat loss (measured by reductions in body weight pre and post march) when compared to the same march without load (means of 1.45 kg versus 0.81, p<.001). This sweat loss was not matched by voluntary fluid replacement, exposing the carrier to an increased risk of heat-related illness.

A final consideration of the impact of distance and duration of load carriage is whether it is more energy efficient to perform fewer trips with a heavier load than performing more trips with a lighter load. Chung, et al. (2005), employing a within-subjects repeated measure design, had participants walk along a 50 metre pathway (walk loaded, return unloaded, repeat) with loads of 40 and 60 kg. The researchers observed a statistically significant increase (p<0.05) in energy costs carrying the 60 kg load along the path five times versus carrying the 40 kg load along the same path eight times. Given that the total loads moved were similar,[33] these findings suggest that for moving a given load, carriers may be less taxed carrying a lighter load more frequently than carrying a heavier load less frequently. It should be noted, however, that while loads were carried against the back in this study, they were not carried within a load carriage device. Furthermore, this was the only study comparing multiple trips in relation to loads carried available to this review. Results, while

---

[33] Total loads were derived from multiplying the number of trips with the load moved. Thus 40 kg x 8 = 320 kg moved; 60 kg x 5 trips = 300 kg.

informative, should be viewed with caution until a greater volume of supporting evidence is available.

The impact of terrain on the soldier conducting a load carriage task

Soldiers operate in many different terrains. From the deserts in Africa (Johnston, 1996) and Iraq (Porter, 1992) to the jungles of Vietnam (McKay, 1996); from the marshes of the Falklands (Hastings & Jenkins, 1983) to the urban sprawl of Somalia (Solgere, 1999); from traversing the flat lands of rice paddies and poppy fields in Vietnam (Taylor, 2001) and Afghanistan (Gardner, 2006) to the hilly Kokoda Track of Papua New Guinea (Brune, 2003), Toktong pass of Korea (Camp, 2000) and Shah-i-Kot Valley of Afghanistan (Kraft, 2002), soldiers have been required to carry loads and fight battles for survival. Considering the impacts of load carriage across different terrains is complex as terrain encompasses not only gradients (incline, flat, decline) but also surface (sand, dirt, bush). Further adding to the complexity of applying terrain considerations to load carriage tasks for the military context is the potential for a variety of terrains to be traversed within a single foot patrol (Brown, et al., 2010).

Changes in both terrain gradients and terrain surfaces have been observed to affect the energy costs of load carriage. A large volume of evidence[34] has associated increases in gradients traversed when walking with increases in the energy costs of carrying loads (Crowder, et al., 2007; Lyons, Allsopp, & Bilzon, 2005; Scott & Ramabhai, 2000b). As an example Crowder et al. (2007) observed an increase in energy cost from a mean of 17.6 $ml.kg^{-1}.min^{-1}$ on a flat terrain to means of 27.1 and 39.6 $ml.kg^{-1}.min^{-1}$ as the gradient increased to five and then ten percent respectively. These increases in energy cost were found regardless of whether the loads were carried on the back, head or shoulders (Legg, et al., 1992; Vaz, Karaolis, Draper, & Shetty, 2005). Providing a numerical reference for walking up incline gradients, Crowder, et al. (2007) claimed that every one per cent increase in gradient demands an approximate 2.0 mL/kg/min increase in oxygen consumption. The study conducted by Crowder, et al. (2007) on inclining gradients of 0%, 5% and 10%, with participants walking at 6.0 km/h and carrying loads of 27.3 kg, reported work efforts of individual participants as high as 90% of maximal aerobic capacity on the 10% gradient. Crowder, et al. (2007) hence advised that the weight of the carried load should be considered secondary to the gradient of the terrain to be covered, but the fast walking speed (6.0 km/h) employed in their study tempers their claim as, based on previous discussions in this paragraph, speed might have influenced their results.

---

[34] See Appendix D.

Just as incline gradients can lead to increases in energy expenditure, so too may decline gradients (Lloyd & Cooke, 2000b; Santee, Allison, Blachard, & Small, 2001; Santee, Blachard, Small, et al., 2001). However, the changes in energy cost per unit decline might not be linear but rather suggest a ‘U’ shape curve. Lloyd and Cooke (2000b) observed that as gradients declined from zero to -5% there was a minor reduction in oxygen consumption requirement, with consumption then increasing steadily as the gradient decreased from -12% to -27%.[35] Further to the studies of Lloyd and Cooke (2000b), both of the studies of Santee, et al. (2001; 2001), investigating the impact of declining gradients of up to -12%, reported similar reductions in energy requirements compared to level walking, occurring up to a decline grade of -12%. Unfortunately, as neither of the studies by Santee, et al. (2001; 2001) included declining grades greater than -12%, their studies cannot support the reversal of energy costs observed by Lloyd and Cooke (2000b). Considering the findings regarding the impacts of incline and decline terrain gradients on load carriage energy expenditure, studies reviewing energy costs on both inclining (up to + 27%) and declining gradients (down to -30%) have reported that load carriage on inclining gradients is more energy costly than that of decline gradients (Lloyd & Cooke, 2000b; Pimental & Pandolf, 1979; Santee, Allison, et al., 2001).

Ascending and descending stairs also constitute changes of terrain grade. A study by Chung, et al. (2005) reported that carrying a 40 kg load on the back up or down four flights of 13 stairs was more energy costly than carrying the same load on flat terrain. Carrying this load of 40 kg on the stairs was also observed to be more energy costly than carrying a 60 kg load on flat terrain. This warrants consideration for soldiers employed in urban tactical scenarios which require them to move through multi-storey buildings.

While the gradient of the terrain traversed has an impact on the energy cost of load carriage, so too does the nature of the terrain surface. Few studies have investigated the extent of the relationship between load carriage and the nature of the terrain surface (Soule & Goldman, 1972; Strydom, Bredell, Benade, et al., 1966). In a study investigating differences in energy cost when carrying load over firm and sandy surfaces, Strydom, et al. (1966) observed that the energy cost of walking at 4.8 km/h with an average load of 23.1 kg (33% body weight) was 80% higher on sand than for the same conditions on a firm surface. Soule and Goldman (1972) conducted a more detailed study of terrains by reviewing the energy costs for load carriage over sealed roads, dirt roads, light and heavy bush, swamp, and loose sand with loads of 8 kg, 20 kg and 30 kg carried at speeds ranging from 2.4 km/h to 5.5 km/h. The results were designed to inform the development of terrain coefficients for

---

[35] Decline gradients investigated were 0%, -5%, -12%, -17%, -22% and -27%.

predictive equations. In increasing order of associated energy costs, the terrain coefficients for marching with load were ranked as: sealed roads (1.0), dirt roads (1.1), light bush (1.2), heavy bush (1.5), swamp (1.8), and loose sand (2.1), with significant differences ($p<.05$) observed between sealed roads, heavy bush, swamp, and sand.[36] Finally, of note, Soule and Goldman (1972) reported that the energy cost for road (blacktop) walking and treadmill walking were similar. While acknowledging that this is a single study, these findings do support the use of treadmills for studies of energy expenditure for load carriage while walking on sealed roads.

There is strong evidence that increases in the incline gradient of terrain increase the energy costs of carrying loads. However, the volume (more than the level) of research is limited with regard to examining the energy costs of load carriage over decline gradients of more than 12%, of carrying loads up and down stairs, and of carrying loads across various terrain surface types. More research in these areas is required to confirm the current evidence which suggests that (a) decline gradients of up to -12% offer an initial reduction in load carriage energy costs when compared to level walking, but steeper declines begin to increase energy costs; (b) carrying loads on the back up and down stairs invokes a higher energy cost than carrying loads on flat grounds; and (c) some specific terrain surface types increase the energy costs of load carriage, with heavy bush, swamp and loose sand extracting the greatest costs reported to date. Furthermore, additional research investigating the relationship between the energy costs of load carriage on a treadmill versus other surfaces (like roads and dirt paths) would be of benefit, especially given that research on the impacts of load carriage is often being conducted on a treadmill (Leyk, et al., 2007; Ling, et al., 2004; Quesada, et al., 2000; Ricciardi, et al., 2008; Sagiv, Ben-Sira, Sagiv, Werber, & Rotstein, 1994; Santee, Blachard, et al., 2001; Sharpe, et al., 2008).

The impact of climate on the soldier conducting a load carriage task

Serving in various countries and terrains around the world brings with it a variety of climatic conditions within which the soldier must operate. Although the climatic conditions in which Australian soldiers are currently carrying load are beyond the scope of this research, a brief review of the literature was conducted to overview the potential impacts of climate on soldier load carriage.

In the Great War (1914-1918) the British coat was known to increase in weight by up to an additional 9 kg when wet (Ellis, 1989; Lothian, 1921). Furthermore, British soldiers could well find that water saturation and mud added an additional 16 kg of load during a march (Ellis, 1989;

---

[36] The statistical assessment methodology was not provided.

Lothian, 1921). Cold weather also has the potential to affect load and the cost of load carriage. Additional weight caused by clothing as well as the possible restrictive effects of multi-layered clothing are plausible causes for increased energy expenditure during cold weather load carriage tasks (Haisman, 1988). Conversely, heat brings its own challenges and has been considered in several load carriage studies (Cadarette, Blanchard, Staab, Kolka, & Sawka, 2001; Cheuvront, Goodman, Kenefick, Montain, & Sawka, 2008; Johnson, et al., 2000; Johnson, et al., 1995; Snook & Ciriello, 1974).

Snook and Ciriello (1974) reported that the ability to conduct work tasks over a continuous period (40 minutes) was significantly ($p<.01$) reduced in a hotter environment (27.0^{o}C versus 17.2^{o}C). Taking this into account, the impact of load carriage systems on the heat induced thermal stress of the wearer is important. Studies by Johnson, et al. (1995) and Johnson, et al. (2000) reported that backpack/front pack load carriage systems were poorly rated subjectively by wearers with regard to thermal comfort. Johnson, et al. (1995) theorised that the front pack limited evaporative heat loss when compared to an ALICE backpack, the primary mechanism for heat loss during exercise (McArdle, et al., 1996; Wilmore, Costill, & Kenney, 2008). Further, Cadarette, et al. (2001) and Cheuvront, et al. (2008) reported impairments to a soldier’s thermoregulation capacity, measured by changes in core body temperature, due to the wearing of body armour. The increase in thermal stress caused by the load carriage system has been associated with the need for soldiers to consume additional water per day in order to maintain hydration (Cheuvront, et al., 2008). This requirement to carry additional water in turn increases the weight borne by the carrier.

A final consideration lies in the indirect and potentially compounding impact of climate on load carriage. Not only can rain increase the energy cost of load carriage, through increasing the weight of a carried load (water logging, more clothing) and potential cost of clothing resistance (wearing additional clothing), but the rain can turn a solid dirt path to mud. This in turn can alter the ground surface which, as discussed previously, can make traversing a given terrain more energy costly (Soule & Goldman, 1972). Hence by influencing the terrain, as an example, climate can indirectly affect the energy cost of load carriage.

2.3.2. The Biomechanical Response of the Body to Load Carriage

The performance of load carriage tasks has been observed to elicit several biomechanical responses from the body, including changes to the carrier’s posture, changes to the gait kinematics (stride length, stride frequency, etc.) and changes to ground reaction forces when walking (Knapik, et al. 2004; Attwells, et al. 2006). Although analysing the biomechanical response of soldiers to a load carriage task was beyond this program of work, a review of soldier biomechanical responses to load carriage has the potential to inform injury risk management, and hence a brief review of the literature was conducted. The key areas of interest were the impact of load carriage on soldier posture, gait, and ground reaction forces.

The impact of load on the posture of the body

Alterations to the degree of the carrier's forward trunk lean, spine shape, spinal compression and spinal shearing forces have all been associated with walking while carrying loads (Attwells, Birrell, Hooper, & Mansfield, 2006; Meakin, Smith, Gilbert, & Aspden, 2008; Orloff & Rapp, 2004; Vacheron, Poumarat, Chandezon, & Vanneuville, 1998). There is strong research evidence that an increase in the carrier's forward trunk lean occurs as the carried load increases (Knapik et al., 2004).[37] Kinoshita (1985), for example, observed that with a backpack load of 40% of body weight, forward trunk lean increased by an average of 11 degrees (n=10). Polcyn, et al. (2000) reasoned that this increase in the carrier's forward trunk lean is a compensatory change in the posture of carriers in an attempt to move their centre of mass (COM) and external load forward over their base of support and to lower their COM to increase stability. Another biomechanical change to body posture induced by load carriage is the observed tendency of the head of the carrier to adopt a more forward posture as both the loads carried and the carrier's forward lean increase

Other studies investigating the impact of load carriage on the posture of the load carrier have identified changes in spinal curvature and longitudinal spinal shrinkage (Meakin, et al., 2008; Orloff & Rapp, 2004). Three studies examined the impact of load carriage on spinal curvature, with two investigating the impact of load on contemporary bilateral loading (in a backpack, for example) (Meakin, et al., 2008; Orloff & Rapp, 2004), and one investigating the impact of unilateral loading (Filaire, Vacheron, Vanneuville, et al., 2001). All three studies observed significant change in spinal curvature following a load carriage event. It is understandable, therefore, that increases in backpack load, which increase forward lean of the trunk, cause possible alterations in spinal shape, increase spinal compression, and increase spinal shearing forces, have the potential to increase the risk of spinal injury due to the stresses they impose on muscles and other body structures (Attwells, et al., 2006; LaFiandra, Lynch, et al., 2003).

With regard to the biomechanical effects of load carriage on other parts of the body, four identified primary studies (Attwells, et al., 2006; Birrell & Haslam, 2009a; Harman, Han, & Frykman, 2000; Kinoshita, 1985) and one meta-analysis of four studies (Polcyn, et al., 2000) investigated the impact

---

[37] The volume of evidence provided in Appendix D.

of increasing loads on knee joint angles. Three of those studies (Birrell & Haslam, 2009a; Harman, et al., 2000; Kinoshita, 1985) and the meta-analysis (Polcyn et al., 2000) reported a decrease in knee range with increases in load weight. In contrast, (Attwells, et al., 2006) observed an increase ($p<.005$) in knee range of motion with increases in load weight carried. A possible cause for the differences in knee joint angle findings in these studies may lie in the measures used. For example, the four studies analysed by Polcyn, et al. (2000) based each segmented joint angle on the minimum value, maximum value and range of motion of the joint over the entire stride. In contrast, Attwells, et al. (2006) determined the knee range of motion based on the degree of knee flexion at heel strike and the degree of knee extension at the beginning of toe-off.

A final biomechanical consideration concerns the impact of load on postural balance. Several researchers have observed that as the carrier's load increases so too does the carrier's postural sway[38] (May, et al., 2009; Qu & Nussbaum, 2009; Schiffman, Bensel, Hasselquist, Gregorczyk, & Piscitelle, 2005; Schiffman, et al., 2004; Zultowski & Aruin, 2008) and the amount of force generated in the medial–lateral axis (Birrell, Hooper, & Haslam, 2007). Conversely, Arellano, et al. (2009) failed to find any significant changes to stability with loads of 10, 20 and 30% body weight. In contrast, the loads in the study by Arellano, et al. (10%, 20% and 30% of the carrier's body weight), were distributed around the waist and, more importantly, the participants were walking (3.5 km/h) rather than static standing. While further study in the area of load carriage and its impact on postural stability is required (carrying operational loads distributed around the body and while moving across uneven ground as an example), the evidence presented here suggests that postural balance decreases and postural sway increases with increases in load while static standing. However, these changes to postural balance with increases in load may be decreased to a significant extent if the carrier is walking.

The impact of load on the parameters of gait

Load carriage has been associated with changes in the parameters of gait, including changes in the duration of the double support phase, stride length and stride frequency (Birrell & Haslam, 2009a; Harman, et al., 2000; Kinoshita, 1985; Ling, et al., 2004; Lloyd & Cooke, 2000a; 2010; Polcyn, et al., 2000). In light of the previously discussed findings regarding the impact of load carriage on postural sway, six studies have observed the duration of the double support phase of the gait cycle to increase as the carried load increases in order to improve stability (Birrell & Haslam, 2009a;

---

[38] Postural sway in this instance being the interplay between external perturbations acting on the body and actions by the postural control system to prevent a loss of balance.

Harman, et al., 2000; Kinoshita, 1985; Ling, et al., 2004; Lloyd & Cooke, 2000a; Polcyn, et al., 2000).[39] However, while it has been suggested that increases in the weight of load carried have been associated with significant increases in the duration of double support time, the correlation between load and time spent in the double support phase, while positive, is not particularly strong (r=+.37,p<.01) (Polcyn, et al., 2000).

The relationships between increases in carried load and the gait parameters of stride length and stride frequency appear variable. Studies by Harman, et al. (2000) and LaFiandra, Wagenaar, et al. (2002, 2003), where participants carried loads of up to 47 kg and up to 40% body weight, have reported decreases in stride length as carried loads increased. With walking speed being the product of stride length and stride frequency (Hoffman, 2002; Kirtley, 2006), shorter stride lengths would be expected to require higher stride frequencies to maintain a given speed (Knapik, et al., 2004; Ralston, 1958; Yamasaki, Sasaki, & Torii, 1991). This expected increase in stride frequency to maintain a given speed was observed in all three load carriage studies (Harman, et al., 2000; LaFiandra, Wagenaar, et al., 2002, 2003).

The studies of Majumber and Pal (2010) and Birrell and Haslam (2009a) provide alternative findings. As in the studies above, Majumber and Pal (2010) observed that as load increased, stride frequency also increased. However, they also observed an increase in stride length. The product of this increase in both stride frequency and stride length was participants completing the very short distance (10 m) at a faster pace as loads increased. Again, in initial support of the findings of Harman, et al. (2000) and LaFiandra, Wagenaar, et al. (2002, 2003) discussed above, Birrell and Haslam (2009) observed a decrease in stride length as loads increased. However, in their study, no corresponding increase in stride frequency was observed. The accuracy of this finding is questionable as speed was set at 5.4 km/h and if stride length decreased, stride frequency would have to increase to maintain the set speed which was not the case. The 5% error margin noted by the researchers in measurement of participant walking speed may account for this discrepancy.

The meta-analysis of four studies by Polcyn, et al. (2000) revealed mixed results. Two of the studies yielded significant positive correlations between carried load and stride frequency whereas the other two failed to observe significant relationships between the two variables. Moreover, the correlation and regression analysis conducted by Polcyn, et al. (2000) on the pooled data generated an almost

---

[39] Although the association was not statistically significant, Lloyd and Cooke (2000) observed a similar trend (p=.058).

negligible low negative correlation between stride frequency and carried load weight (r=0.14, p<.01).

Three studies found no differences in gait parameters (double support time, stride length or stride frequency) as the carrier's load increased from an unloaded condition to various loaded conditions (maximal acceptable load, 34 kg, and 30% of body weight) (Goh, Thambyah, & Bose, 1998; Maloiy, et al., 1986; Nottrodt & Manley, 1989). Potential reasons for these differences between studies lie in the study protocols for establishing both walking speed and nature of the load carriage task. In the studies which found increases in double support time and/or decreases in stride length parameters as carried loads increased (Birrell & Haslam, 2009a; Harman, et al., 2000; Kinoshita, 1985; LaFiandra, Wagenaar, et al., 2002, 2003; Ling, et al., 2004; Lloyd & Cooke, 2000a; Polcyn, et al., 2000) the speed of march was set and enforced. In contrast, the speeds employed by Nottrodt and Manley (1989), Goh (1998) and Majumber and Pal (2010) were self-selected, allowing the participants to select the speeds at which they carried the loads. Maloiy, et al. (1986) did not report the speeds of the trials, stating '*Five African women walked on a motorized treadmill at five different speeds…*' (Maloiy, et al., 1986, p. 668).

Finally, it must be acknowledged that different load carriage systems can affect the above findings regarding changes in the parameters of gait due to increases in the loads carried. While three studies (Johnson, et al., 2000; Kinoshita, 1985; Lloyd & Cooke, 2000a)[40] failed to observe significant differences in stride length, stride frequency and duration of double support during load carriage tasks, two of those studies (Kinoshita, 1985; Lloyd & Cooke, 2000a)[41] observed a trend towards increases in stance support times when load was carried in a backpack when compared to a backpack and front pack split system. Harman, et al. (2001) assessed the biomechanical impact of carrying an 8.7 kg load using three different load carriage systems,[42] and observed differences in both spatiotemporal and kinematic gait variables for the same given load. For example, when wearing the MOLLE backpack, participants demonstrated longer stride lengths than when wearing the *Special Operations Forces Personal Equipment Advanced Requirement (SPEARS)* backpack (MOLLE M = 1.553 m; SPEARS M = 1.539 m; p<.05). Conversely, when wearing the SPEARS backpack they demonstrated greater forward arm swing than when wearing the MOLLE backpack

---

[40] Loads in these studies ranged from 25.6 kg to 36 kg or 40% of the carrier's body weight and were carried in conventional back systems or split backpack and front pack systems.

[41] Kinoshita, 1985 (p=0.0058): Lloyd & Cooke, 2000a (p>.05 with % of double support for back pack =21.03% and double pack 20.73% with 40% BW load).

[42] MOLLE backpack with a 20.4 kg load, MOLLE-Extended with a 20.6 kg load and *Special Operations Forces Personal Equipment Advanced Requirement (SPEARS)* backpack with a 21.1 kg load.

(SPEARS M = -1.48 degrees of maximum shoulder flexion-extension angle; MOLLE M = - 5.26 degrees; p<.05).

The impact of load on ground reaction forces

Ground reaction forces (GRF) have been reported to significantly increase (p<.05) in downward, antero-posterior and medio-lateral directions as the carried load increases (Birrell & Haslam, 2008; Birrell, et al., 2007; Kinoshita, 1985; Knapik, et al., 1992; Lloyd & Cooke, 2000a; Park, et al., 2008; Polcyn, et al., 2000). This increase in impact force, generated through the foot's contact with the ground, can increase the potential for injury to the load carrier through increases in the total volume of impact forces (Birrell, et al., 2007) and by creating shearing forces across the foot which induce blisters (Akers & Sulzberger, 1972; Knapik, Reynolds, & Barson, 1999). Another potential mechanism through which increasing GRF may induce injuries is that of joint stiffness. Joint stiffness is defined by Holt, et al. (2003) as the change in joint torque divided by changes in the angular displacement of the joint during loading. Increases in joint stiffness, such as those caused by increasing backpack loads (Holt, et al., 2003), lead to a transfer of force to other joints further up the kinetic chain. Serving as an example, force transmission from the ankle to the head, as a product of increased joint stiffness and increased GRF, has been observed (Holt, Wagenaar, Kubo, LaFiandra, & Obusek, 2005). The importance of these findings becomes more significant when they are combined with the findings of the increases in GRF caused by increased loads and/or speeds (Birrell & Haslam, 2008; Birrell, et al., 2007; Kinoshita, 1985; Knapik, Reynolds, Staab, Vogel, & Jones, 1992; Lloyd & Cooke, 2000a; Park, et al., 2008; Polcyn, et al., 2000), as not only is there greater force transmission of force further up the kinetic chain as load increases (Holt, et al., 2005), but the amount of force transmitted also increases. This combination (increased force and increased force transmission) in turn increases the potential for musculoskeletal injuries (Holt, et al., 2005).

2.3.3. The Influence of Physical Composition on Load Carriage Ability

Impact of participant morphology on load carriage performance

Research has demonstrated that although uniformed personnel come in a variety of shapes and sizes, certain morphological characteristics may be more favourable to load carriage tasks. From as early as Lothian's (1921) review of load carriage it has been identified that load has a relationship to a participant's *absolute* strength, which is in turn related to a participant's body weight (Lothian, 1921; Scott & Ramabhai, 2000b). On this basis, a participant's weight may be advantageous to load carriage tasks. Three studies observed heavier participants to be less affected by load and to perform load carriage tasks to a higher standard (Bilzon, Allsopp, & Tipton, 2001; Harman, Gutekunst, Frykman, Sharp, et al., 2008; Harper, et al., 1997). Assessed tasks included a 10 km walk, as fast as possible, with loads up to 36 kg (Harper, et al., 1997); casualty rescue (dragging an 80 kg manikin 50 m) as fast as possible while wearing battle dress weighing around 18 kg (Harman, Gutekunst, Frykman, Sharp, et al., 2008); and loaded running with an 18 kg load (Bilzon, Allsopp, et al., 2001). It should be noted, however, that in all these studies loads were *absolute* (each soldier carrying the same load regardless of body weight) and not *relative* to the individual's body weight. As heavier men and women tend to have greater *absolute* strength (Vanderburgh, 2000; Zatsiorsky & Kraemer, 2006), and all loads were *absolute*, these results are unsurprising.

For uniformed personal, dividing the unit's load *relatively* (i.e. as a percentage of the carrying soldier's body weight) rather than *absolutely* among unit soldiers may provide a more optimal load distribution. Validating this concept, Scott and Ramabhai (2000b) found that for soldiers conducting a 12 km weight load march, physiological and perceived responses indicated less stress when loads were normalised to 37% of body weight as opposed to when carrying an *absolute* load of 40.5 kg (56% of mean male BW: 63% of mean female BW). Likewise, Koerhuis, et al. (2009, p.1304) found that a redistribution of load in their study resulted in a more homogeneous group performance '*with an increase in endurance time for the weakest link.*'

Of differing opinion, Lyons, et al. (2005) claimed that body composition, rather than total body mass, is more closely associated with the aerobic demands of heavy load carriage tasks. Of most interest was the influence of body fat on load carriage performance. Both Lyons, et al. (2005) and Ricciardi, et al. (2007) observed a reduced aerobic capacity and load carriage task performance ability (p=.01) in participants with increased levels of body fat. Even when participants were wearing a *relatively* light load (10 kg body armour), the amount of body fat of males (17%) and females (26%) was found to negatively correlate (r=-0.88; p<.001) with physical task performance (Ricciardi, et al., 2007).

Not all studies supported these findings of poorer load carriage task performance with increased levels of body fat. Both Frykman, et al. (2000) and Pandorf, et al. (2002) found that body fat (21-32%) did not affect assessed performance of load carriage tasks like obstacle courses and a 3.2 km loaded run. It should be noted, however, that the studies with the conflicting views used different measures and consisted of different cohort groups. The two studies observing an impact of body fat on load carriage ability (Lyons, et al., 2005; Ricciardi, et al., 2007) used load carriage walking activities of 30 to 60 minutes in duration undertaken on treadmills with either an all-male cohort (Lyons, et al., 2005) or a mixed gender cohort (Ricciardi, et al., 2007). Conversely, participants in the studies in which no significant association was found between load carriage task performance and body fat levels (Frykman, et al., 2000; Pandorf, et al., 2002) were assessed on obstacle course performance while carrying load (Frykman, et al., 2000; Pandorf, et al., 2002) and on the completion speed of a loaded run activity on a paved path over mild hills which lasted for no longer than 18 minutes (Pandorf, et al., 2002). Moreover, both cohorts of the latter studies were comprised of all-female participants who had a lighter mean body weight (*M*=61.3 kg, *SD*=6.7 kg) and lower oxidative capacity (*M*=48.8 mL/kg/min, *SD*=4.6 mL/kg/min) than the participants in the study by Lyons, et al. (2005) (*M*= 80.3 kg, *SD*=9.2 kg; *M*=54.4 mL/kg/min, *SD*=5.1 mL/kg/min).[43]

Finally, although the study of Pandorf, et al. (2002) did not indicate a significant association between load carriage performance and the body fat levels of participants, it did identify a positive association between load carriage performance and the muscle mass of participants. Larger female participants with more muscle mass were able to carry a 41 kg load over a 3.2 km distance faster than their female cohorts (Pandorf, et al., 2002). This observed difference did not reach statistical significance with lighter loads (14 kg; p=.41, and 27 kg; p=.29). From the evidence provided, a greater absolute mass and greater muscle mass appear to be advantageous to load carriage task performance, while higher levels of body fat may hinder the performance of longer (more than 30 minutes) load carriage walking tasks but may not affect the performance of load carriers during shorter duration tasks (less than 30 minutes). Due to the variability in the observed associations between load carriage task performance and body fat levels, all results should be treated with caution until a greater volume of evidence is available.

Gender differences evident with load carriage

The number of women serving in defence forces is growing (Brothers & Wilson, 2010; Davison, 2007; Schjolset, 2010). Whether women are restricted from direct combat roles (Davison, 2007; Schuster, Beusse, Chambers, Coffey, & Luna, 1998) or soon to be serving on the front line (Healy & McPhedran, 2011), the changing nature of warfare and combat environments (Nuciari, 2006; Sheppard & Waggener, 2007) has seen female soldiers engaging with the enemy (Burnes, 2008), receiving awards for combat actions (Nuciari, 2006; Sheppard & Waggener, 2007), and becoming combat fatalities (Sheppard & Waggener, 2007). These warfare changes require female soldiers, like their male counterparts, to wear body armour and carry increasingly heavy loads (Knapik, et

---

[43] Mean cohort body weight and oxidative capacity were not provided by Ricciardi et al. (2007).

al., 2004), loads ranging from 40 to 60 kg in Iraq (Scales, 2005) and Afghanistan (Hobbes, 2003; Task Force Devil Combined Arms Assessment Team, circa 2003). Debate continues, however, over whether female soldiers should serve in frontline combat units, like infantry (Attwells & Hooper, 2005).

Physiological differences are cited as one of the reasons for exclusion, with a key issue among male soldiers in combat units being the perceived lack of physical fitness of female soldiers (Coppola, LaFrance, & Carretta, 2002) and their ability to carry load (Attwells & Hooper, 2005). Serving as a functional employment example, a study involving U.S. soldiers entering the army found that, where 99% of men could meet the 'occasional lifting standards' (absolute load) for their assigned jobs, only 51% of women were able to meet the required standard (Sharp, Knapik, Hauret, Frykman, & Patton, 1999). Earlier research supports this occupational performance difference between genders (Sharp, 1994). Of note however, the findings of Sharp (1994) suggest that an overlap exists where fitter female soldiers may perform similarly to less fit males, a finding supported by the work of Patterson et al. (2005). Furthermore, research does suggest that following a structured physical training program might increase the number of female participants able to meet army heavy lifting standards (Harman, Frykman, Palmer, et al., 1997).

Physiological Differences

In general, during load carriage tasks, female participants have been found to work at a higher percentage of their aerobic capacity than their male counterparts when carrying the same given loads at the same intensity (e.g. speed). Six studies (Bhambhani & Maikala, 2000; Harper, et al., 1997; Holewijn, et al., 1992; Leyk, et al., 2007; Patterson, et al., 2005; Scott & Ramabhai, 2000a) identified significant differences in performance between male and female participants while performing a variety of load carriage tasks which included backpack and stretcher carry activities. These results are unsurprising, given the lower tidal and ventilatory volumes, lower blood haemoglobin, lower aerobic power and lower absolute strength (Costa & Guthrie, 1994; Mc Ardle, Katch, & Katch, 2006; Voight, Hoogenboom, & Prentice, 2006; Wilmore, Costill, & Kenney, 2008) of the average female when compared to the average male.

Female participants have been found to walk at a slower pace and take significantly longer than their male counterparts when able to complete a load carriage task over a given distance at a self-determined pace (Holewijn, et al. 1992). Holewijn, et al. (1992) reported female participants to work at a 22% higher intensity level (determined by $VO_{2\ max}$) than their male cohorts ($p \leq .05$) while performing a load carriage task at various given speeds in boots and wearing a load of 12 kg in a waist pack. However, when both genders worked at the same relative aerobic intensity levels the female participants walked at a slower pace (-0.7-0.8 km/h). These findings are supported by the studies of Bhambhani and Maikala (2000) and Harper, et al. (1997). Bhambhani and Maikala (2000) observed similar results in that female participants averaged a pace slower (-1.0 km/h; p<.05) than that of male participants. Similarly, Harper, et al. (1997) found that for three load conditions (18, 27 or 36 kg), marching a distance of 10 km at a self-selected pace, the completion times of male soldiers were 21% faster than those of their female counterparts (p<.01). The research therefore suggests that when required to maintain a given task intensity, female participants, in general, work harder than their male counterparts, in general, and, when task intensity (i.e. speed) can be varied, they work at a similar relative aerobic intensity to their average male counterpart (in turn resulting in longer event durations).

Key differences in body compositions exist between the average female and average male soldier. With the average female being lighter than the average male (Ebben & Jensen, 1998; Mc Ardle, et al., 2006; Voight, et al., 2006; Wells, 1991; Wilson, 1995), they are, in general, disadvantaged during load carriage tasks that are of an *absolute* nature (Vanderburgh, 2008). A study of recreational hikers in New Zealand, who were able to choose their own loads, found that the male hikers reported carrying more load than the female hikers, yet when expressed as a percentage of body weight, both genders carried the same relative loads, being around 19% of their body weight (Lobb, 2004). Conversely, Scott and Ramanhai (2000a) found that female participants were taxed significantly more (27%) than male participants when carrying an absolute load, and they were still taxed significantly more (24%) than their male counterparts when the loads were adjusted to 37% of body weight. These female participants had a mean body fat mass of around eight kilograms more than that of their male counterparts. Thus, the female participants carried a mean load of 24 kg (37% body weight) plus 17 kg (fat mass), equating to a total passive load of 41 kg, whereas the male participants carried a mean load of 27 kg (37% of body weight) plus nine kilograms (fat mass), equating to a total passive load of 36 kg. When considered in conjunction with discussions earlier in this section of the chapter on the potential impact of fat mass on load carriage performance, differences in performance between the average female and average male soldiers may be influenced more by average differences in body weight and fat mass than by gender per se. On this basis, broader individual differences, rather than gender alone, may play a role in load carriage performance.

Several studies support the hypothesis that broader individual differences than gender alone may play a role in load carriage performance (Leyk, et al., 2007; Pandorf, et al., 2002; Patterson, et al., 2005). Serving as intra-gender examples are the findings of Pandorf, et al. (2002) and Patterson, et al. (2005) who observed that larger, heavier and stronger female participants performed better on load carriage tasks (3.2 km and 15 km completion times) than their fellow female cohorts. Providing an inter-gender comparison, Leyk, et al. (2007) observed six (40%) female participants to have a significantly ($p<.05$) longer time to volitional fatigue during a bilateral stretcher carry task than that of the least fit male.

Biomechanical Differences

On average, women tend to walk with shorter stride lengths than males (Knapik, et al., 2004; Martin & Nelson, 1986; Yamasaki, et al., 1991). Consequently, with gait speed the product of stride length and stride frequency (Hoffman, 2002; Kirtley, 2006), the shorter stride lengths can require the average female participant (and shorter male participants) to require a higher stride frequency to maintain a given pace (Knapik, et al., 2004; Martin & Nelson, 1986; Ralston, 1958; Yamasaki, et al., 1991).

Two studies explored and compared the impact of load carriage on gait parameters of female and male subjects. Martin and Nelson (1986) examined the gait differences in male and female load carriers from no load to a 36 kg load. They found female load carriers to have shorter stride lengths than male load carriers under all load conditions. However, the differences were only significant when carrying 10 kg and 36 kg. Conversely, Attwells and Hooper (2005) observed no significant differences between genders in stride length and stride frequency when female (mean body weight of 68.8 kg) and male (mean body weight of 78.6 kg) soldiers carried loads of 7% BW plus weapon and 40% BW plus weapon.

Female soldiers have been observed to increase stride frequency rather than stride length when required to carry greater loads or increase walking speed (Knapik, et al., 2004; Martin & Nelson, 1986; Yamasaki, et al., 1991). In the aforementioned study by Martin and Nelson (1986), both female and male participants significantly ($p<.05$) increased their stride rates (Female: $M=2.14$: $SD=0.09$ str/s to $M=2.25$: $SD=0.12$ str/s: Male $M=2.05$: $SD=0.08$ str/s to $M=2.09$: $SD=0.08$ str/s) as loads increased from gym shorts, T-shirt and shoes up to around 36 kg. However, female participants did so to a significantly greater extent than male participants. In contrast, Ling, et al. (2004), whose study included only female participants, observed no significant differences in stride frequency or stride length as loads increased (unloaded to 22.7 kg). Different protocols might account for the differences in findings, with Ling, et al. (2004) capturing more data (3 trials per load, as opposed to two strides from a single trial) and having participants walk at a slower speed (4.8 km/h versus 6.4 km/h). Furthermore, Ling, et al. (2004) ceased the trial if participant heart rates breached 80% of their age-expected maximal heart rate. On the basis of the conflicting and limited studies, the changes to spatial gait parameters with increases of load cannot be accurately determined, and more research in this area is required.

Caution is still advised until further research evidence becomes available. If female soldiers, on average, naturally increase their stride rate to accommodate increases in load weight, forcing them to march ‘in-step’ or to a cadence may require them to increase stride length to maintain pace. This adaptive response to increases in the load weight may result in overstriding, which in turn can lead to injuries like pelvic stress fractures (Kelly, et al., 2000; Pope, 1999). The same concern regarding overstriding would apply to shorter males.

Injury profiles

Female soldiers, in general, are injured to a greater degree during military basic training (Gemmell, 2002; Knapik, Canham-Chervak, Hauret, et al., 2001; Ling, et al., 2004; Macleod, Houston, Sanders, & Anagnostopoulos, 1999; O'Connor, 2000), on operations (Belmont, Goodman, Waterman, et al., 2010) and, more specifically, during load carriage events (Boulware, 2003) than male soldiers.

A review of a six-week Marine Corps Officer Basic training course, where load carriage is part of both physical and field training, found a cumulative injury incidence of 80% for female candidates and 59.5% for male candidates (O'Connor, 2000). Similarly, over the longer 11-week U.S. Marine Basic Training Course, the incidence of stress fractures was 3.9% and 1.7% for the female and male recruits respectively. In the latter study, female recruits showed increased levels of bone resorption markers in weeks 2, 8, 9, 10 and 11 whereas their male counterparts showed increases in weeks 11 and 12 only (Sheehan, Murphy, Reynolds, Creedon, & al., 2003). This result was found even though the female recruits completed less overall mileage of weight-bearing training than the male recruits. In the British Armed Forces, the change from a ‘gender fair’ regime, where standards were adjusted to account for gender physiological differences, to a ‘gender free’ regime, where workload was based on requirement regardless of gender, saw a greater tendency to overuse injuries in female trainees (Gemmell, 2002). Moreover, medical discharges of female trainees, due to these injuries, more than doubled from 4.6% to 11.1%.[44]

---

[44] Gender odds ratio for medical discharge following overuse injury rose from 4.0 (95% CI 2.8 to 5.7) to 7.5 (95% CI 5.8 to 9.7, p=.001) (Gemmell, 2002, p.24).

However, gender may not be an independent risk factor for injury, with suggestions that lower levels of aerobic fitness are the primary cause of the greater injury incidence among female recruits during initial training (Gemmell, 2002). With the average female having a lower aerobic capacity than the average male (Ortego, Dantzler, Zaloudek, et al., 2009; Wilmore, et al., 2008), and findings by Pope, et al. (1999) on recruits undergoing training within the Australian Army showing that less aerobically fit recruits were at a 25% higher risk ($p<.001$) of not completing training due to injury, the determining factor behind high female injury presentations may be lower average aerobic fitness levels rather than their gender.

2.3.4. The Impact of Load Carriage on the Soldier

As discussed earlier in this chapter, load carriage can elicit both a physiological (Section 2.3.1) and biomechanical (Section 2.3.2) response from the soldier carrying the load. These responses to load carriage, together with other factors (like the soldier's morphology) may further affect the soldier in a more overt fashion. Physical injuries and impairments in performance of given military tasks provide two such examples.

Injuries caused by load carriage

Load carriage tasks are acknowledged as placing increased stress on the musculoskeletal system of the carrier (Harman, et al., 2000; Polcyn, et al., 2000). This physical stress of carrying heavy loads can lead to musculoskeletal injury (Wright, 2009). However, attributing musculoskeletal injuries directly to load carriage tasks can be very difficult. A key reason for this difficulty is the nature of some physical injuries which are due to an accumulation of microtrauma, such as stress fractures, resulting from of repeated stressors over time (Brukner & Khan, 2011). With the nature of military training involving a physical component and with soldiers and trainees often involved in more than one training activity over a period of time, establishing a direct causal link between load carriage and injuries over time is very difficult. On this basis, this review considers both studies of acute injuries that occur during or immediately after a load carriage event and studies examining injuries in specific military populations that undertake load carriage activities, like trainees, while acknowledging that the links between load carriage and injuries in this latter group of studies are tenuous.

When body sites of injuries are aggregated, the lower limbs have been found to be the most frequent anatomical site of injury for military personnel (Almeida, Williams, Shaffer, & Brodine, 1999; Jennings, Yoder, Heiner, Loan, & Bingham, 2008; O'Connor, 2000). Even when injuries during military load carriage marches were specifically reviewed, the lower limbs appear as the leading sites of injury (Knapik, et al., 1992). More specifically, Lobb (2004) reported sprains to the knees and ankles as the leading cause of reported injuries in recreational hikers, whereas the studies of Reynolds, et al. (1999) and Knapik, et al. (1995) reported foot blistering to be the most frequent injury type sustained during load carriage events. One potential reason for the differences in the nature of injuries between recreational hikers and military load carriers may lie in the differences in the terrain covered. Recreational hiking typically involves walking along narrow dirt and pebbled paths, and military marching, in the studies reviewed, is generally performed on hard dirt paths and roads (Knapik, et al. 1992; Knapik, et al. 1995; Reynolds, et al. 1999; Lobb, 2004). A second potential reason may be the heavier loads carried by military personnel when compared to recreational hikers, with heavier loads associated with an increased risk of foot blistering (Harper, et al., 1997; Knapik, et al., 1992).

Foot blisters

Although foot blistering may appear to be a relatively minor condition, complications like infection may be more serious (Akers & Sulzberger, 1972; Bush, Brodine, & Shaffer, 2000; Knapik, et al., 1999) and have led to soldier deaths (Berkley, McNeil, Hightower, et al., 1989). Furthermore, blisters have also been associated with causing other musculoskeletal soft tissue injuries which may result through alteration of movement patterns as ‘hot spots’ develop (Bush, et al., 2000).

Caused by shearing forces within the epidermis (Akers & Sulzberger, 1972; Knapik, et al., 1999), Knapik, et al. (1992) suggest that a plausible risk factor for blisters may be the increased loads carried by soldiers. This is unsurprising considering that, as previously discussed, the biomechanics of gait have shown GRF to increase with increasing loads (Birrell & Haslam, 2008; Birrell, et al., 2007; Kinoshita, 1985; Knapik, et al., 1992; Lloyd & Cooke, 2000a; Park, et al., 2008; Polcyn, et al., 2000). Therefore, as external forces increase, frictional forces increase to the point where movement within the epidermis occurs (Knapik, et al., 1995). In a study comparing different loading methods, Knapik, et al. (1997; 1993) found backpacks to be associated with a higher proportion of blisters (with a maximal load of 61 kg) when compared to an experimental backpack/front pack load carriage system. However, no differences were found between the two systems with lighter loads (34 kg and 48 kg). The authors suggest that the higher braking forces while carrying the backpack combined with the load weight, are the source of the higher proportion of blisters while wearing the backpack. Although increasing blister injuries during load carriage may be attributed to load weight alone, several other risk factors have been identified in the military population, including ethnicity, smokeless tobacco, age, and sickness within the last 12 months as significant risk factors in increasing the risk of foot blistering during load carriage marching (Knapik, et al., 1999; Reynolds, et al., 1999). Although foot blistering was the most frequently observed injury to occur during studies of two specific load carriage events (Knapik, et al., 1992; Reynolds, et al., 1999)[45], load carriage has been associated with a range of other injuries, including stress fractures, knee and foot pain, neuropathies (digitalgia, meralgia, and brachial plexus palsy) and lower back injury (Knapik, et al., 2004; van Dijk, 2009).

Stress fractures

For the military, stress fractures are of particular concern due to their protracted recovery periods (Kelly, et al., 2000; O'Connor, 2000; Pope, 1999; Rome, Handoll, & Ashford, 2005; Ross, 2002). Stress or fatigue fractures are attributable to repetitive overloading of the bones where the bone remodelling balance is upset and bone remodelling is outpaced by bone stress and fatigue (Knapik, et al., 2004; Nordin & Frankel, 2001; Rome, et al., 2005).

Stress fracture sites of military personnel include the pelvis, tibia (shaft and condyles), calcaneus and metatarsals (Greaney, et al., 1983; Kelly, et al., 2000; Milgrom, et al., 1985; Pester & Smith, 1992; Pope, Herbert, Kirwan, & Graham, 1999; van Dijk, 2009). Pelvic stress fractures, which are of particular concern due to their longer recovery and rehabilitation period, have been found to occur more frequently in the female army recruit population (Kelly, et al., 2000; Pope, 1999). A plausible reason for the higher female incidence rate for stress fractures in army basic training could lie in the average gender-related height differences previously discussed (Section 2.3.3), which can lead to female soldiers overstriding in order to keep pace with male soldiers, which in turn places additional shearing stress on the pubic ramus, resulting in local stress reactions (Kelly, et al., 2000). With this in mind, the study of Pope (1999), which evaluated a multi-faceted intervention that included reducing marching speed, encouraging female recruits to march at comfortable stride lengths, and providing earlier awareness of upcoming obstacles, observed a 95% decrease in pelvic stress fracture incidence ($p<.001$). More generically, modifications of training load (pace, volume, etc.) have been found to decrease the incidence of stress fractures (in both males and females)

---

[45] In the study by Reynolds et al. (1999) the proportion of blister injuries was 54% of injuries followed by foot pain at 12% of injuries. In the study by Knapik et al. (1992) this proportion was 35% of injuries followed by back strain at 18% of injuries.

without necessarily affecting physical development (Bennell, Matheson, Meeuwisse, & Brukner, 1999; Pester & Smith, 1992; Sherrard, Lenne, Cassell, Stokes, & Ozanne-Smith, 2002).

Knee pain

Given variations in findings of changes in knee range of motion in response to load carriage walking[46], increases in the range of knee flexion during load carriage walking is thought to increase as a postural adjustment in response to increases in load weight (Polcyn, et al., 2000). Thus, it is not surprising that knee pathologies often result from load carriage tasks. Knee injuries are common in military training and, together with the lower back, the knee has been found to be the most frequent specific site of injury for U.S. Army personnel on modified work plans due to musculoskeletal injuries (Jennings, et al., 2008). In the Australian Army, aggregated injury data showed that knee injuries accounted for the highest proportion of lower limb injuries (35%) associated with a single body site and the highest proportion of working days lost (40%) (Defence Health Services Branch, 2000). Considering this, the precise accounting for knee injuries varies. In two separate studies of U.S. Marine Corps recruits, the incidence of knee injuries differed. In the study of Almeida, et al. (1999) knee injuries were the second most frequently injured site, accounting for 28.1% of injuries. In contrast, Bush, et al. (2000) observed an knee injury rate as low as four per cent of injuries for the same population group in the same training location. Although population demographics in the study groups (percentage of white, Hispanic, black and 'other' members) and data capture periods (Jan to Sep) were similar, the method of injury data collection for these two studies by Almeida, et al. (1999) and Bush, et al. (2000) differed. In the study by Almeida, et al. (1999) injury data was captured through a review of recruit medical folders. Conversely, Bush et al. (2000) gathered data from an injury data base where injury details were entered retrospectively and coded using standardised grading criteria. As such, procedural limitations associated with formally reporting injuries (e.g. severity of injury) may have led to an underestimation of injury presentations (Rosenman, Kalush, Reilly, et al., 2006).

As with accounting for knee injuries, the severity of knee injuries has been found to vary. In a study of military soldiers conducting a 20 km march with a 46 kg load, Knapik, et al. (1992) observed an injury frequency of one per cent (two of 335). These two knee injuries equated to 14 days of limited duties. A subsequent study by Knapik, et al. (1993) found that, of the soldiers who could not complete a series of load carriage trials (six 20 km marches with loads ranging from 34 to 61 kg utilising two difference pack designs), 50% (three of six) were diagnosed with a knee strain.[47] Conversely, Reynolds, et al. (1999) found a three per cent (seven of 218) knee injury incidence

---

[46] See section 2.3.2.

[47] The remaining three injury cases were back pain, metatarsalgia and cellulitis.

during a 161 km march with a load of around 47 kg. However, only one working day was lost from a total of seven reported knee pain incidents during and immediately following the load carriage march.

Foot pain

Heavy loads have been found to change the dynamics of the foot during gait (Kinoshita, 1985) and hence foot-related injuries through load carriage activities are not uncommon. Ranging from metatarsal stress fractures and plantar fasciitis to digitalgia (discussed in next section) and non-specific foot pain (Knapik, et al., 2004; Knapik, et al., 1992; O'Connor, 2000; Reynolds, et al., 1999; Rudzki, 1989; van Dijk, 2009), foot injuries have been found to be the leading cause of working days lost or restriction of duties or training failure, in many (O'Connor, 2000; Reynolds, et al., 1999; Rudzki, 1989) but not all (Knapik, et al., 1992) studies. Unfortunately, with the lack of specific information often accompanying foot related injuries associated with load carriage (e.g. ‘foot pain’ (Knapik, et al., 1992) or ‘foot pain not otherwise specified’ (Reynolds, et al., 1999)), further investigation into the nature of these injuries was difficult. A study by Rudzki (1989) did provide more detailed and specific foot injury information with a painful pes planus or ‘flat feet’ ($n=3$) and plantar fasciitis (n=2) the two types of foot injuries associated with load carriage. Given the limited number of cases in this single study, further research, specifically examining foot related injuries associated with load carriage, would be beneficial if the impacts of these injuries are to be addressed.

Digitalgia and Meralgia

Apart from injury to the musculoskeletal system, load carriage activities have been associated with two main neuropathies to the lower limbs: digitalgia and meralgia. Digitalgia, or numbness in the toes, has been found to present in participants undergoing military training and load carriage activities (Boulware, 2003; Stein, Shlamkovitch, Finestone, & Milgrom, 1989). A study of Israeli trainees undergoing infantry basic training reported 47% of trainees presenting with digitalgia over the 14-week period (Stein, et al., 1989). Of note, no significant differences were found between the group wearing running shoes and the group wearing boots. In a study of paraesthesias in backpackers, Boulware (2003) reported an incidence rate of 34% in 280 backpackers carrying loads from 16.5 to 19 kg over 2000 km, with digitalgia being the most commonly identified[48] (22% of reported paraesthesias).

The second most frequently reported paraesthesia in the study of Boulware (2003) was meralgia (10% of reported paraesthesias). Meralgia presents as a paraesthesia of the lateral femoral cutaneous nerve on the anterolateral aspect of the thigh (Boulware, 2003; Fargo & Konitzer, 2007; Sanders & Nemeth, 1996). The nerve is considered vulnerable to entrapment as it is compressed against the anterior iliac spine when a waist belt, like that on a backpack, is tightened (Boulware, 2003). Recently Fargo and Konitzer (2007) reported on two case studies of soldiers serving in Iraq, both of whom suffered meralgia due to prolonged wearing of body armour. In these two case studies both soldiers still presented with symptoms a month after being diagnosed. Although limited to only two persons, the findings raise awareness of other potential neurological conditions that might arise through continual exposure to worn loads, in this case body armour.

Brachial plexus palsy

Brachial plexus palsy (also known as ruck sack/backpack palsy) is a debilitating injury associated with heavy load carriage activities (Charteris, 2000; Corkill, et al., 1980; Knapik, et al., 2004; Makela, et al., 2006; Maurya, et al., 2009) and as such most reported cases occur in military personnel (Wilson, 1987); although cases have also been reported in recreational backpackers (Corkill, et al., 1980) and scouts (White, 1968). The mechanism of brachial plexus palsy has been postulated as a traction or compression injury to the C5 and C6 nerve routes caused by backpack straps exerting a heavy downward pressure in the region of the upper trunk of the brachial plexus (Corkill, et al., 1980; Drye & Zachazewski, 1996; Kawabata, 2000; Knapik, et al., 2004; Makela, et al., 2006; Reid, 1992). Symptoms include numbness, pain and weakness in upper limb musculature (Charteris, 2000; Corkill, et al., 1980; Knapik, et al., 2004; Makela, et al., 2006; Reid, 1992; Wilson, 1987) and can present during a load carriage activity (Makela, et al., 2006; Wilson, 1987).

In a study of U.S. soldiers in basic training, Bessen, et al. (1987) found a brachial plexus neuropathy rate of 1.17 incidence per 1,000 trainees over a 14 month period, and in a later study of Finnish military conscripts Makela, et al. (2006) observed an incidence rate of 0.537 cases per 1,000 conscripts per year. The difference in findings could be due to numerous factors from the load carriage context, including load, duration, and differing types of backpacks. Both studies,

---

[48] 64% (n=61 of 96) of reported paraesthesias lack sufficient detail to categorise them by injury site.

however, observed that soldiers carrying backpacks without a frame had a higher incidence of this injury type, with Bessen, et al. (1987) claiming an injury rate 7.4 times higher for soldiers wearing a backpack without a frame compared to those using a frame.

Although the rates of these injuries may not seem high compared to those for other load carriage injuries, recovery can take up to several months (Bessen, et al., 1987; Corkill, et al., 1980; Makela, et al., 2006; Reid, 1992; Wilson, 1987), with surgical intervention recommended following failure to recover strength and endurance after 24 months (Drye & Zachazewski, 1996). Thus the nature of this injury has both tactical and strategic implications. Tactically, military operations are affected when upper limb paraesthesia and weakness have notable impacts on the ability of a soldier to employ personal weapons. This issue was highlighted by Bessen, et al. (1987) when soldiers presenting with this condition noted difficulty in simply carrying their personal rifle. Operationally, the lengthy recovery time for the injury can remove trainees from a training program and soldiers from operational duties. Again this issue was highlighted by Bessen, et al. (1987) who reported that only a third of the trainees suffering from a brachial plexus palsy were retained on active duty, to continue training after a period of convalescence.

With excessive loads and the incorrect adjustment of pack straps noted as causative mechanisms (Attard, 1985; LaFiandra & Harman, 2004; Wilson, 1987), the use of hip belts attached to framed backpacks, which can reduce load on the shoulders (Knapik, et al., 2004; LaFiandra & Harman, 2004; LaFiandra, Lynch, et al., 2003; Reid & Whiteside, 2000) has been suggested as a means of reducing the incidence of this injury type (Bessen, et al., 1987; LaFiandra & Harman, 2004).

The lower back

Injuries to the lower back are also common during or following load carriage tasks (Knapik, et al., 1992). As with knee injuries, findings vary as to the frequency of occurrence of load carriage induced lower back injuries. Whereas Reynolds, et al. (1999) found a relatively low rate of back injury (four percent of injuries) during a 161 km march, Knapik, et al. (1992) found the frequency of back injury (22% of all injuries) to be second only to that of blisters in rate of occurrence during a 20 km march with a 46 kg load. Of greater importance in the Knapik, et al. (1992) study, over half of the participants who suffered a lower back injury during the march were unable to complete the activity.

The earlier review of research pertaining to the biomechanical impact of load carriage on the spine highlighted potential increases in lumbar compression and shear forces and increases in forward lean as carried loads increased (see Section 2.3.2). On this basis, injuries to the lower back during or following load carriage tasks are not unexpected. Considering this, trunk conditioning programs, which have been shown to reduce spine deformation (Debeliso, O'Shea, Harris, Adams, & Climstein, 2004), may assist in limiting lower back injury during load carriage tasks. Further research in this area is still required.

The impact of load carriage on soldier performance

The U.S. Field Manual 21-18 (FM 21-18) entitled *'Foot Marches'* states that the primary consideration is not how much soldiers can carry, but how much they can carry without impairing combat performance (Department of the Army, 1990). With fatigue defined as *'a state of weariness caused by physical and/or mental exertion'* (Murphy, 2002, p. xiii) and load carriage found to increase physical exertion (Knapik et al., 2004), load carriage can be expected to contribute to soldier fatigue and consequently affect soldier combat performance in functional areas including mobility, lethality, ability to perform general tasks, and even cognition.

The impact of load carriage on soldier mobility

From strategic tactics in the Great War (Lothian, 1921) to chasing Militia in East Timor (Breen, 2000), the load carried by a soldier has reduced and can be expected to reduce soldier mobility and the mobility of their unit (Mayville, 1987). This hypothesis is validated by strong evidence suggesting that as the weight of the carried load increases, the mobility of the carrier, in terms of time to move a given distance and time and ability to complete an obstacle course, decreases. Four separate studies, with loads ranging from 14 kg to 61 kg, have reported increases in time to march a given distance as the carrier*'s load*s have increased (Harper, et al., 1997; Johnson, et al., 1995; Knapik, et al., 1997; Pandorf, et al., 2002). As an example, in the study of Pandorf, et al. (2002) female participant times to complete a 3.2 km loaded run increased by 19% when the load was increased from 14 kg to 27 kg and by 44% when the load was increased to 41 kg. Similarly, Harper et al. (1997) observed male and female participant times, over a longer distance of 10 km, to increase by 4% when loads increased from 18 kg to 27 kg and by 23% when the loads increased from 18 kg to 36 kg. Moreover, a subsequent analyses yielded a significantly longer march time with the 36 kg load compared to either the 18 kg or 27 kg loads (Harper, et al., 1997). These results suggest that as the weight of the carried load increases, the associated decrease in mobility may be more pronounced.

Decreases in obstacle course performance have been associated with increases in load carriage weight. Several studies (Frykman, et al., 2000; Pandorf, et al., 2002; Park, et al., 2010; Park, et al., 2008) and a meta-analysis of four studies (Polcyn, et al., 2000) observed increases in time taken to negotiate individual obstacles and obstacle courses with associated increases in the weight of the load carried. Furthermore, three studies (Frykman, et al., 2000; Park, et al., 2010; Park, et al., 2008) found that the numbers of participants able to successfully negotiate individual obstacles decreased as the load weight carried increased. In one study of interest, Park et al. (2010) used obstacles to simulate debris faced by fire fighters. They found that loads of 9.1 kg led to 42 % (10 of 24) of participants making contact, at least once, with a 30 cm obstacle while stepping over it. Soldiers could be expected to face similar debris in battle-damaged buildings or areas. On this basis, increases in load weight could present the soldier with additional risks of tripping and falling while carrying loads in a potentially threatening environment.

A further aspect for consideration is that of the physical space taken up by increases in load weight. Two studies considered the potential for increases in load size to affect obstacle course performance (Pandorf, et al., 2002; Park, et al., 2010). Pandorf, et al. (2002) observed a two-fold increase in time to complete a 3.7 m crawl obstacle when the carried load was increased from 14 kg to 27 kg. The authors considered the increase in physical space taken up by the additional load equipment to have been a contributing factor to the reduced performance, by decreasing crawl space and altering movement technique. These results contrast with those of Park et al. (2010). In Park et al's. (2010), study, participants carried four different sized SCBA (two weighing 5.1 kg and two weighing 9.1 kg) while walking up to and over an obstacle. When their results were subjected to a statistical analysis, it was observed that, although associated with increases in load weight, increases in times to negotiate the obstacle were independent of load size. However, it should be noted that this latter study employed only a step-over obstacle, lighter loads (5.4 kg and 9.1 kg), and smaller sized loads (various self-contained breathing apparatus).

Finally, a single within-subjects (repeated measures) study with a randomised presentation of trials found that increases in loads carried in front of the body led to participants adopting a more conservative gait pattern (Perry, et al., 2010). A change in visual information provided by the load position relative to the floor obstacle was considered an influencing factor (Perry, et al., 2010). This study provides evidence of conservative changes to gait associated with increases in carried load weight. However, the results must be considered with caution when applied to the general military load carriage population until a greater volume of research is available as the loads in this study were no heavier than 10 kg and only carried in the hands, as opposed to military populations who carry heavier loads predominantly on the back.

The impact of load carriage on soldier lethality

Research suggests that military load carriage has the potential to affect a soldier's lethality capability in terms of both marksmanship and grenade throwing ability (Knapik, et al., 2004). Of the five identified studies investigating the impact of load carriage on marksmanship performance, four reported reductions in shooting performance to be associated with load carriage tasks (Knapik, et al., 1997; Knapik, Bahrke, Staab, et al., 1990; Knapik, et al., 1991; Rice, et al., 1999). In three separate studies, Knapik, et al. (1997; 1990; 1991) found a decline in shooting performance with an M16 Assault Rifle (weighing 3.5 kg) following the completion of load carriage tasks (20 km march carrying loads of up to 61 kg).[49] Likewise, Rice, et al. (1999) found a decrease in marksmanship ability following a stretcher carry task, with reductions in both accuracy ($p<.001$) and speed and accuracy ($p=.02$) when firing an M16 fitted with a laser firing simulator.

Conversely, Patterson, et al. (2005) found no significant difference in shooting performance in seven of eight paired marksmanship trials (2 male cohorts, 2 female cohorts, 2 trials [standing and prone] paired pre- and post-load carriage event). In that study, male and female participants fired an F88 Austeyr Assault Rifle (weighing 3.6 kg) during a laser simulated range practice approximately 30 minutes after their load carriage task (15 km march carrying 35 kg).

The differences in findings among the studies observing a reduction in marksmanship following load carriage (Knapik, et al., 1997; Knapik, et al., 1990; Knapik, et al., 1991; Rice, et al., 1999) and the study that observed no reduction in marksmanship (Patterson, et al., 2005) may have been due to differences in elapsed time between march completion and the firing assessment. With grip strength and hand steadiness essential for the accurate employment of personal weapons, the negative physiological impact of load carriage on hand steadiness and grip strength (Leyk, et al., 2007; Leyk, et al., 2006) can be anticipated to adversely affect marksmanship performance (Knapik, et al., 1990; Knapik, et al., 1991). Elevated heart rates have also been associated a negative impact on weapon fire accuracy (Hendrick, et al., 2007; Knapik, et al., 1990; McNab & Keeter, 2008), and heart rates have been observed to remain elevated for at least five minutes following the completion of a 12 min (one kilometre at a speed of 5 km/h) load carriage task (Datta, et al., 1975). Considering these findings of reduced hand steadiness and grip strength and increased heart rates following load carriage events, the longer period of recovery used by Patterson, et al. (2005) might account for the

---

[49] In the studies of Knapik et al., (1990:1991) marksmanship hits on target decreased by 43% and 26% respectively and distance from the target centroid increased by 59% and 32% respectively. No comparative data was available for Knapik et al., (1997).

differences in findings regarding effects of load carriage on marksmanship in their study when compared to others.

Research on grenade throwing performance following load carriage tasks yielded similar results to research on marksmanship, with three (Harper, et al., 1997; Knapik, et al., 1990; Knapik, et al., 1991) of four (Knapik, et al., 1997) identified studies observing a negative association between participation in load carriage tasks and grenade throw performance. A possible cause for the observed reduction in throwing ability following a load carriage event could be attributed to nerve entrapment with heavy loads (36 to 46 kg) bearing down on the shoulder (Harper, et al., 1997; Knapik, et al., 1990; Knapik, et al., 1991). Confirming the likelihood of nerve entrapment as a possible cause of reduced grenade throw performance, Knapik, et al. (1991) reported that participants in their study complained that shoulder pain limited their grenade throw ability.

In contrast to the above findings, in another study Knapik, et al. (1997) observed no associations between participation in a load carriage task and grenade throwing ability. Unlike the previous three studies, this study was based on throwing accuracy as opposed to throwing distance. This being considered, the centroid of the target used for throwing accuracy was placed 35 m from the throwing point, a distance further than the mean distances thrown (both pre and post march) in the three studies investigating a throw for distance. Apart from differences in grenade throw intent between the studies, differences in these findings might arise from differences in grenade throwing practices (throwing position for example) as well as the suspected higher levels of fitness and technical skills of the special operations soldiers who participated in that study, which found no change in grenade throw performance.

The impact of load carriage on the ability of soldiers to perform general duties

Load carriage can affect the carrier's ability to perform general tasks both during the load carriage task and for a period immediately following it. Three studies investigated the impact of load carriage on the performance of subsequent general duties (Blacker, Fallowfield, Bilzon, & Willems, 2010; Ricciardi, et al., 2008; Shoenfeld, et al., 1977). Participants in the study of Shoenfeld, et al. (1977) who carried loads of 30 kg over 20 km at a self-determined pace, demonstrated significant drops in aerobic capacity ($p<.001$) following the march, indicating fatigue and a decreased ability to do work. The value of that study is limited as the authors failed to describe how initial oxidative capacity, the measure used to determine the loads to be carried in different groups, was determined.

However the studies of Ricciardi, et al. (2008), whose participants performed simulated work while wearing 10 kg body armour, and Blacker, et al. (2010), whose participants marched on a flat and decline gradient (-8%) for two hours with a 25 kg load, provide some support to the hypothesis that load carriage can affect the subsequent performance of general duty tasks. These studies observed decreases in physical work capacity (combined measures of metabolic fitness [oxygen uptake and number of stairs stepped in one minute] and physical strength [number of chin ups and isometric extensor force]) (Ricciardi, et al., 2008) and reductions in the neuromuscular functioning (force production through voluntary and electrically stimulated contractions) following load carriage (Blacker, et al., 2010).

The cognitive impact of a load carriage task on the soldier

Three studies identified in this research have observed an association between load carriage and impaired cognitive function. Alertness, executive processing of mental operations (situational awareness) and vigilance have all been observed to be negatively affected following load carriage tasks (Johnson, et al., 1995; Mahoney, Hirsch, Hasselquist, Lesher, & Lieberman, 2007; May, et al., 2009). Johnson, et al. (1995) observed that, apart from increased fatigue and muscle discomfort, feelings of alertness diminished following a load carriage event with the 61 kg load having a greater impact on alertness than the 48 kg and 34 kg loads (mean symptom factor scores of 3.14, 3.4 and 3.68 for each load respectively: $F_{2,28}$ =7.86, p<.01). More recently, May, et al. (2009) observed a degradation of mental operations involved in executive processing (i.e. performing goal directed actions in an environment featuring complex stimuli) when military personnel stood loaded with 30% of their body weight in a military backpack. The study observed a reduction in both the speed (1,047 millisecs loaded and 1, 032 milliseconds unloaded, p=.002) and accuracy of decision making (4.8% errors loaded and 3.6% errors unloaded) when carrying loads during 22 minute trials. Perhaps of most concern are the findings of Mahoney, et al. (2007), who observed that, when a 40 kg load was added to military personnel, vigilance to randomly presented stimuli declined over a 30 minute period of walking. While vigilance to auditory stimuli decreased, a post hoc analysis indicated significantly greater decreases in vigilance to tactile and visual stimuli (mean scores of 99.5 [auditory], 92.5 [visual] and 90.4 [tactile]). Moreover, post hoc analysis identified poorest vigilance while walking around obstacles, followed by general walking, then standing.

The three studies above provide strong evidence of impairments to cognitive function associated with load carriage. This is important in the military context as it suggests that when burdened with heavy loads, soldiers may fail to notice visually-observable cues, such as improvised explosive devices when on patrols and concealed weapons when conducting checkpoints. Additional research is required, however, to determine the impact of load carriage on cognitive function in dynamic field conditions and the degree to which preparatory and physical training could moderate the impairment of cognitive function while load carrying.

2.3.5. PHYSICALLY CONDITIONING THE SOLDIER FOR LOAD CARRIAGE

Recognition of the need to condition soldiers for military marching with load can be traced back as far as the Roman legionnaires (Renatus, 1996). It appears that physical conditioning may improve load carriage task performance and help prevent load carriage injuries (Buckalew, 1990; Genaidy, et al., 1989; Harman, Gutekunst, Frykman, Sharp, et al., 2008; Knapik, et al., 2004; Maurya, et al., 2009; Soule & Goldman, 1969; Williams & Rayson, 2006), but the nature of the conditioning must be taken into consideration. Consideration of the conditioning stimulus is vital, especially when load carriage activities are recommended as a conditioning tool (Genaidy, et al., 1989; Knapik, et al., 2004; Vitiello & Pollard, 2002; Williams, Rayson, & Jones, 2004) and yet load carriage in itself is a source of injury (Knapik, et al., 1992; Reynolds, et al., 1999).

Considering that load carriage activities can cause injury, the use of load carriage in a conditioning program may be questionable. However, the requirement to include specific load carriage activities in a load carriage conditioning program is validated by studies reporting that performance on a load carriage marching activity was a good predictor of load carriage marching ability (Simpson, Gray, & Florida-James, 2006; Williams & Rayson, 2006; Williams, et al., 2004) and the physical conditioning principle of specificity which identifies the need for the conditioning context to meet the requirements of the performance context (Ehrman, Gordon, Visich, & Keteyian, 2008; LeBoeuf & Butler, 2007; Wilmore, et al., 2008). Further validating the argument for specific training to meet specific tasks is the study of Genaidy, et al. (1989). That study investigated an eight training session (2.5 weeks) conditioning program replicating a repetitive lift-and-carry task with a 20 kg load. Following completion of the conditioning program, the ability of the experimental group to sustain the repetitive lift-and-carry task improved significantly ($p<0.001$) when compared to the control group.

Reviewing the literature on conditioning for load carriage presents several challenges, most notably concerning the variations in conditioning parameters. Differences in training dose (volume, intensity and frequency of training), training purpose (increase strength, endurance, aerobic fitness), and the method of conditioning (load carriage, circuit training, resistance training, aerobic training) serve as examples. These areas of variation make direct comparisons of conditioning regimes difficult, and comparisons are restricted to basic methodological approaches.

Two studies were identified that investigated the impact of different training doses on load carriage capability (Knapik, et al., 1990; Visser, van Dijk, Collee, & van der Loo, 2005). In the first study, Knapik, et al. (1990) investigated the impact of a 9-week conditioning program on the performance of a 20 km load carriage task carrying 46 kg. The frequency of load carriage sessions ranged from no training to four sessions per month (0, 1, 2, 4 sessions per month with loads from 18 to 34 kg up to a distance of 16 km per session). The researchers found that the groups participating in two (GP2) or four (GP4) sessions per month were significantly faster (GP2=319 min: GP4=307 min) and when carrying a load of 46 kg over a 20 km distance than the groups who did not train (GP0=359 min) or trained once per month (GP1=353 min). They also observed no significant difference between the groups that trained twice (GP2) versus four times (GP4) per month.

Visser, et al. (2005) compared a high intensity (load) and low volume (distance) training regime (35–67.5% body weight [BW] for 4.1-5.5 km per session) to one of a lower intensity (load) and higher volume (distance) (20-40% BW for 8.3-16.5 km per session). Speed was kept constant at 5.5 km/h. Both training dose combinations were reviewed against the effects of training frequency (number of sessions per week). In that study, all groups improved in both speed of march and progressive load march performance. In particular, the higher intensity (load), lower volume (distance) groups improved to a greater degree in a progressive load march test than the lower intensity, higher volume groups (17.9% and 9.1% versus 7.3% and 5.7% improvement in incremental load and speed, respectively). Furthermore, the groups training with a higher frequency (once per week) improved significantly more than those training with a lower frequency (once per fortnight).

The differences in findings between Knapik, et al. (1990) and Visser, et al. (2005) regarding load carriage training frequency may lie in the markedly different training programs, most notably load carriage intensity (load) and load carriage volume (distance). Considering this, the findings of Knapik, et al. (1990) suggest that a ‘law of diminishing returns’ might exist, where fitness gains decrease with the amount of exposure (in this case training frequency) (Zernicke, Wohl, & LaMothe, 2005). Thus the carrier’s risk of injury might be increased through greater exposure to load carriage (that is an overuse injury) for minimal fitness gains. As a result of the above findings, Knapik, et al. (1990) recommended that weight load marching be conducted at least twice a month. When considered with the findings of Visser, et al. (2005), who found greatest improvements with sessions conducted weekly versus fortnightly, a load carriage training session conducted every 7-14 days may be considered optimal until further research evidence is available.

Rudzki (1989) provided the only study found during the literature search to directly compare a conditioning program involving load carriage and a conditioning program without load carriage. Two 11-week Australian recruit conditioning programs were compared. One program, (run group), consisted of endurance running, other conditioning activities, and load carriage (as part of military training only), the other program replaced all the endurance running sessions with weight load marching (load-marching group). Rudzki (1989) found that although both groups made similar gains in aerobic fitness, the rate of development was different between the groups. The run group made significant improvements in aerobic fitness in the first six weeks of the conditioning program whereas the load-marching group made gains in the last five weeks. In the latter case, the time period in which significant improvements occurred coincided with an increase in walking speed (from 5 km/h to 7.5 km/h) and an increase in loads carried (16.2-21.2 kg to 23.8-29 kg). Although the paper does not specifically detail changes to volume (duration) or frequency (times per week), it is expected that both these parameters increased as the field training focus increased towards the latter half of the recruit training program. Ultimately, however, these results suggest that to make significant gains in aerobic fitness and load carriage ability, the load carriage program needs to be at an intensity (load and speed) that is sufficient to stimulate adaptation. These findings, together with those of Visser, et al. (2005), suggest that load carriage intensity (load and speed) is a key factor in improving load carriage performance. Ultimately, the conditioning stimulus needs to be designed to ensure that load carriers are being conditioned to carry loads at the intensities required for military exercises and operational tasks (Leslie, 2007) with strategic direction and guidance for military training advocating training that closely approximates the realities of combat operations (Australian Army, 2002; Marshall, 1980). At the same time however, it must be remembered that, no matter how much conditioning a load carrier undertakes, there is still a point beyond which the load carriage task will become too much for the carrier to withstand physiologically (Porter, 1992).

In contrast to the need to conduct specific load carriage tasks to improve load carriage performance, research evidence also suggests that improvements in load carriage ability may be made without including load carriage training in the conditioning program Four studies investigated such a conditioning approach, with all studies observing improvements in load carriage performance measures (Hendrickson, Sharp, Alemany, et al., 2010; Knapik & Gerber, 1996; Kraemer, Mazzetti, Nindl, et al., 2001; Kraemer, Vescovi, Volek, Nindl, & al., 2004). Knapik and Gerber (1996) investigated the impact of a combined training program, employing both resistance training and aerobic training, on manual handling and load carriage performance. The program alternated progressive resistance training (generally 3 days per week) and aerobic training (2 days per week) for a period of 14 weeks (including 2 weeks of familiarisation). Following training, the female participants improved their time to complete a loaded (19 kg [15 kg pack]) 5 km run by four percent (mean 44.7 min reduced to 43.1 min), a statistically significant result (p=0.02). Most notable was the nature of the improved loaded run time, with participants becoming progressively faster over the 5 km (measured every km) and with the most improvement over the final kilometre.

In a 12-week study involving male soldiers (Kraemer, et al., 2004) and a 24-week study involving untrained females (Kraemer, et al., 2001), Kraemer, et al. (2001, 2004) had groups training three (untrained females) to four (male soldiers) times per week following various training protocols which included resistance training (full body or upper body, power orientated or hypertrophy orientated), and aerobic training (long distance running and sprint intervals), either in combination or in isolation. The conditioning programs that employed a combined training approach of both resistance training and aerobic training were associated with significant improvements in 3.2 km run completion time with a 44.7 kg load. Interestingly, in both studies, the participants who followed programs employing either resistance training (Kraemer, et al., 2004) or aerobic training (Kraemer, et al., 2001; Kraemer, et al., 2004) in isolation failed to make any significant improvements in loaded run times.

The findings of Kraemer, et al. (2001, 2004) are supported, in part, by the work of Hendrickson, et al. (2010) who observed improvements in 3.2 km run times while carrying a load of 32.7 kg, following a combined aerobic and resistance training program. In contrast, however, although Hendrickson, et al. (2010) likewise observed no improvement in load carriage performance following a resistance training only regime, they did observe improvements in 3.2 km run times following an aerobic only training regime. Differences in aerobic training protocols, including intensity (70-80% $V0_2$ max (Kraemer et al., 2004): 70-85% maximal heart rate (Hendrickson, et al. 2010)) and time and type (40 min of long slow distance running (Kraemer et al., 2004): 20-30 min of continuous running (Hendrickson, et al. 2010)) might contribute to the differences in findings. As may differences in load weight for the 3.2 km assessment (44.7 kg (Kraemer et al., 2004): 32.7 kg (Hendrickson, et al. 2010)) and backgrounds of participants (active women versus military personnel).

With the limited volume of evidence comparing a combined training methodology to an aerobic-only methodology or resistance training only methodology, more research in this field is required. Considering this, the volume of evidence provided by the studies of Knapik and Gerber (1996), Kramer, et al. (2001, 2004), and Hendrickson, et al. (2010) does suggest that a combination of both resistance training and aerobic training might be of value for load carriage conditioning. However, while research does suggest that load carriage performance can be improved with combined training that excludes specific load carriage training, two factors need to be considered, the impact of initial conditioning responses and provision of load carriage experience.

First, it should be noted that participants with lower levels of fitness and exercise participation make greater initial gains regardless of the type of training employed, after which specific training is needed to improve performance for a specific task (Hernandez & Salazar-Rojas, 2004; Williams, et al., 2004). On this basis, the programs lacking specific load carriage conditioning may be limited to improving load carriage performance in those of low initial fitness as the overall fitness levels improved, a hypothesis that warrants further investigation. Second, specific training can impart gains other than those measured by objective means. The aforementioned study by Rudzki (1989) identified that although the run group and the load-marching group made similar gains as shown in assessments of aerobic fitness, the load-marching group were subjectively rated by staff as performing better at military tasks than the run group. Better familiarity and experience with carrying field loads and performing vigorous activity while dressed in military fatigues and carrying a weapon were suggested as potential reasons for these subjective findings. Furthermore, conducting load carriage tasks as part of physical conditioning increases load carriage experience, which can reduce the risk (Knapik, et al., 1992). This was demonstrated by Vacheron, et al. (1998; 1999), who found that experienced load carriers were better able to control the postural adaptations required in response to heavy load carriage when compared to novice load carriers who demonstrated greater (57%) sinusoidal fluctuations. This in turn decreased spinal oscillations in comparison with more novice carriers, and reduced the force on the shoulders through the backpack straps, potentially reducing injury risks.

Rather than conducting load carriage training in isolation or a combination of resistance training and aerobic training, these conditioning methods may all be conducted concurrently. The suggestion of concurrent training is supported by findings of research which correlated load carriage task ability with neuromuscular ability (Frykman, et al., 2000; Harman, Gutekunst, Frykman, Sharp, et al., 2008) and aerobic fitness (Lyons, et al., 2005; Patterson, et al., 2005; Shek, 2001). Frykman, et al. (2000), for example, found that whereas body fat had no impact on obstacle course performance, female soldiers who could do more push ups and sit ups had faster times while carrying loads of 14 kg and 27 kg (Frykman, et al., 2000). Further, Lyons, et al. (2005) noted that as load increased (from 0 kg to 20 kg to 40 kg) and participants became less efficient, a higher *absolute* aerobic capacity was essential for performance during a 60-minute load carriage task (4 km/h at inclines of 0, 3, 6, and 9 %).

Several researchers (Harman, et al., 1997; Harman, Gutekunst, Frykman, Nindl, et al., 2008; Patterson, et al., 2005; Williams, Rayson, & Jones, 1999) have investigated the specific use of concurrent training, and variations in concurrent training, on load carriage performance. Harman, et al. (2008), compared two concurrent styled physical conditioning programs. The first program followed a new U.S. Army Standardised Physical Training (SPT) regime (including weight load marching, stretching, calisthenics, sprints, shuttle runs, and medium-distance runs (12-18 min runs) and the second a weight-based training (WBT) program with an increased resistance training focus (including weight load marching, full body resistance, longer-distance, ability based runs (20-30 min runs), sprinting, and agility training). Both groups were observed to make similar, significant improvements in short duration load carriage abilities. In the 400 m sprint (18 kg load) SPT improved by 14% and WBT by 15% and in the 3.2 km move (32 kg load) SPT improved by 11% while WBT improved by 16%. These findings suggest that the WBT training approach may have some advantage over the SPT training approach, however further studies with larger groups (SPT n=17; WBT n=15) in a military population are required to further explore the benefits of the WBT over the SPT. In general however, these findings support an earlier study by Harman, et al. (1997) observing improvements in 3.2 km loaded (34 kg) run performance over mixed terrain following a 24-week combination of resistance training, aerobic training and a single weekly load carriage session. In this study by Harman et al. (1997), speed improved by nearly a third following the training, increasing from 5.5 km/h to 7.1 km/h.

Partially supporting the findings of Harman, et al. (1997; 2008) is the research by Williams, et al. (1999). In a study reviewing the British Army basic training conditioning program, which consisted of seventy-one 40-minute periods of physical conditioning (sports, circuits, swimming and endurance sessions) as well as prolonged marches with various loads during military exercises, Williams, et al. (1999) found that only one of the two platoons made significant improvements in load carriage performance. A male-only platoon (n=33), which was assessed completing a 3.2 km distance as fast as possible with a 25 kg load, improved significantly in time (15.7%), whereas an integrated platoon (male *n*=13; female *n*=8) showed no significant improvement in an assessment undertaken over the same distance, in the same manner, with a load of 15 kg, even when the results were separated by gender. These different outcomes might also arise from typical inter-platoon differences (e.g. platoon construct, platoon staff and daily program), making it impossible to draw firm conclusions about the value of concurrent training from these results. These inter-platoon differences may be mitigated through research spanning several training platoons, preferably either male-only or integrated-only.

In a study of Australian soldiers, Patterson, et al. (2005) evaluated the impact of a specialised 12-week conditioning program, which included circuit and resistance training, running, and load carriage marching, on load carriage performance. This study, observing increases in soldier strength and aerobic capacity following the program, found no significant improvements in completion time for both a 15 km march with a 35 kg load and an agility course carrying a 10 kg load. Seasonal temperature variations (Wet Bulb Globe Temperature during assessments; pre=19°C vs post =26°C) were expected to have contributed to producing this non-significant finding. The limitation of the physical conditioning program to only two load carriage sessions throughout the program, a frequency of training below that considered optimal for load carriage improvement (Knapik et al., 1990; Visser et al., 2005), may have also been a factor in minimising any observable effect of the training. Furthermore, the duration of the longest conditioning load carriage march (30 minutes) was notably shorter than the duration of the assessed 15 km event (165 minutes). On this basis, soldiers might have been under-conditioned for the assessed event.

Based on the literature reviewed, optimal load carriage conditioning programs consist of a load carriage specific physical training session conducted at least once every 10 to 14 days at an intensity (load, speed) sufficient to bring about the required training response. Conditioning programs that include both resistance training and aerobic training are more likely to improve load carriage performance than either training method in isolation. Finally, programs that include additional concurrent training (resistance training and aerobic training) may still provide load carriage conditioning gains if sufficient load carriage conditioning is included in the program.

2.4. BRIEF REVIEW SUMMARY

This review of the literature has identified and discussed the impacts of load carriage on both the physiological and biomechanical systems of the soldier’s body, the manifestations of which can lead to potential injuries and affect soldier task performance. Further, load carriage ability may be influenced by the carrier’s morphology and gender and may be enhanced through appropriate physical conditioning. Of most note, it was identified that load weight alone was not the sole parameter defining and influencing soldiers’ response to load carriage, with the context in which the load is carried identified as a major influence. Elements of this context include the position of the load around the body, the speed at which the load is carried, the terrain over which the load is carried, the duration of the load carriage event and the climate. A dot point summary of key findings in this literature review is provided in Appendix E.

2.5. RISK CRITERIA

As part of *establishing the context* in the RMF there is a need to broadly construct the risk criteria to be used in the framework (Standards Australia Working Group MB-002-01, 2004b). Risk criteria form the terms of reference against which risks, as defined in Chapter 1, are evaluated. The risk criteria selected for a given risk management process must correspond to the types of risk involved (and of concern to stakeholders) and the way in which the levels of risk are expressed (International Electrotechnical Commission, 2009; Standards Australia Working Group MB-002-01, 2004c). The factors considered in the establishment of risk criteria for this program of research include the causes and consequences of load carriage risks, the likelihoods of the risks occurring, and the levels of risk.

2.5.1. Causes and Consequences of Load Carriage Risks

Based on the evidence provided in the preceding review of the literature, physical injury and a reduction in military task performance constitute two types of risk associated with load carriage performance that are important to both the individual soldier and the Australian Regular Army. The literature review identified load carriage as a source of risk for a variety of upper body, trunk, and especially lower body injuries. Load carriage tasks also provide a source of risk to military task performance, with load carriage observed to reduce soldier mobility, lethality, cognitive performance and performance of general duty tasks.

Potential causes of risk in load carriage tasks include load weight carried and the broader context in which the load carriage takes place (with examples including, but not limited to, speed of march, terrain traversed and load carriage event duration). From the scientific and professional evidence provided in the current literature review the soldier*'s load* carriage context encompasses more than just the physical load carried. Load positioning, speed of movement, task duration and terrain have all have been found to affect, in some way, soldiers' capacity to carry load and perform effectively.

On this basis, the load carriage context, including load weight, speed of carriage, terrain traversed (*cause*) can lead to soldier injuries and a reduction in task performance (*consequences*). The probability of these *causes* of load carriage risk leading to an associated *consequence* constitutes the *likelihood* of occurrence of the risk event (International Electrotechnical Commission, 2009; Standards Australia Working Group MB-002-01, 2004c).

2.5.2. The Likelihoods of the Risk Events Occurring

In a risk management construct, the term '*likelihood*' is used to refer to the chance of something occurring (Standards Australia Working Group MB-002-01, 2004b). Likelihood is described using terms like 'probability' and 'frequency' (International Electrotechnical Commission, 2009). As load carriage forms part of the soldier's vocation, the probability that soldiers will have to carry a load at some point in their career is a certainty. However, the frequency with which soldiers carry loads will vary, and can range from a very high to a very low rate. Considering this fact, for this program of research *likelihood* is defined as the probability of the *causes* of risk during load carriage (identified as load weight and contextual factors that include, but are not limited to, speed of march, terrain traversed and load carriage event duration) leading to a *consequence* of concern (injury or reduction in performance). Once the *likelihood* of the risk leading to a *consequence* is considered, the *level of risk* can be determined.

2.5.3. The Level of Risk

Establishment of the *level of risk* for a given event permits determination of whether the risk is severe enough to warrant treatment or action (Standards Australia Working Group MB-002-01, 2004c). Determination of the *level of risk* for an event depends on considering the combination of *consequences* and their *likelihood* (International Electrotechnical Commission, 2009). On this basis, the *levels of risk* for a load carriage event are analysed through the use of a risk-ranking matrix which combines scales of *consequence* and *likelihood* (Standards Australia Working Group MB-002-01, 2004a). Further, *risk controls*, which provide means of avoiding or reducing the *level of risk* (Standards Australia Working Group MB-002-01, 2004a) are considered.

2.6. RISK TOLERANCE

Risk tolerance thresholds are in essence the overall level of risk that an organisation is willing to tolerate for a given event (Great Britain Office of Government Commerce, 2007). To determine whether a risk requires treatment, the *level of risk* is compared to *risk tolerance thresholds* (Australian Army, 2007a). This process allows identification of risks needing treatment and the risk treatment priorities (Standards Australia Working Group MB-002-01, 2004a). Typically, when treating risks, identified risks that are above a broadly accepted level of risk but below that of unacceptable risks must be reduced to a level that is 'as low as reasonably practicable' (ALARP) (Cameron & Raman, 2005). The ALARP principle is in essence a balance between risk and costs associated with averting the risk (Cameron & Raman, 2005; Melnik & Everitt, 2008). Furthermore, acknowledging that not all risk can be removed, the ALARP principle requires a continual reassessment of risk reduction measures in order to achieve and maintain a level of risk that is ALARP (Cameron & Raman, 2005). In accordance with the Australian Army approach to risk management, the criterion for risk tolerance accepted for this program of research is therefore ALARP (Australian Army, 2007a).

2.6.1. Risk Criteria in This Program of Research

The risk criteria employed in this program of research are broadly defined in order to contribute to the process of *establishing the context* of contemporary military load carriage. On the basis of the literature review, potential causes of risk to a load carriage event include load weight carried as well as the broader context in which the load carriage takes place (e.g. speed of march, terrain traversed, etc.). The consequences of these identified risks to the soldier include injury and a reduction in military task performance. Following further investigation of both risk *causes* and *consequences* and risk *likelihoods, levels of risk* are estimated and compared against established *risk tolerance thresholds* which are used to determine and guide levels of acceptance and treatment, with the intent to reduce the risk to a level that is *as low as reasonably practicable*. Finally, although there is a need to broadly outline risk criteria in these initial stages of the RMF, they can be further developed (Standards Australia Working Group MB-002-01, 2004b), as occurs in Chapter 8.

3. A HISTORICAL REVIEW OF SOLDIER LOAD CARRIAGE

3.1. INTRODUCTION

The requirement for soldiers to carry load is not new and can be traced back to armies of antiquity (Gabriel, 2002). In previous conflicts, the weight of these loads have reduced army size, altered battle tactics (Lothian, 1921), and led to soldier deaths in the field (Marshall, 1980). These concerns cannot be relegated to the past events, with more recent reports indicating similar concerns for the modern soldier (Bernton, 2011a; Brown, et al., 2010; Lowell Sun, 2010; McPhedran, 2009a; Tyson, 2009). More concerning is the possibility that these loads are increasing (Beekley, Alt, Buckley, Duffey, & Crowder, 2007; Knapik, Harman, & Reynolds, 1996; Knapik, et al., 2004). Just over 20 years ago, a paper by Knapik, et al. (1989) was ground-breaking in its provision of a brief historical review of the soldier's load up to that time. Although generally limited to considering *absolute* loads (the load carried regardless of soldier body weight), the review suggested that soldier loads were increasing, with the modern soldier at that time carrying more load than ever before. This review was important for two key reasons. First, as increased loads have the propensity to affect combat capability (Knapik, et al., 1997), it is highly undesirable for loads to increase. This was a concern highlighted by General Shinseki, the U.S. Army Chief of Staff who threatened to stop the U.S. LAND WARRIOR modernisation program if there was any further increase in weight the soldier would have to carry (Siebrand, 2002). Second, military forces often study previous conflicts and engagements to improve tactics and processes, by 'learning lessons' from the past (Combined Arms Center, 2010). Knapik's (1989) review provided such an opportunity in relation to soldier loads. Knapik later updated this work with two further reviews (Knapik, 2000; Knapik, et al., 2004), each review advancing the historical period to consider more recent loads.

Updating and extending the earlier works of Knapik, et al. (1989; 2000; 2004) by increasing both the scope and depth of the historical review of load carriage, and introducing the historical context of Australian soldier load carriage, the historical review presented in this chapter continues the Risk Management Framework process of *establishing the context* (outlined in Chapter 1). This integral step in the risk management process, which was commenced in Chapter 2 (Soldier Load Carriage: A Review of the Literature), is further informed by two key questions addressed in this review:

- What historical trends in soldier load carriage can be identified from the literature?
- What lessons can be learned from history to inform future soldier load carriage practices in Australia?

3.2. METHOD

3.2.1. Review Approach

By systematically exploring the past, a historical review can provide insight into past events (Rowlinson, 2005), in this instance load carriage. Moreover, a historical review provides a means by which current findings can be placed in perspective and by which the relationships between past and present load carriage practices can be explored (Berg, 2001).

The five steps of historical research, described by Johnson and Christensen (2010), formed the approach for this review. With the first step, *identification of the research topic and formulation of the research problem or question* presented above, the remaining four steps were used to guide the historical review presented in this chapter. These steps were:

- Data collection or literature review;
- Evaluation of materials;
- Data synthesis; and
- Report preparation or preparation of the narrative exposition.

3.2.2. Data Collection - Literature Search and Review

An initial load carriage time-line was established using three key texts (Knapik, et al., 2004; Lothian, 1921; Marshall, 1980). These texts were selected as they specifically included some historical load carriage data, were widely circulated (and referred to) within the Australian Defence, and were known to the investigator from previous research.

Before commencement of the review, the historical time periods and the geographical focus were determined. The initial starting point in the time period was drawn from the works of Lothian (1921) and Knapik, et al. (1989, 2000, 2004).[50] These works commenced with loads carried by the Greek hoplites (circa 700 BC). In research into this time period, soldier load weights from an earlier civilisation, that of the Assyrians, were identified. On this basis, the timeline commenced with the Assyrian spearman loads (circa 700 BC) and progressed to loads from current conflicts in Iraq and Afghanistan (2010).

---

[50] Marshall's (1980) work was in the form of themed narrative and did not follow a chronological timeline.

In terms of a geographical framework, data collection was focused primarily on the European continent. This geographical location was selected for the following reasons:

- The English language can be traced back to the European continent (Marsh, 1885) and thus the translation of ancient text into English is anticipated to hold more reliability for texts derived from the European continent than, for example, the translation of texts from ancient China.
- The European military context has greater relevance for the Australian Army load carriage context than those of South American, African, or Asian nations, since Australia was colonised by the English, adopted a British military structure, and has fought in all of its major conflicts alongside (and in some cases against) European nations (Australian Army Staff, 2008).

To collect the data, a literature search and a literature review were undertaken using a three-stage approach. As a starting point and employing the timeline as a guide, the first stage employed a matrix of key search terms that were entered into Australian Department of Defence and non-defence databases in order to identify initial literature of relevance to the review. The intent of the matrix was to purposefully employ search terms in a structured sequence that would progressively narrow the search field to the desired data. Initially constructed of five groups of terms, a sixth group was added as terms specific to a given period were progressively identified (e.g. panalopy [armour worn by ancient Greek soldiers], Operation CITADEL) during the source capture process. Search terms from groups one through five were employed progressively. Initially terms from groups one and two were entered. If more than 200 responses resulted, terms from group three were added. This process continued until either less than 200 responses resulted or all five groups of search terms had been entered. The terms for the sixth group were applied in isolation. The search terms selected were based on key load carriage terms employed in the literature review (Chapter 2) as well as terms identified in the three key initial texts. The databases, key search terms and matrix employed are detailed in Table 2. In an attempt to identify additional publications of relevance to this historical review, both Australian Department of Defence and non-defence colleagues were also contacted in this first stage of the literature search and review.

The second stage of the literature search and review, guided by the research questions, entailed review of identified journal articles and texts, with sources subjected to preliminary critical consideration regarding the potential reliability of their available evidence. Potential additional sources were also identified from the reviewed texts. Notes from this process of literature search and review were transcribed into a journal. Identified load weights and contexts were highlighted and additional time periods and military forces operating within specific time periods were identified. As well, observations regarding preliminary critical consideration of the available literature were transcribed into a journal in preparation for the evaluation phase (Section 3.2.3).

Table 2: Historical literature review databases, key search terms and search method.

DATABASE	**SEARCH TERMS**				
	GROUP 1	**GROUP 2**	**GROUP 3**	**GROUP 4**	**GROUP 5**
PROQUEST; Journal Storage (JSTOR); Australian Defence Force Intranet (DEFWEB)	load AND carriage OR carry; load AND marching OR march; pack AND march OR marching; endurance AND march OR marching;	Assyrian OR Assyria;	Soldier OR Army OR infantry OR spearman		kg OR Kilogram OR lb OR pound
		Greek OR Hoplite			
		Legionnaire OR Roman		Marius AND mule; muli AND mariani	
		Macedonia OR Macedonian;			
		Byzantine OR East AND Roman			
		English	pike AND man	Corselet AND amour OR armor OR pike OR halberd	
		War AND Napoleonic OR Crimean OR French AND Revolutionary	Soldier OR Army OR infantry	French OR British; Red AND Coat…	
		American AND War AND independence		….OR American	
		American AND Civil AND War		Union OR Confederate	
		World AND War AND I OR One; Great AND War		American OR U.S. OR GI OR British OR Australian OR digger OR German…	
		World AND War AND 2 OR II OR Two		... OR Japanese	
		Korean AND War		American OR U.S. OR Marine OR Australian OR Digger; South OR North AND Korean	
		Vietnam AND War		American OR U.S. OR Marine OR GI OR Grunt OR Australian OR Digger; South OR North AND Vietnamese; Chinese	
		Falklands AND War		British OR Marine OR Argentine OR Argentinean	
		Grenada		U.S. OR Marine OR American	
		Persian AND Gulf AND War; Gulf AND WAR; Iraq AND War		American OR U.S. OR Marine OR Australian OR digger OR Iraqi OR British OR Canadian	
		Somalia		U.S. OR Marines OR American OR Australian OR digger OR Somali	
		East Timor		Australian OR digger OR Indonesian	
		Afghanistan AND War		American OR U.S. OR Marine OR Australian OR Digger OR Taliban OR Afghanistan OR British OR Canadian	
	GROUP 6				
	Scutati; skeuphorou; panoply; sarissa; operation AND urgent AND fury; operation AND desert and shield OR storm; operation AND enduring AND freedom; operation AND united AND shield; operation AND citadel.				
METHOD:					
1. Group 1 + Group 2 term/s entered into database. If more than 200 responses Group 3 term/s added. If more than 200 responses Group 4 term/s added. If more than 200 responses Group 5 term/s added. **2.** All Group 6 terms entered as a single search entries.					

This second stage process was repeated until a saturation point was reached where no new information or information sources were identified. The final stage of the literature search and review involved reviewing military textbooks available through the American Library in Paris and the Australian Defence Force Library Service, in order to improve the author’s understanding of the relevant temporal contexts and to glean further detail where information gaps had been identified. This process resulted in the capture of an additional three journal articles and two historical texts.

3.2.3. Evaluation of Materials

The time period covered by this historical review constrained the majority of data to those from secondary sources, these being sources of information that reported the findings of earlier or other sources (Berg, 2001; Lusk, 1997; Nokes, Dole, & Hacker, 2007). For example, data regarding the loads carried by the ancient Romans and Greeks were limited to secondary source interpretations of ancient text. In these secondary sources, external validation (like handwriting analysis, carbon dating of documents, etc.) was limited, as was application of extensive internal validation (determining reliability or accuracy of the source, e.g. first-hand witness). To mitigate validity concerns and apply rigour to the data, three critical-thinking heuristic measures employed by historians were used during evaluation of the collected data, namely sourcing, contextualisation, and corroboration (Hynd, 1999; Rowlinson, 2005).

Sourcing involves consideration of the nature of each source, that is, the author, date of creation, type of source, etc. (Rowlinson, 2005). In this current research, sources were specifically selected based on specialisation in a given time period of interest, a given conflict, a relevant culture of nations of antiquity, or military load carriage. Sources were also evaluated against the background of the author of the source (i.e. professional such as a military historian, trade such as an infantry soldier discussing infantry loads, or academic such as a military researcher) and the text in which the data were published. Contextualisation requires the researcher to identify when and where an event took place (Rowlinson, 2005). This critical-thinking heuristic measure was applied by collating and mapping the data into a timeline while considering the context in which the load carriage data were supplied (e.g. discussion of equipment, logistics, activity being undertaken, etc.). Corroboration involves comparison of information from different documents to identify similarities and contradictions (Nokes, et al., 2007; Rowlinson, 2005). This further measure was applied by the collection and comparison of data from as many documents as possible which discussed a specific time period or conflict. When differences in the reported load contexts of a specific military force were found and both sources demonstrated heuristically-valid sourcing and contextualisation measures, both sources were presented, with potential causes for their differences explored and discussed. This measure (i.e. corroboration) was considered the most difficult to apply, as there were instances where only one reference on a specific time period or force could be found, and this is an acknowledged limitation of the current review.

3.2.4. Data Synthesis

Data meeting the requirements of the critical-thinking heuristic measures of sourcing, contextualisation, and where possible corroboration were transcribed into a journal and sorted into collective themes by time period, conflict and nation. These themes were then chronologically ordered by date and, if required, subdivided into conflict and nationality. Finally, data pertaining to each time period of interest were further reviewed and considered together, to develop the comprehensive narrative exposition reported in Section 3.3 in which each subsection considers and provides a synthesis of all available data of relevance to its focus.

3.3. NARRATIVE EXPOSITION

The narrative exposition below provides a historical account of load carriage along a timeline usefully divided into historical time periods. The time periods, based on historically themed military warfare texts (Archer, Ferris, Herwig, & Travers, 2002; Parker, 2005), are:

- Loads carried by pre-musket soldiers (700 BC – 1651 AD).
- Loads carried by musketeers (1702 AD – 1865 AD).
- Loads carried through the world wars (1914 AD – 1945 AD).
- Loads carried through modern conflicts (1950 AD – present).

The historical account is then extended by two additional sections which focus on answering the research questions posed in Section 3.1.

3.3.1. Loads Carried by Pre-musket Soldiers (700 BC – 1651 AD)

In the seventh century B.C. the Assyrian King, Sargon II, created the first iron army (Gabriel, 2002; Hanson, 1989). The Assyrian spearman of this army, dressed in iron scale armour, helmet, iron shinned boots and carrying a shield, sword, and spear, is thought to have borne a load of between 27.5 kg and 36.5 kg (Gabriel, 1990, 2002). A century later, the Greek infantry soldier, the hoplite, dressed in a complete *panoply* of breastplate, greaves, helmet and carrying a shield, spear and sword, is thought to have borne a load of between 22.5 kg and 32 kg (Ashley, 1998; Gabriel, 2002; Hanson, 1989, 1991, 1995b). For the hoplites, who themselves might not have weighed more than 68 kg (Hanson, 1989), this equated to a load of between 33% and 47% of their body weight. However, the hoplite might not have carried load alone. Each soldier had one or more slaves who carried the soldier's provisions, bedding and personal kit (Chamoux, 1965; Hanson, 1989; Montross, 1960; Sekunda, 2000) and, when no threat was imminent, may have carried the soldier's shield, handing it to him moments before battle (Ashley, 1998; Hanson, 1989, 1991). The use of slaves as baggage carriers presents as an early example of aids being used to reduce the soldier's load. Whether the prime purpose of having these slaves carry the soldier's load was to reduce the impact of load carriage on the soldier, or for another purpose (e.g. a measure of status), was not able to be determined.

In preparation for his war against the Greek hoplites and the Persians, King Philip II of Macedon aimed to increase the mobility and speed of his army (Gabriel, 2001). Philip gave orders that all troops were to carry their own equipment and that wheeled vehicles were not to be used, to be replaced by pack mule and horse (Gabriel, 2001), an order later echoed by his son Alexander (Addington, 1990). These orders reduced the number of camp followers (by as much as two thirds) and increased the army's speed of march (Gabriel, 2001), but the Macedonian soldier became a beast of burden carrying 13.5 kg of grain (10 days rations) plus 22.5 kg of battle equipment and arms; a total load of 36 kg (Gabriel, 2001). In an attempt to reduce costs and enable more Macedonian soldiers to purchase their own equipment, the more expensive components of the soldier's armour (e.g. grieves and breast plates) were replaced with cheaper, lighter, composite materials or simply abandoned altogether (Billows, 1995; Hanson, 1995a; Powell, 1995). Moreover, the Macedonia spear or *sarissa*, although longer and heavier (weighing between 5.5 kg and 7.5 kg) than its hoplite counterpart (Billows, 1995; Gabriel, 2002; Hanson, 1995a; Markle, 1977), was used as both an offensive and a defensive weapon, thereby permitting abandonment of the armoured breastplate (Markle, 1977). Hence, while the weapon load increased, the armour load decreased. To effectively carry this load and still be able to function in combat, the Macedonian soldier needed to be physically conditioned. This was accomplished by vigorous battle hardening drills which included marching between 55 km and 64 km per day while carrying armour, weapons, equipment, and food at a pace of 8 km per hour (Ashley, 1998; Bose, 2003; Campbell, 2004). The combined results of these changes was the fastest army the world had ever seen up to this point in history with the entire army capable of covering 21 km a day while carrying a load of between 27.5 kg and 36.5 kg (Archer, et al., 2002; Gabriel, 2001, 2002).

Around 100 BC, following the trend established by King Philip II, Gaius Marius introduced sweeping reforms to the Roman army which included the reduction of pack animals in the baggage train to one mule per 50 soldiers (Addington, 1990). The reform, aimed at increasing the logistical efficiency of the Roman army, led to the labelling of the Roman infantryman as *Muli Mariani* or 'Marius mules' (Addington, 1990; Jordan, 2001; Roth, 1998). Carrying personal possessions and some food and drink, the Roman soldier or legionnaire was thought to haul a load of up to 45 kg (Jordan, 2001; Roth, 1998).

Like the Greek hoplite, the Roman legionnaire may not have had to carry his load alone. With the ability to relegate load to beasts of burden and even to human baggage carriers, the legionnaire may have carried a load of only around 22.5 kg (Lothian, 1921). Evidence supporting the use of these load carriage aids is drawn from sculptures and reliefs of the Roman army depicting carts carrying warlike equipment and being hauled by beasts (Lothian, 1921). However, even if the ancient works are accurate depictions of the period,[51] there is the question as to how much weight these beasts of burden would have removed from the legionnaire. With the maximum load a mule can carry over distance being around 113.5 kg (Haldon, 1999), each soldier could unload only around 2.5 kg onto the mule.[52] This, of course, was under the supposition that the mule was not carrying its own food or any additional supplies. As such, even with a baggage train of 520 pack animals, the legionnaire was still considered to have carried a load of up to 38.5 kg (Scott, Rainey, & Hunt, 2000).

There are understandable variations in estimations of the Roman legionnaire's load, but the volume of evidence supports a load of around 37 kg to 38 kg (Addington, 1990; Ezell, 1992; Halberstadt, 2006; Jordan, 2001; Marshall, 1980; Mayville, 1987; Montross, 1960; Ropp, 1962) although heavier loads up to 45 kg are considered possible (Jordan, 2001; Roth, 1998). Based on specimen samples from Pompeii and Herculaneum (King, 2005) and predictions against U.S. Army desirable height / weight tables (Roth, 1998), the average Roman male body weight of the era was thought to be approximately 66 kg. On the basis of this predicted body weight, the average Roman soldier would have carried a load of around 56% body weight (Dodge, 1995).

To carry this load and march up to 32 km per day and then fortify their night camp, legionnaires needed to be physically conditioned (Addington, 1990; Jordan, 2001; Montross, 1960). On this basis, Flavius Vegetius, in his work *Epitoma rei militaris* (Epitome of Military Science),

---

[51] Trajan's Column is one piece of work cited as evidence for legionnaires not carrying their entire loads (Lothian, 1921). The artist for this work is considered to have used 'artistic licence' in its production (Roth, 1998), raising questions as to its historical accuracy . See the limitation section (Section 3.4) of this review.

[52] Figure based on 1 mule per 50 legionnaires as per the Marius reforms.

recommended that recruits carry a load of up to 60 Roman pounds (19.6 kg), marching at a pace of 32 km for 5 hours (6.4 km per hour) or 39 km in the same time (7.7 km per hour) (Lothian, 1921; Renatus, 1996). This load did not include the soldier's clothing and weapons (Roth, 1998) and was designed to condition the soldier to carry rations as well as arms during campaigns (Renatus, 1996).

Defeat of the Roman Legion at the Battle of Adrianople in 378 A.D. saw the horse archer replace the legionnaire as the principal soldier of the Byzantine Empire (Dupuy, 1980; Montross, 1960). However, the infantry soldier did still serve. The Byzantine *scutati* or heavy infantrymen wore a mail shirt or armour weighing 16 kg (Schreiner, 1997) with grieves and gauntlets, and carried a spear or lance, a sword, and a spiked axe (Jones, 2001; Montross, 1960), a total load of approximately 19.5 kg to 36.5 kg (Haldon, 1999). Each soldier was required to carry his own equipment, personal necessities, and sufficient food for several days (Dupuy, 1980). Although baggage trains still accompanied the army, they carried the equipment and supplies needed for sustained operations and siege craft (Dupuy, 1980) and did little to reduce the soldier's load (Ezell, 1992). With the infantry unable to provide the rapid shock action of the mounted cavalry, infantry forces and marching soldiers became a subsidiary arm and the armoured mounted knight became the centre point on the battle field (Brodie & Brodie, 1973; Dupuy, 1980; Gabriel, 2002).

It was the longbow, crossbow, and invention of powdered weapons (Dupuy, 1980; Keegan & Homes, 1985; Kleinschmidt, 2000; Zentner, 2005) that were to lead to the return of the foot soldier in Europe. Initially, these missile-based infantry could not withstand the shock attack of mounted cavalry, thus pikemen were used to provide protection, especially during the vulnerable period needed to rearm weapons (Cassidy, 2003; Eltis, 1998; Kirkpatrick, 2001; Lynn, 2001; Montross, 1960; Peterson, 1947). English pikemen took to the field during the English Civil War (1638–1651). Typically dressed in corselet armour (Eltis, 1998; Fairholt, 1847; Peterson, 1947), which together with helmets and leg guards weighed around 11 kg, these foot soldiers carried a knapsack containing food and spare clothing which brought their carried load to between 22.5 to 27.5 kg (Carlton, 1992) – a load excluding the weight of their pike and other melee weapons (sword or axe) (Fairholt, 1847; Mongariello, 2004). With the pike weighing between 1.8 kg and 2.3 kg (Bachrach & Aris, 1990) the total load carried by the pikemen is considered to be at least 29.5 kg.

3.3.2. Loads Carried by Musketeers (1702 AD – 1865 AD)

By the start of the Spanish War of Succession (1702–1714) the pike was replaced by flintlock muskets and socket bayonets (Childs, 1994). Armed with muskets, shot and powder, the British

Redcoats carried a load of around 36.5 kg through the American War of Independence (Ermatinger, 2004; Higginbotham, 1961; Marsh, 1997; Marshall, 1980) and into the French Revolutionary Wars (Rothenberg, 1978). During the Napoleonic Wars, the Redcoats' loads fluctuated between 22.5 kg and 36.5 kg (Kuring, 2002; Marshall, 1980), with the load at the landmark Battle of Waterloo (1815) being between 27.5 kg and 32 kg (Marshall, 1980). During the Crimean War (1853 to 1856), loads remained similar, ranging from 26 to 31 kg (Lothian, 1921).

The Redcoats' counterparts, the French, carried similar loads of around 27.5 kg during the French Revolutionary Wars (Fremont-Barnes, 2005) and into the Napoleonic wars (Dufour, 1864; Rothenberg, 1978). Loads reduced slightly to 25 kg during the Battle of Waterloo (Marshall, 1980) but rose again during the Crimean War to between 33 kg and 36.5 kg (Lothian, 1921; Marshall, 1980). Reasons for this fluctuation could not be determined. Under the command of Napoleon, French troops routinely marched from 16 km to 43 km per day (Moore, 1960; Rothenberg, 1978) and were expected to be fit for fighting at the end of the march (Ropp, 1962). Marshal Davout, a French Marshal under Napoleon, generally expected his men to march in column at a pace of 4 km per hour for up to 10 hours a day (Rothenberg, 1978). In a 16 day period, Marshal Davout marched his soldiers 280 km in order to engage the Prussians (Rothenberg, 1978). Likewise, to win the Battle of Dresden, Napoleon reportedly marched his army a staggering 144 km in 72 hours (Montross, 1960). With these long continuous marches, it is little wonder that the French soldiers quipped, '*Our emperor makes war not with our arms but with our legs*' (Rothenberg, 1978). These examples highlight the importance of an army's load carriage marching ability, with soldiers at the time required to march long distances while carrying load.

In 1861 the American Civil War began. Armed with shoulder arms, 60 rounds of ammunition, a piece of shelter tent and 7 kg to 11.5 kg (Coggins, 2004; Hagerman, 1998) in their knapsack, the soldiers of the Union Army of the Potomac carried loads of 20.5 kg to 22.5 kg (Coggins, 2004; Hagerman, 1998; Hobbes, 2003). Each eight-man section also had to carry additional stores of picks, axes, and various other tools (Hagerman, 1998). However, Union Army loads were not universal. The 24th Wisconsin Volunteer Infantry Regiment of the Union Army's Middle Military Division, for example, were noted as carrying around 22.5 kg in their knapsacks plus their 4.5 kg musket: a total load of around 27.5 kg (Beaudot, 2003). Furthermore, Union Army soldiers were also known to discard equipment, throughout the conflict, in order to lighten their loads (Mahon, 1961).

The load of the Confederate army's infantry soldier varied greatly, ranging between 13.5 kg and 36.5 kg (Coggins, 2004; Hagerman, 1998; Katcher, 1999). Soldiers of the 21st Virginia Infantry F Company, for example, were claimed to carry loads of between 13.5 kg and 18 kg, and in some cases up to 22.5 kg, in their knapsacks (Katcher, 1999). In general, however, limited supplies and more lax regulations meant that the Confederate soldier usually carried less weight than his Union counterpart (Katcher, 1999), and their 7 kg to 11.5 kg knapsacks vanished early in the war (Coggins, 2004). With the average weight of the American soldier in the Civil War being around 62 kg (Marshall, 2001) the average Confederate soldier's load ranged between 22% and 59% body weight and the Union Army soldier's load ranged between 33% and 44% body weight.

3.3.3. Loads Carried through the World Wars (1914 AD – 1945 AD)

In the Great War, heavy loading of the foot soldier reduced the marching ability of the average soldier and was claimed to have altered the tactics of war (Lothian, 1921). The Battles of Cambrai and Amiens provide examples in which forward movement, limited predominantly by physical exertion, was reduced to 9 km to 12 km per day (Lothian, 1921).

During this war, German troops carried loads ranging from 25 to 45.5 kg, although a load of around 32 kg was considered average (Ellis, 1989; Showalter, 2004). Hauling this load, the German fusiliers were said to have marched for 27 consecutive days, covering a distance of 656 km, averaging 24 km per day (Stringer, 2000). French soldiers, meanwhile, carried heavier loads of up to 38.5 kg (Ellis, 1989; Ezell, 1992), with the French 6th Army once marching 70 km with only a single 3-hour halt. During their North African campaign, soldiers of the French Foreign Legion were required to carry loads that were even greater, at around 45.5 kg, for up to 40 km per day (Ezell, 1992). Both these military forces not only carried heavy loads but had to traverse substantial distances under this weight. These examples again highlight the requirement of soldiers to march long distances while carrying load.

American soldiers carrying a load between 22 kg and 32 kg (Hobbes, 2003; Keene, 2006), and weighing an average of 64.5 kg (Coffman, 1998; Keene, 2006; Zieger, 2000), hauled a load between 34% and 50% body weight. This load was claimed to leave soldiers exhausted during the short distance assaults between trenches, even before contact with the enemy (Keene, 2006). The British soldiers started off with similar loads (20.5 to 27 kg) in 1914 (Lothian, 1921), but found that over a period of three to four years their loads increased to 30 to 40 kg (Ellis, 1989; Gilbert, 2006; Lothian, 1921; Neilberg, 2006; Showalter, 2004; Terraine, 1997; Tucker, 1996; Whiter, 2004). With British recruits of the era weighing an average of 60 kg (Ellis, 1989), these soldiers were carrying a load equal to around 50% to 58% body weight. Likewise, Canadian soldiers carried a load of between 30 kg (Steele, 2002) and 36 kg (Brennan, 2003). Highlighting the first textual appearance of Australian soldier load carriage in a major conflict, Australian soldiers at Gallipoli were thought to carry a load of 33.5 kg (Stanley, 2005). Assaulting Mont St Quentin, Australian soldiers of the 6th Australian Infantry Division were thought to carry slightly lighter loads of between 27 kg and 28.5 kg (Landers, 1998).

Little changed leading into the Second World War. During the D-Day landings at Omaha Beach (1944) the American troops landed with a load of around 27.5 to 41 kg (Balkoski, 1999; Hobbes, 2003; Lewis, 2001; Mayville, 1987; Porter, 1992), a load credited with causing deaths in the water (Mayville, 1987; Schwendiman, 2008). The Canadian and British soldiers carried similar loads (Porter, 1992). Even if, with these loads, the soldiers made it to the beach, they faced another problem: getting across the beach quickly and under intense enemy fire. Again, weight was against the soldiers as *'The GI's were so laden with ammunition and equipment that every step was a strain'* (Balkoski, 1999, p. 3). With an average body weight of 65.5 kg (Kennedy, 1999), the American soldiers carried a load between 42% and 63% body weight, while charging through chest deep water and then across sands, all while exposed to heavy enemy fire (Mayville, 1987).

On the Eastern Front, Russian soldiers carried loads of between 28 and 35.5 kg (Lucas, 1980), while in the North African desert, Australian troops carried loads of between 22 and 32 kg into the battles at Bardia and El Alamein (1941–1942) (Johnston, 1996; Millett & Murray, 1988). (Johnston, 1996; Millett & Murray, 1988). In the Pacific theatre, the loads carried by Australian soldiers were similar: 20.5 to 41 kg in Papua New Guinea (1942) (Australian Army Staff, 2008; Brune, 2003; Kuring, 2002) and up to 37.5 kg in Borneo (1945) (Johnston, 2002). Operating behind the lines in Burma, the British 'Chindits' likewise carried loads of between 32 and 41 kg (Ezell, 1992). The opposing force in the Pacific theatre, the Japanese soldier, carried loads ranging from the standard 28 kg up to 56 kg for machine gun units (Australia-Japan Research project, 2008). With the average Japanese soldier weighing around 53 kg (Clarke, 2007; North & Musser, 2004), this equated to a load of between 52% and a staggering 105% body weight.

Of interest, after viewing a Canadian exercise conducted in May 1942, Field Marshal Montgomery, in a letter to General Crerar (a Canadian General), recommended a load that would not impact on the soldier's fighting ability: a maximum 22.5 kg (English, 1991). For the Canadians, with an average body weight below 72 kg (Copp, 2003), this would suggest a load of around 31% body weight. The Canadians carried precisely that recommended load, a maximum of 22.5 kg, into the Korean War in 1950 (Watson, 2002).

3.3.4. Loads Carried through Modern conflicts (1950 AD – present)

In the Korean War (1950–1953), when the American soldier's load rose from 18 to 22.5 kg, the straggler effect was noticed, with troops falling behind the main column of march. Infantry troops arrived at their march destination in a state of fatigue, with men complaining that they struggled as a result of carrying things they never used in combat (Edwards, 2006). Even so, the loads kept climbing, with claims that American soldiers had to carry 37.5 kg at a speed of around 4 km per hour (during the day when on roads) for a distance of 19 to 32 km per day (Shrader, 1995). Moreover, in December 1950, the American 7th Marines of the 1st Battalion were reportedly required to carry loads of around 54.5 kg through the snows and steep slopes of Toktong Ridge (Camp, 2000).

During the Vietnam War (1959 – 1975), just as the Roman legionnaires had adopted the term *Marius Mules,* the American soldiers endeared the term *'grunt'* (Rottman, 2005). U.S. Marines carried loads that were in excess of 22.5 kg and more likely 36.5 to 45.5 kg (Melson, 1998), while the typical load for the American infantry soldier patrolling through the jungle was 27.5 kg to 32 kg (Dockery, 2002; Mackenzie, 1997; Rottman, 2005). Australian infantry soldiers generally carried heavier loads of between 32 to 36.5 kg (McKay, 1987) and, in some cases, more. Several members from the 8th Battalion, Royal Australian Regiment (RAR), weighed their packs and found themselves carrying loads of between 36.5 kg and 54 kg (Hall, 2000). Interestingly, even when their mission changed from reconnaissance to pacification, and the nature of the loads changed, the overall load weight remained the same (Hall, 2000). Consequently, Australian soldiers, like the aforementioned Union Army soldiers, were constantly taking measures to lighten their loads by removing non-essential stores (Hall, 2000). These loads were similar for the soldiers of the 4th Battalion, RAR, who likewise carried loads of between 30 kg and 40 kg for a rifleman and up to 47.5 to 56 kg for radio operators (Kuring, 2002; McKay, 1996; Taylor, 2001). The native Viet Cong were not as encumbered as the foreign forces and carried noticeably lighter loads of around 12 kg (Archer, et al., 2002; Kuring, 2002). These loads were perhaps indicative of the advantages of fighting on 'own' soil.

During the Falklands conflict (1982) the British infantry and Royal Marines carried loads of 32 to 36.5 kg in Fighting Order (essential fighting stores) (Kuring, 2002) and 45.5 to 54.5 kg (Hobbes, 2003; Kuring, 2002) in Marching Order (short duration sustainment stores together with fighting stores). In a well-known 'yomp', the elite 45 Royal Commando Marines marched a distance of 129 km in a period of just three days while carrying a load of 54.5 to 66 kg (Hastings & Jenkins, 1983;

Stringer, 2000), crossing terrain that ranged from marshland to rocky scree (Hobbes, 2003; Marsh, 1983; Stringer, 2000). This march provides yet another example of the requirement of soldiers (albeit the elite) to march long distances while carrying load.

A year later, Operation URGENT FURY had American troops landing in Grenada carrying loads of up to 54.5 kg (Mayville, 1987). One of the assaulting soldiers described the assault on the airhead as follows:

> *'We were like slow moving turtles. My ruck weighed 120 pounds… There were all those guys sitting on the side of the road with IV tubes in them. There's no way the guys could [have gone on]'* (Mayville, 1987, p.25).

Acknowledging the potential impact of environmental conditions (that is, heat and humidity), this observation highlights the impact of overburdened soldiers on military force capability, as these soldiers not only were unable to continue but also drew on medical resources. During the same operation, American Army Rangers parachuted onto the runway at Salinas airfield, carrying even heavier loads of around 76 kg (Ezell, 1992).

During Operations DESERT SHIELD (1990–1991) and DESERT STORM (1991), American soldiers carried loads up to 45.5 kg (Porter, 1992). In 1995, during Operation UNITED SHIELD in Somalia, American Army infantry soldiers came ashore with a load of around 49.5 kg. Claimed to be weighing an average of 75 kg, these soldiers were carrying a load of around 70% body weight (Solgere, 1999). In one well-known operation, popularised by the book and movie *Black Hawk Down*, personnel are claimed to have removed portions of personal body armour and left behind equipment that later affected their capability during a prolonged engagement (Bowden, 1999; Owen, 2008). These actions again provide examples of soldiers taking action to reduce their load.

Little has changed in more recent conflicts. In East Timor, Australian soldiers on Operation CITADEL (2002–2003) carried loads in excess of 45 kg, with gunners and signallers carrying loads in excess of 50 kg (Paulson, 2006). These loads affected their ability to chase fleeing militia (Breen, 2000). In Iraq (Scales, 2005) and Afghanistan (Hobbes, 2003; Scales, 2005; Task Force Devil Combined Arms Assessment Team, circa 2003), U.S. soldiers carried loads of 45.5 to 54.5 kg and marched around 10 to 15 km per day (Bachrach & Aris, 1990). In 2003, a detailed study of the 82nd Airborne Division on Operation ENDURING FREEDOM III in Afghanistan was undertaken by the Combat Arms Assessment Team attached to Task Force Devil (circa 2003). In that study the researchers accompanied U.S. Marines on combat operational deployments, weighing the Marines and taking detailed accounts of their load compositions. The study found that the Marines carried an average *fighting load* [53] of 29 kg, an *approach march load* of 43.5 kg, and an *emergency approach march load* [54] of 58 kg. With the average weight of the soldiers in that study being 79.5 kg, this equated to loads of 36%, 55% and 71% body weight respectively. To date, that review provided the most comprehensive and reliable data on soldier load carriage in an operational environment available to the investigator.

3.3.5. What Historical Trends in Soldier Load Carriage Can Be Identified from the Literature?

On the basis of the information presented in the preceding subsections and in response to the first research question posed in the current study (Section 3.1), it is possible to identify trends in *absolute* and *relative* (to body weight) loads carried over the time periods examined. As encapsulated in Figure 4, the soldiers' typical *absolute* load, for most but not all countries, appears to have remained generally unchanged for over three millennia (around 25 to 35 kg), before progressively increasing after the World Wars.

It should be noted, however, that several of the more recent weights may be somewhat misleading. The loads described for Grenada and Somalia, for example, are for forces coming ashore and not necessarily for the duration of the campaign. These loads are therefore more than likely *emergency approach march loads*, which are defined by the U.S. Army Manual FM 21-18 'Foot Marches' as loads carried by soldiers acting as porters for several days over distances of 20 km a day (Department of the Army, 1990). These loads may differ considerably from typical patrol loads[55] and field loads,[56] which are lower in weight (Department of the Army, 1990; Patterson, et al., 2005; Task Force Devil Combined Arms Assessment Team, circa 2003) and more typical of the loads carried by soldiers discussed in this review.

---

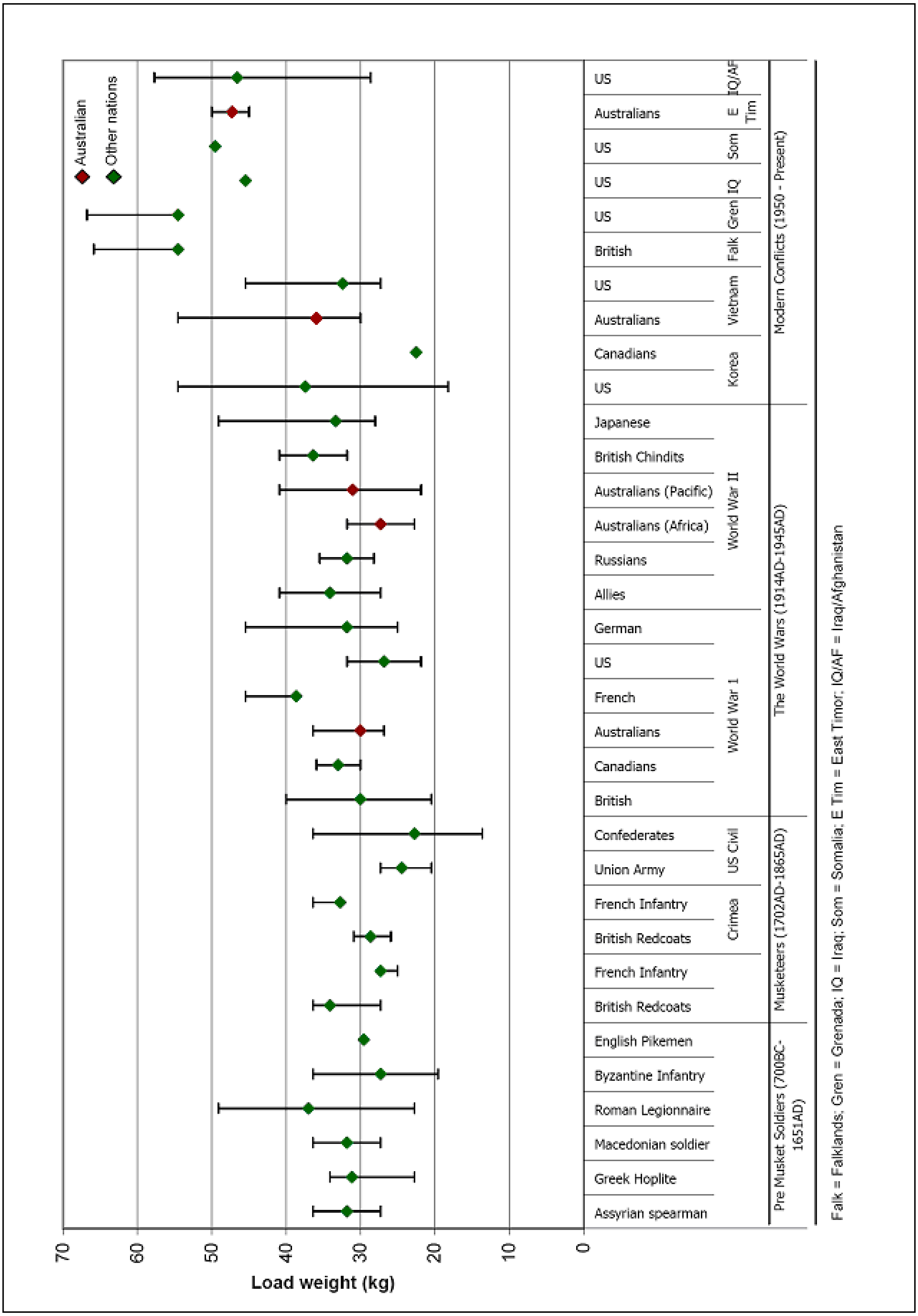
[53] Fighting Load is akin to Australian Patrol Order (described in the Glossary and Annex A: ARA Load Carriage Systems Orders-of-Dress).

[54] Both Approach March Load and Emergency Approach March Loads are akin to Australian Marching Order (described in the Glossary and Annex A: ARA Load Carriage Systems Orders-of-Dress) which may be described as Marching Order – Light and Marching Order – Heavy, depending on the unit and tasking.

[55] Australian Patrol Order or U.S. Fighting Order.

[56] Australian Marching Order or U.S. Approach March Order.

Figure 4: An encapsulation of the means and ranges of loads carried by soldiers through history as found in this study.



Furthermore, in the context of *relative* loads, it can be seen that the Roman loads of around 37 kg to 38 kg, or 56% of average Roman soldier body weight at that time (Addington, 1990; Dodge, 1995; Ezell, 1992; Halberstadt, 2006; Jordan, 2001; King, 2005; Mayville, 1987; Montross, 1960; Ropp, 1962), were very similar to the *approach march loads* of the 82nd Airborne Division in Afghanistan, where the soldiers carried loads of 43.5 kg or 55% of their average body weight at that time (Task Force Devil Combined Arms Assessment Team, circa 2003). This example shows how, although *absolute* loads of soldiers in general may have increased in recent times, the *relative* loads carried by the soldier in general may in fact have remained unchanged, due to parallel changes in average soldier body weight over time, although several exceptions identified in the review are acknowledged.

Although covering only a relatively short period in history, trends in Australian load carriage practices were identified. First, the loads carried by Australian soldiers appear to be commensurate with the loads carried by other international forces with which Australia has been allied (e.g. U.S., U.K., and Canada). Second, like the trend identified with these allied forces, the absolute load carried by Australian soldiers appears to be progressively increasing from around 30 kg in the World Wars to around 36 kg in Vietnam and over 45 kg in East Timor.

3.3.6. What Lessons Can Be Learned from History to Inform Future Soldier Load Carriage Practices in Australia?

Based on the information presented in the preceding subsections and in response to the second research question posed in the current review (Section 3.1), history can provide three key lessons to inform future load carriage practices. These three lessons, each discussed in further detail below, are:

- Changes in the context of warfare might not reduce the soldier’s load or requirement to carry heavy loads over long distances.
- Excessive loads can cause injury and lead to loss of life.
- Soldiers will find a way to reduce excessive loads.

Changes in the context of warfare might not reduce the soldier’s load or requirement to carry heavy loads over long distances

It is evident that, even though the nature of warfare has changed significantly, the typical weights of loads carried by soldiers have not decreased (Figure 4). Over the historical period reviewed in this chapter there have been changes in the military tactics employed by various armies in various theatres of war, from phalanxes and ranks on open fields to trenches and complex warfare (Lothian, 1921; Hobbes, 2003; Scales, 2005; Keene, 2006). With these changes in the nature of warfare the soldiers' loads have not decreased. The weaponry and the equipment carried by soldiers have changed through history. As technology has advanced, so too have the weapons of war craft, from spears and pikes to muskets and firearms. However, even with these changes in the nature of warfare and advances in technology, the typical loads carried by soldiers have not reduced. The persistent need, across history and military contexts, for soldiers to have access to the basic trade craft tools and equipment that provide lethality, protection and sustainment may provide one plausible reason for a lack of load weight reduction. There is also a danger that the introduction of new soldier technology and capabilities, such as night vision devices, personal signals equipment and signal jammers, will increase soldier load weight (Brown, et al., 2010; Mayville, 1987; Owen, 2008). On this basis, history suggests that military decision makers should not rely on changes in the nature of warfare or advances in technology to reduce the soldier's load.

Moreover, history has shown that although logistical aids (like carts, mules, motorised vehicles, and aircraft) have changed, these changes have not noticeably reduced the soldier's typical load nor reduced the need for soldiers to carry these loads over long distances. Plausible reasons for these findings are that these aids might have been provided in insufficient numbers to reduce the soldiers' loads, or used to carry other logistical stores, and that even with technological advancement in transport, soldiers may still have to physically carry heavy loads. Another reason might be soldiers' reluctance to separate themselves from their stores in a hostile environment. Soldiers may have preferred to carry their essential lethality, survivability and sustainment stores rather than trust logistical support when in foreign lands, particularly when contact with enemy was likely. Consider for example the differences in loads carried by the Australian soldiers during operations in Vietnam (30 to 56 kg) and the loads carried by the local Viet Cong soldiers (12 kg) (Archer, et al., 2002; Hall, 2000; Kuring, 2002).

The excessive loads carried by soldiers can cause them injury and even loss of life

History has clearly demonstrated that load carriage can be detrimental to soldiers' health, causing injury and even loss of life (Schwendiman, 2008). During the D-Day landings at Omaha Beach in 1944, American troops were so overburdened that their loads were credited with causing deaths in the water (Mayville, 1987). This incident is not isolated. Other examples of marching injuries noted through history include those of Cyrus's Greek mercenaries (circa 400 B.C.) and the Prussian Guards (1870). The infamous 10, 000 Greek mercenaries of Cyrus (accompanied by Xenophon) were thought to suffer a range of injuries that included stress fractures, torn ligaments, muscle damage, blisters and abrasions (Lee, 2007). Although some of these injuries can be considered minor in light of today's medical treatments, for the Cyrean soldier it was life or death as they hobbled to keep up with the moving army (Lee, 2007). In the Franco-Prussian War in 1870 the Prussian Guards left the Rhine with 30,000 soldiers, but following 7 weeks of marching this army lost 12,000 fighting men from fatigue induced by carrying heavy loads. These losses were greater than the number suffered in actual combat (Lothian, 1921). A more recent example comes from the conflict in Afghanistan. A U.S. soldier, wounded in action, said '*When you get shot at, you move as fast as you can…but it wasn't very fast. You are just tired. So tired…*' with regard to the loads they were carrying (Bernton, 2011c). These examples, the most recent one in particular, demonstrate how load carriage can increase the risk of soldier injuries and loss of life, factors which reduce military force strength and in turn reduce capability and lethality (Edwards, 2006; Mayville, 1987).

Soldiers will find a way to reduce excessive loads

History suggests that in some cases soldiers may simply throw away or refuse to carry heavy or functionless equipment (Hall, 2000; Mahon, 1961). Indeed, there have been cases where soldiers have decided not to carry equipment or have discarded equipment that was later required during engagements with their adversaries (Kraft, 2002; Owen, 2008).

In ancient Greece, the hoplite's shield, weighing between 6 kg and 8 kg (Guttman, 2008; Hanson, 1989, 1991; Sanz, 2006), was thought to be the piece of equipment most frequently discarded when fleeing the battlefield (Hanson, 1989). With the hoplite main battle formation being the infantry phalanx (Gabriel, 2002), warriors discarding their shields placed fellow Greeks at risk (Hanson, 1991). This act was considered a disgrace, and led to the infamous saying attributed to Spartan mothers: '*Come back with your shield or upon it*' (Redner, 2001). Several examples of soldiers taking action to reduce their loads were found in this review; including Union Army soldiers in the American War of Independence (Mahon, 1961), Australian Army soldiers in the Vietnam conflict (Hall, 2000) and U.S. soldiers during operations in Somalia (Owen, 2008).

These examples suggest that soldiers may independently take action to reduce their loads by discarding equipment in order to lighten their loads. Such actions have resulted in situations where soldiers' lives may be placed at risk when the discarded equipment was needed.

3.4. LIMITATIONS

Three key limitations of this historical review are acknowledged, namely lack of scientific quality of some sources of evidence, the use of average or typical loads, and the use of ‘dry’ loads (i.e. not laden with water, mud, snow, etc.).

The first limitation is that of scientific quality of the sources of evidence. Given the nature of the topic (e.g. load weight), the circumstances in which the loads were carried (e.g. combat) and the historical time period covered by the review, the investigator had to rely on secondary sources, predominantly from textbooks and journal articles, that frequently cited quite dated primary sources of information. Moreover, sources were open to interpretation.

The use of beasts of burden to carry the Roman legionnaire’s load presents as an example. Major Lothian (1921) cited depictions of beasts of burden carrying warlike equipment on Trajan’s Column in Trajan’s Forum, Rome, as evidence for reduced legionnaire loads. Roth (1998), a military historian, questioned the historical accuracy of the column, claiming that the sculptor used ‘artistic licence’ in the work. A personal review of Trajan’s Column raises an additional consideration, that of perspective. Noting the depictions of animal-drawn carts and considering the period of history covered in the works (being Roman Empire expansion and conquest), questions could be raised as to whether these beasts were hauling stores and spare equipment, needed when marching into foreign lands where future stores were in doubt or whether they were hauling loot. This example of Trajan’s Column highlights the difficulty in ascertaining accurate load carriage weights of these ancient armies.

Acknowledging these limitations, corroboration of facts from multiple sources was sought in an attempt to improve the reliability and precision of the review. Unfortunately, there were instances covering specific time periods, cultures or conflicts where only a single reference could be found, loads carried by Canadian soldiers during the Korean War as an example. On this basis, loads and contexts described in this review, most notably those of armies of antiquity, are based more on educated estimates than on experiments or primary sources.

The second limitation is the use of load weights, when in most cases the reported loads carried by soldiers are based on an average or typical load. This may dilute the true appreciation of loads carried by individual soldiers, most notably those who had specific roles within their unit; a machine gunner or signal operator, for example, would usually carry a noticeably heavier load than that of a rifleman (Australia-Japan Research project, 2008; Hall, 2000; Rottman, 2005; Task Force Devil Combined Arms Assessment Team, circa 2003; Taylor, 2001).

The third limitation is the use of load weights that are typically estimated ‘dry’ loads. These ‘dry’ loads are subject to change within a given environment. In the trenches of the Great War, for example, the 3.2 kg British coat could absorb up to 9 kg of water (Ellis, 1989; Lothian, 1921). British soldiers, who would start a march with 27.5 kg, could well finish with loads in excess of 43.5 kg when both water saturation and mud were taken into account (Ellis, 1989; Lothian, 1921). The American overcoat in the Second World War likewise increased in weight by around 3.6 kg (Neill, 2000).

These three limitations provide the reasoning behind the soldier’s loads often being presented in ranges, throughout the current chapter. Thus, although single set figures could not be provided, these ranges should be considered a more accurate reflection of the soldier’s load than a single figure. The use of ranges of weight is pertinent, given that even during a single load carriage event soldiers’ loads might change as they consumed rations and water and expended ammunition.

3.5. CONCLUSION

In conclusion, the soldier’s *absolute* load weight has increased notably since the Vietnam War, whereas *relative* load weights have been generally similar (around 55% body weight) at various points in history (Roman legionnaires, U.K soldiers in the Great War, U.S. soldiers in the World War 2, and U.S. soldiers in Afghanistan). That is, in spite of changes in the nature of warfare, protective and lethality equipment and sustainment stores, and logistical and technological transport aids, the soldier’s load has not reduced.

Three lessons were learned during this review, which may inform future load carriage research and decision-making processes. These were: (a) soldiers will find a way to reduce excessive loads, (b) excessive loads can cause soldiers injury and even loss of life, and (c) changes in the context of warfare may not reduce the soldier’s load or requirement to carry heavy loads over long distances.

From the limited Australian load carriage information available it would appear that the loads carried by Australian Army soldiers have been commensurate with the loads carried by international forces with which Australia has been, and currently is, allied (e.g. U.S., U.K., and Canada). As is the case with our allies, the absolute load carried by Australian soldiers appears to be increasing. Whether these trends of increases in *absolute* loads and alignment of Australian loads with those of foreign forces are still relevant in the current Australian Army environment has yet to be determined, and this issue is explored further in Study A (Chapter 4).

4. STUDY A: THE AUSTRALIAN ARMY LOAD CARRIAGE CONTEXT: THE SOLDIERS' PERSPECTIVE

4.1. INTRODUCTION

The literature review (Chapter 2) and the Historical Review of Soldier Load Carriage (Chapter 3) formed the initial steps in the Risk Management Framework (RMF) of *establishing the context* of Australian military load carriage practices.[57] The literature review (Chapter 2), examined the impact of load weight on the carrier. The review also identified the importance of context when considering the load weights carried by soldiers, since contextual factors like speed and terrain influence the impact of load weight on the carrier. The historical review (Chapter 3) provided a detailed review of the load carriage practices of military personnel across a range of nations over three millennia (circa 800 BC to circa 2000 AD). Due largely to the relatively recent establishment of Australia as a nation, in relation to the period of history reviewed,[58] information on Australian Army load carriage practices was limited. However, trends towards increasing *absolute* loads and alignment of Australian loads with those of allied nations were identified. Whether these trends are still relevant in the current Australian Army environment has yet to be determined. Considering this limitation, investigation of the current, wider context of Australian Army load carriage, and of the Australian soldier specifically, is needed to further inform the RMF process of *establishing the context* for this program of research.

Apart from its role within the RMF, the capture of this information on current load carriage weights and context is vital to inform future load carriage research. Of the 157 research papers meeting the inclusion criteria for the literature review reported in Chapter 2, approximately 90% involved participants carrying less than 42 kg in their backpacks, yet the historical review of soldier load carriage (Chapter 3) suggested that in more recent military events Australian and U.S. soldiers carried loads of 43 to 55 kg in East Timor (Paulson, 2006), Iraq (Scales, 2005) and Afghanistan (Hobbes, 2003; Scales, 2005; Task Force Devil Combined Arms Assessment Team, circa 2003). Thus, although current research provides valuable insight into the possible effects of 'lighter' loads (below 42 kg), on soldiers, limited data exist on the impact of current 'heavier' loads (≥42 kg) carried by soldiers.

---

[57] Described in detail in Chapter 1, Section 1.3.1.

[58] The Federation of Australia was established in 1901 (Grey, 2008).

Three research questions guided the cross-sectional study reported in this chapter. These questions were:

- What loads are currently carried by Australian Army soldiers, in training, during field training exercises and during military operations?
- What are the characteristics (tasks, duration, terrain, etc.) that form the context of these load carriage activities?
- Does the current load carriage weight and context vary with corps or gender?

4.2. METHODS

4.2.1. Setting

The Australian Regular Army (ARA) is a full time arm of the Australian Defence Force (ADF) and forms the setting within which all four studies (Studies A to D) of this program of research were both conceived and undertaken. A detailed description of the ARA setting is provided in Appendix A. Data collection was undertaken from 30 August to 17 December 2010, a period in which ARA forces were deployed on several operations, both at home and abroad. A list of operations, geographical locations, and force strengths is also provided in Appendix A. A major ADF exercise, Exercise HAMEL, was undertaken from early October to early November 2010 in northern Queensland, Australia, involving 6,000 ADF personnel (Defence Media Release, 2010).

4.2.2. Research Design

This study was informed by the Risk Management Framework (RMF) (discussed in Chapter 1). In order to assess the risks posed by various threats the context in which the risks take place must be examined (Australian Army, 2007a; Standards Australia Working Group MB-002-01, 2004a, 2004b, 2004c). This study continues to inform the first step in the RMF, namely to *Establish the Context* (Standards Australia Working Group MB-002-01, 2004a, 2004b, 2004c); in this case, the current Australian military load carriage context.

A cross-sectional design was used to collect data. This approach enables researchers to document facts at a single point in time (Ruane, 2004). By enabling the description of practices across various contexts in a sample population, valuable point-in-time descriptive data are captured (Babbie, 2008; Fos, 2010; Merrill, 2010). This information was needed to quantitatively detail the current load carriage practices of the ARA and key subgroups within it.

4.2.3. Command Approvals

The research was sponsored by Joint Health Command. Support for the research was provided by Forces Command which either initiated or authorised contact with the military units regarding the research.

4.2.4. Ethical approval

Ethical approval for the research was granted by the Australian Defence Human Research Ethics Committee (Protocol: 569-09), and the Behavioural and Social Sciences Research Ethics Committee of the University of Queensland (Project number: 2009001820). Ethics approvals for this study were received prior to the study's commencement and are presented in Appendix F.

4.2.5. Data Collection

Participants[59]

ARA units comprised principally of personnel from selected corps were invited to engage in the study. These corps selected were identified via purposive sampling. Purposive sampling of units meant that the sample was based on known characteristics of the population (Cwikel, 2006). The selected ARA corps included the Royal Australian Infantry, Royal Australian Artillery, Royal Australian Engineers, Royal Australian Armoured Corps, and the Royal Australian Corps of Signals. These corps represent trades within the ADF which experience the greatest occupational exposure to load carriage(Australian Army, 2005). By nature of their corps differences they also provide different perspectives on military load carriage (Attwells, Pope, Billing, et al., 2007; Defence Science and Technology Organisation, 2009).

Subsequent to agreement from each unit, all personnel posted to the selected units at the time of this study were invited to participate in the research. The recruitment and informed consent procedures detailed below were employed. The inclusion criteria were: 1) in full time service, 2) posted to one of the selected units, and 3) a member of the ARA.

---

[59] An explanation of the ARA context is provided in Appendix A.

Survey Data

Used in previous load carriage research (Birrell & Haslam, 2009b; Birrell & Hooper, 2007; Legg, Perko, & Campbell, 1997; Lobb, 2004; Mackie & Legg, 2008), survey data were used to inform all four studies reported in this thesis. A key benefit of employing a survey approach is that it can capture information directly from the people (Fink, 2005), in this instance Australian soldiers. Furthermore, with Australian soldiers serving in various locations across Australia and overseas (see Appendix A), the use of a survey allowed for data capture across numerous geographical locations. When surveys are used for research, they can be augmented by other sources of information (Fink, 2005). This approach of collecting survey data with other data sources provides a means of triangulation through which the validity and reliability of survey responses are improved (Cwikel, 2006). As such, in conjunction with the survey undertaken to inform the research reported in this thesis, data were sourced from several other areas, including injury surveillance data (Study B), documented unit training programs (Study C) and army doctrines and policies (Study D). To minimise the impact of the survey on military resources, optimise the capture of personnel willing to complete the survey, and allow for cross-validation of data, a single online questionnaire, purpose-built and divided into themed sections, was used to capture data for all four studies.

Online Survey Questionnaire Design

The online survey questionnaire was designed in accordance with the evidence-based recommendations of experienced online survey questionnaire design experts including Couper, et al. (2001), Dillman, et al. (1998), Parsons (2007), Schonlau, et al. (2002), and Sue and Ritter (2007). These online survey questionnaire design recommendations included; the use of an introductory welcome screen, having a first question that was easily comprehensible, allowing respondents to answer subsequent questions without having answered previous questions, and limiting the number of forced response questions. The use of low graphic (to limit down load time) progress indicators and multiple item screens, as recommended by Dillman, et al. (1998) and Schonlau, et al. (2002) were also employed as these tools have been shown to reduce completion time and non-substantive answers and to increase completion rates (Couper, et al., 2001). Furthermore, respondents were allowed to interrupt and then re-enter the survey (Schonlau, et al. (2002). However, respondents were only able to complete and submit their online questionnaire once (Sue & Ritter, 2007) before their unique defence profiles restricted access to the online questionnaire.

To limit potential measurement error, Dillman, et al. (1998) recommend that the use of check-all-that-apply and open-ended questions be avoided. Considering this, several opportunities to expand on closed-answer questions through the provision of 'comments' sections, were provided. These opportunities, commonly applied in online survey questionnaires (Fink, 2002), were deliberately placed to allow responders to add context to their answers but did not constitute the primary measure of interest.

While the use of unique password protection for the online survey questionnaires was recommended by Dillman, et al. (1998), Schonlau, et al. (2002), and Sue and Ritter (2007), passwords were avoided for this questionnaire as they have been found to potentially reduce responses when ambiguous characters are used (e.g. the number '0' [zero] and the letter 'O' ['oh']) (Couper, et al., 2001). Concerns that the online questionnaire might be impacted upon by accessibility to the survey tool by the general population (Schonlau, et al., 2002: Sue & Ritter, 2007) were mitigated by the need for each respondent to log into the Defence Restricted Network to access the link to the online questionnaire.

Considering these guidelines, the developed online questionnaire consisted of 22 questions, grouped into six sections, allowing for up to 135 responses. These included questions regarding demographic details (2 questions: 8 mandatory responses), nature of recent load carriage activities (4 questions: up to 19 responses), operational experience (5 questions: up to 44 responses), load carriage training (7 questions: up to 21 responses), load carriage injuries (3 questions: up to 40 responses), and other specific aspects of load carriage (1 question: 3 responses). Each section was designed to capture specific data to inform at least one, and often more than one, of the four studies (Figure 5). Two questions (Questions 12 and 22) investigating soldier perceptions of load carriage captured data for use in postdoctoral studies. The online survey questionnaire is reproduced in Portable Document Format (pdf) in Appendix G. The relevance of specific survey questions to each of the four studies is shown in Figure 5.

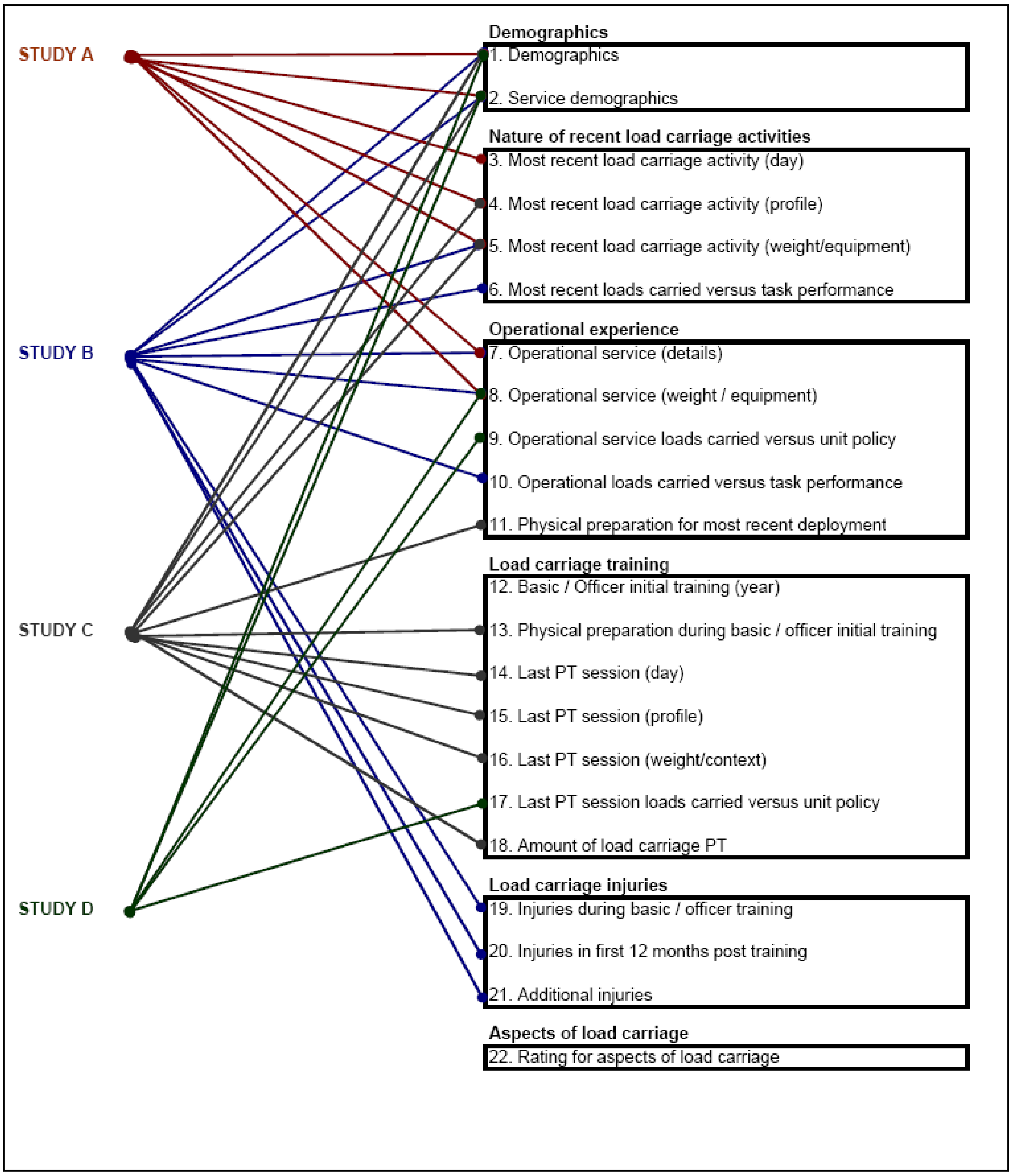
The survey questions were designed by the investigator, specifically catering for the military environment, context and terminology. While the formats of the main questions were select response matrix drop-down questions (13 questions), order rating questions (8 questions) and a matrix of choices question (1 question), respondents were also provided an opportunity to include written comments.[60] To improve the reliability of the participant responses to factual questions, internal checks were used with several questions designed to confirm previous responses – an approach recommended by Oppenheim (2001). For example, responses to Question 4, relating to operational experience, were compared to the operational experience responses provided for

---

[60] Terminologies of question types taken from the *'SurveyMonkey'* survey design tool (*SurveyMonkey*, Oregon: USA).

Question 8 using paired t-tests to compare load carriage weights. Questions that required the participant to recall previous operational experiences were compared to load carriage information collected as part of the Historical Review of Soldier Load Carriage (Chapter 2). This process of triangulation has been recommended by Cwikel (2006) as a means of improving data reliability by addressing potential recall bias.

Figure 5: Survey question distribution across Studies A through D.



This study reports the findings from Questions 3-5 and 7-8 (Appendix G) for various participant groups, each defined by the demographic data (Questions 1 and 2: Appendix G). The findings from Questions 4-5 (Appendix G), which are derived from participant responses detailing their most recent load carriage experience, were used as internal checks to confirm responses for Questions 8-

9. As discussed above, this method is recommended to improve the reliability of survey results (Oppenheim, 2001).

Pilot surveys

Prior to administering the survey, two pilot surveys were conducted. Finke (2005) recommends this process as a means of increasing survey reliability. The purposes of these pilot surveys were to (a) evaluate the effectiveness of the survey for capturing required data; (b) obtain feedback regarding the investigator-designed questions; (c) ensure that matrix drop-down questions allowed responses that captured all answer options of relevance to a given question; and (d) test and ensure accessibility to the online survey through the internal defence internet (DEFWEB) firewalls. The first pilot survey (*n*=9 respondents; 60% participation rate) included Army personnel from three of the four rank groups of interest for the survey (invited Senior Non-Commissioned Officers (SNCOs) did not complete the survey), both genders, six different units and four different corps. Following the first administration of the pilot survey and discussions with respondents, several amendments were made to the survey tool. A second pilot survey (*n*=9 respondents; 64% participation rate) was then conducted. This survey group included members from three of four rank groups (invited Other Ranks (ORs) did not complete the survey), both genders, eight different units and two different corps. Following this second administration of the pilot survey, final changes were made to the survey tool. These changes included correcting basic errors (e.g. date ranges 1 to 7 and 7 to 14), reducing bin ranges from units of five (e.g. 1 to 5 kg) to single units for age, body weight, height and load weights and including additional weapon variations (e.g. F88 Steyr with Grenade Launching Attachment, F88 Steyr with Night Aiming Device and ‘mock’ weapons). Once refined, the survey questions were resubmitted for ethical approval. The results of each pilot survey were compared to the intended scope of the research questions in order to inform revisions to the survey tool that would maximise the external validity of the topics covered and the results generated by the survey, a method advised by Fink (2005).

Survey Questionnaire Distribution

Data were collected via an online survey questionnaire hosted by *SurveyMonkey*, an independent online survey provider (SurveyMonkey, Oregon:USA). *SurveyMonkey*, which employs several layers of security as well as a third-party firm to audit security on a daily basis, was used to ensure respondent anonymity and data security (SurveyMonkey, Oregon:USA). This anonymity, combined with the option afforded by *SurveyMonkey* that allowed personnel to complete the survey from any internet-enabled location, eliminated the potential for workplace coercion to pressure personnel into completing the online survey (SurveyMonkey, Oregon:USA). The *SurveyMonkey* service allowed multiple personnel to complete the online survey simultaneously from any geographical locations (SurveyMonkey, Oregon:USA).

Personnel responded to questions online, with each response being saved automatically in the secure data base of the online survey service provider once data had been entered. Prior to survey completion, responses could be altered by the participant at any time during the survey, and respondents could navigate freely between questions and pages. The survey provider securely tracked computer IP addresses in order to enable respondents to return to the survey at any stage within the survey time frame, if required. These IP addresses were used by *SurveyMonkey*, for this sole purpose only (SurveyMonkey, Oregon USA).

To facilitate data collection during a period of ongoing military training and operations, the surveys were distributed in two phases. To accommodate this requirement, two separate but identical copies of the online survey questionnaire were created in *SurveyMonkey* and each was assigned a distinct survey weblink. This process allowed the investigator to open and close each survey separately in order to collect responses in allocated time periods. Several Army units were engaged in each phase. The first phase of survey data collection remained open for a period of 8 weeks (30 August to 29 October 2010). Many of the units conducted short duration (1–2 week) field training exercises during this time, effectively reducing the window of opportunity for unit respondents to access the survey to 6-7 weeks. The second phase of survey data collection was truncated by the commencement of annual recreational leave, remaining open for a period of 6 weeks (01 November to 17 December 2010).

Research Survey Administration

Army units which indicated a willingness to engage with the research each nominated a point of contact (POC) with whom the investigator could liaise. Unit POCs were then contacted by the investigator and provided with a generic synopsis of the research and their roles. On initiation of the data collection phase, the unit POCs were sent an email by the investigator providing a link to the online survey questionnaire. The unit POCs were asked to distribute the link via email to personnel within their units via the Defence Restricted Network (DRN), along with information provided by the investigator describing the research and inviting respondents. With the email going to all soldiers of the unit, regardless of circumstances, any potential ‘healthy worker’ measurement bias, whereby only personnel healthy enough to perform their duties would respond (Bonita, Beaglehole,

& Kjellstrom, 2006), was controlled. Two weeks after the survey data collection period opened and two weeks prior to the closing of the online survey questionnaire, reminder emails were sent to the unit POCs for distribution to their unit personnel.

To determine online survey questionnaire response rates, unit POCs were contacted and asked to detail the number of personnel within their unit to whom the survey email was sent. With unit personnel numbers expected to fluctuate over the survey period, the number of personnel on the email distribution list on the day the initial survey link was distributed to unit personnel was used. Due to temporary attachments, detachments, and periods of leave, this figure, considered an overestimate of actual personnel numbers available to complete the online survey, was the only denominator data available from which to calculate survey response rates. Moreover, no ability to track 'delivery failures' or 'incorrect addresses' was available to the investigator. Likewise, non-eligibility to participate, refusal to participate, non-contact figures, and inability to respond statistics (technical failure, unable to access a DRN computer, etc.) could not be collected due to military specific barriers (including method of survey distribution through chain-of-command). On completion of the allocated time periods for each phase of data collection, the surveys were closed.

4.2.6. Data Extraction

Once both surveys were closed, data were extracted and downloaded as Microsoft Office Excel spreadsheets using Microsoft Office Excel 2003 Professional Edition for Windows (Microsoft, WA:USA, 2003). Data were downloaded in two forms: an 'all responses collected' format, which provided all raw data collected, and a 'summary report' which collated responses to specific questions. In the 'summary report' extractions, the option to include all open-ended responses was selected. Once both forms of data had been collected from each of the two identical online survey questionnaire, the data from both were merged into one Microsoft Office Excel (Microsoft, WA:USA, 2003) data sheet for each format (summary and raw data). In order to address the research questions that underpinned this study, data from Questions 1 to 5 and 7 to 8 were separated into identified data sets within each Microsoft Office Excel (Microsoft, WA:USA, 2003) data spreadsheet. This chapter reports the findings from these questions.

4.2.7. Data Analysis

Unit cooperation and survey response rate calculations were based on methods recommended by the Institute for Social and Economic Research (ISER) (Lynn, Roeland, Johanna, & Jean, 2001) and the American Association for Public Opinion Research (AAPOR) (The American Association for

Public Opinion Research, 2011). Unit cooperation rates were defined as the percentage of units, from those identified and approached, that were willing to participate, and included consideration of those units that declined to participate and those units from which no further contact was received by the investigator. Survey response rates were defined as the percentage of personnel invited to participate in the survey who met the criteria of having completed the survey (over 80% of questions) or partially completed the survey (51% to 80% of questions). Survey response rates were adjusted for anticipated errors (AE) via the formula provided in Appendix H, as recommended (The American Association for Public Opinion Research, 2011). Anticipated errors included disruption to internet services and invitation emails being captured in spam filters. The anticipated error rate as determined was estimated at 10% based on feedback from Unit POCs. Unit cooperation and survey response rate nomenclatures and formulae are shown in Appendix H.

Responses to the survey questions were analysed using descriptive and inferential statistical analyses in order to determine (a) the loads carried by Australian Army personnel, in training, during field training exercises and during military operations; (b) the context (i.e. tasks, task duration, terrain) in which the loads were carried; and (c) whether any corps or gender differences in load carriage weight and context existed. Frequency distributions and descriptive statistics were generated for all data sets, with means and standard deviations calculated for interval data and modal responses identified for categorical data. Before any comparative analyses were conducted, consideration was given to the assumption of normality by using the Kolmogorov-Smirnov test and the assumption of homogeneity of variances by using Levene's test. Student t-tests were used to compare numeric data between two groups (e.g. load weight by gender) and a chi square test for independence was used to compare frequency distributions for nominal data (e.g. sample rank frequencies compared to broader Army rank frequencies). An analysis of variance (ANOVA) was employed to compare data between three or more groups (e.g. load weight by corps groups) and if significant, Bonferroni post-hoc tests for multiple comparisons were used to determine where the differences were. A Bonferroni post-hoc test for multiple comparisons was used to control for Type 1 errors (Cabin & Mitchell, 2000; Field, 2000). This technique has more power than Tukey's test when sample sizes are small (Field, 2000). In instances where there were significant differences in variance between samples being compared, t-tests assuming unequal variances or Dunnett's C comparisons were used. Dunnett's C was selected as the multiple comparison tool as it allows for testing means against a control mean (Field, 2000). When loads were required to be expressed as a percentage of body weight, these relative loads, expressed as a percentage of body weight, were in each case calculated by dividing the absolute reported load carried by the respondent by the respondent's body weight multiplied by 100. Mean relative loads for any specific group of respondents were calculated by dividing the sum of all relative loads in the group by the total number of respondents who formed the group. As length of service responses were reported in bin ranges of 1 year (4-5 years, 5-6 years), the formula for estimating median length of service across survey respondents, adapted from the method used by Howell (2009, p. 33), can be expressed as:

Median length of service = (n + 1)/2)th value to determine bin range
(Bin range lowest value + Bin range highest value)/2

Data were analysed using the IBM Statistical Package for the Social Sciences (SPSS) Statistics Version 19.0 for Macintosh and Windows (SPSS Inc., Delaware:USA, 2010) with the level of statistical significance set at 0.05.

4.3. RESULTS

4.3.1. Survey Results

Unit Participation and Survey Response and Completion Rates

Of the 30 units approached, eight units agreed to participate in the study, two units declined and a higher command authority declined the participation of seven other units which were situated under its umbrella of command. The investigators received no responses from the remaining 13 units. On this basis, unit cooperation rate was calculated as 27% (n=8), unit refusal rate as 30% (n=9) and unit non-contact rate as 43% (n=13).

With eight Army units willing to engage in the research, an invitation to participate in the survey was sent, by email, to an estimated 1,793 email addresses for personnel posted to these units. This figure is based on the number of personnel posted to the units. Discussions with unit POCs, who sent out the invitations by email, confirmed that the email invitations were sent out to group lists and did not exclude personnel who might have been on leave, detached to other units, on training courses, or on deployment, and hence would not have received the emailed invitation during the survey period. Furthermore, the majority of participating units (n=6 of 8) conducted field training exercises of between 1 and 2 weeks during their 6 (LCGrp2) to 8 (LCGrp1) week survey period. One unit POC acknowledged that approximately 15% of that unit's personnel were away on other tasks during the survey period. Another unit POC reported having had oversight of the email being distributed to six staff members, who were then asked to disseminate the email to their sub-unit staff. These factors are considered to have adversely affected survey response rates.

A total of 380 personnel commenced the online survey, completing demographic data (Questions 1 and 2). From these respondents, completion rate was calculated as 88% (*n*=333), partial completion rate as 1% (*n*=5), and 'break off' rate as 11% (*n*=42). The survey response rate (see formula in Appendix H) was then determined as 19%. With this in mind, if a conservative 10% AE rate is allocated in response to the survey dissemination concerns identified above, the response rate (corrected) would be calculated as 21%. This response rate is equivalent to that for a recent ADF survey (Directorate of Strategic Personnel Policy Research, 2009) and similar to those for surveys in foreign military forces (Moradi, 2010). All completed data were utilised in the analysis, with partial responses included where possible (i.e. when responses to a question being analysed contained the required data).

Survey Respondent Characteristics

Of the 338 partial and complete respondents, 22 (7%) were female. The female respondents ranged in age from 20 years to 46 years (Mean [*M*]=31.6 years, *SD*=8.0 years), in height from 1.53 m to 1.76 m (*M*=1.66 m, *SD*=7.8 m), and in body weight from 52 kg to 80 kg (*M*=66.8 kg, *SD*=7.7 kg). The male respondents (93%, *n*=316) ranged in age from 18 years to 56 years of age (*M*=31.5 years, *SD*=7.6 years), in height from 1.50 m to 2.00 m (*M*=1.80 m, *SD*=7.3 m) and in body weight from 60 kg to 126 kg (*M*=85.5 kg, *SD*=11.1 kg). The median length of service was 9.5 years. The demographic characteristics of survey respondents are shown in Table 3.

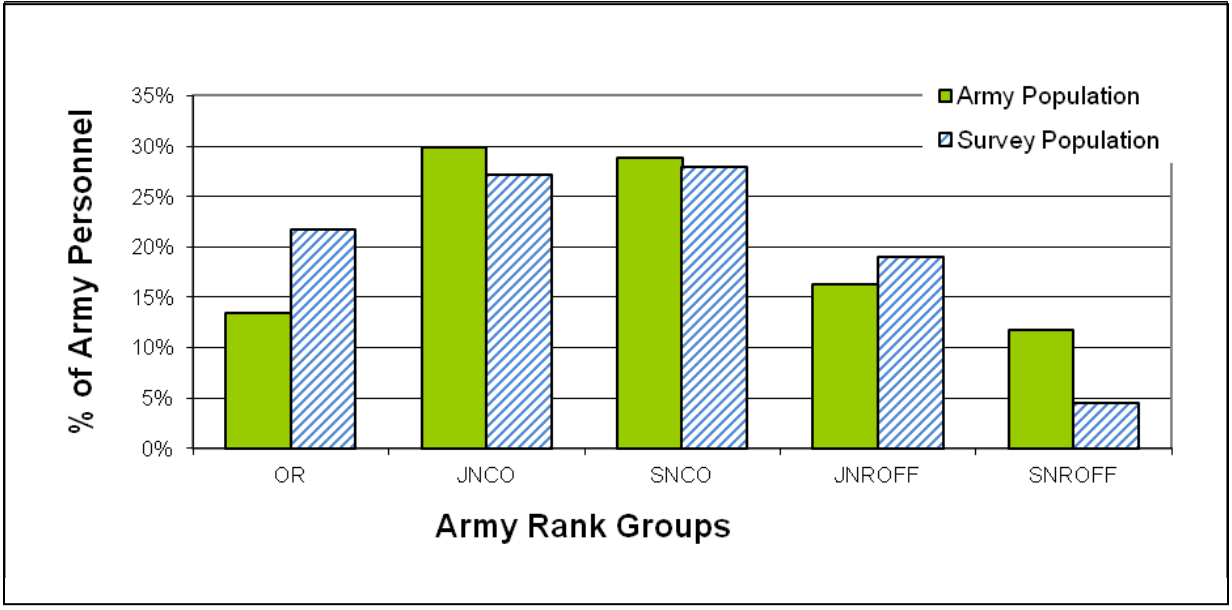
Table 3: Demographic characteristics of respondents for Study A.

Corps	**Number** ***n***	**Age (y)** ***M* (*SD*)** **Range**	**Weight (kg)** ***M* (*SD*)** **Range**	**Height (cm)** ***M* (*SD*)** **Range**	**Range of Ranks**
Artillery	15	29. 2(6.2) 20-41	87.1 (9.5) 65-105	184.0 (6.2) 172-194	OR-SNR OFF
Armoured	19	29.8 (4.7) 21-38	88.1 (13.5) 62-108	178.8 (9.1) 155-193	OR-JNR OFF
Engineers*	93	28.4 (7.0) 18-50	83.2 (11.6) 52-110	180.1 (7.7) 154-200	OR-SNR OFF
Infantry	99	33.1 (6.9) 22-50	87.3 (10.5) 65-126	180.3 (7.6) 150-198	OR-SNR OFF
Signals*	27	29.2 (7.3) 21-46	77.5 (8.1) 60-102	175.9 (7.3) 153-187	OR-SNR OFF
Other*	85	34.6 (8.3) 20-56	82.6 (13.3) 56-116	176.4 (8.5) 154-194	OR-SNR OFF
Combined*	338	31.8 (7.8) 18-56	84.2 (11.9) 52-126	178.9 (8.0) 150-200	OR-SNR OFF

* includes female members
~ OR = Other Ranks, JNR OFF = Junior Officer, SNR OFF = Senior Officer

The majority of respondents were enlisted soldiers (77%), with Senior Non Commissioned Officers (SNCO) the most represented enlisted rank (28%) closely followed by Junior Non Commissioned Officers (JNCO) (27%) and then Other Ranks (OR).[61] Officers made up the remaining 24% of respondents with Junior Officers (JNROFF) the most represented officer rank (19%) followed by Senior Offices (SNROFF) (5%).[62] The distributions of ranks for both survey respondents and the ARA as a whole are shown in Figure 6 to enable comparison.

Figure 6: Frequency distribution histogram of ranks across both the survey sample and ARA as a whole.



A Chi-square test for independence indicated a significant difference in the distribution of ranks between the ARA as a whole and the survey respondents, $\chi^2(4)=40.47$, $p<.001$. However, although differences in rank distributions between the sample and the population exist, the distribution favours this body of research. The higher ratio of 'soldier' (OR) ranks and generally similar 'middle ranks' (JNCO, SNCO and Junior Officer) skews the survey population towards the 'soldier' ranks, the ranks that are more likely to carry loads on a regular basis and that were the focus of this research (Australian Army, 1986, 2003, 2009a).

Respondents were from combat arms corps, combat support arms and combat service support corps, with Infantry (29%), Engineers (28%) and the grouped 'Other' corps (25%) the most represented corps. The percentages of respondents from Signals (8%), Armoured (6%) and Artillery (4%) were notably smaller. The periods of military service of respondents ranged from one year to over 30 years.

---

[61] For a description of Army ranks and meanings see Annex A.

[62] Total does not equal 100% due to rounding.

General Load Carriage Context

Recent Loads Carried

Just under half of the survey respondents (48%) indicated that their most recent load carriage activity had taken place within two weeks prior to survey completion. In fact, over a third (34%) of respondents claimed to have participated in a load carriage activity within the previous seven days. Accounting for the remaining respondents, 18% of all respondents reported conducting their most recent load carriage activity in the last 2 to 4 weeks, and the remaining 34% claimed to have not conducted a load carriage activity over the last month. Fourteen percent of this latter group reported not conducting a load carriage activity over the last three months.

Detailing their most recent load carriage experience, 15% of respondents reported dressing in Patrol Order, which comprises uniform, boots and webbing without a large field backpack. In these cases, any load was carried in the webbing (Australian Army, 1986). The remaining 85% reported wearing Marching Order – uniform, boots and webbing with a large field backpack (Australian Army, 1986). As well as wearing Patrol Order or Marching Order, 22% of respondents wore body armour, 25% wore field helmets and 41% carried additional stores. Around three quarters of respondents (76%) carried a weapon or training equivalent (i.e. simulated weapon). The distributions of the reported loads and equipment are shown in Table 4.

Table 4: Distribution of loads and equipment by order of dress for respondents' most recent load carriage activity.

Dress		**Webbing**	**Field Back pack**	**Body Armour**	**Helmet**	**Weapon**	**Stores**	**MEAN TOTAL**
Patrol Order	Respondents (%)	100%	N/A	30%	38%	56%	38%	15%
	Absolute load (kg) *M* (SD)	8.8 (3.9)	N/A	11 (0)	1.8 (0)	4.0 (0.8)	17.0 (12.9)	21.5 (16.2)
	Relative load (% BW) *M* (SD)	11 (4.8)	N/A	13 (1.2)	2 (0.2)	5 (0.9)	19 (13.7)	25 (17.7)
Marching Order	Respondents (%)	100%	100%	20%	23%	81%	34%	85%
	Absolute load (kg) *M* (SD)	9.4 (5.0)	25.2 (7.9)	11 (0)	1.8	3.8 (1.0)	8.7 (8.7)	43.3 (15.8)
	Relative load (% BW) *M* (SD)	11.4 (6.6)	30.1 (9.5)	12 (3.3)	2 (0.5)	5 (1.3)	10 (10.9)	52 (19.9)

Recent Loads Carried, by Corps

As described in Appendix A, different army corps have different roles. Core equipment for sustainability, lethality and protection remains the same, but there can be differences across and within corps in the types of equipment carried and hence in the total load weight carried. An

ANOVA of most recently carried loads, across all activities (PT, field training exercises and on operations) identified significant differences between the different corps in the *absolute* loads carried by different corps (F[5,270]=7.38, p<.001). A post hoc Dunnett's C identified the grouped 'other' corps as carrying significantly lighter loads (*M*=34.58 kg, *SD*=9.35 kg) than those carried by both the infantry corps (*M*=48.90 kg, *SD*=15.89 kg) and engineering corps (*M*=42.88 kg, *SD*=17.35 kg).[63] An equivalent analysis of *relative* loads[64] yielded a similarly significant result (F[5,270]=5.06, p<.001). The grouped 'other' corps (*M*=43% BW, *SD*=13%BW) again carried significantly lighter relative loads than the infantry corps (*M*=57% BW, *SD*=20% BW). In contrast, however, *relative* loads for the grouped 'other' corps were not significantly different from those for the engineering corps (*M*=51% BW, *SD*=21% BW).[65]

To account for any load differences that might have been due to differences in the nature of the recent activities undertaken, the reported loads carried by different corps during their most recent field training exercises were reviewed in isolation. Statistical analysis identified significant differences between corps (*F*(5,108)=3.93, p=.003), with a post hoc Bonferroni comparison again confirming that both the infantry corps (*M*=49.39 kg, *SD*=16.21 kg, p=.016) and engineering corps (*M*=54.53 kg, *SD*=16.93 kg, p=.002) carried significantly heavier *absolute* loads than the grouped 'other' corps (*M*=36.81 kg, *SD*=9.37 kg). However, in contrast to initial findings, when loads most recently were reviewed in *relative* terms, the engineering corps respondents reported carrying significantly heavier *relative* loads (*M*=65% BW, *SD*=25% BW) than the grouped 'other' corps (*M*=46% BW, *SD*=14% BW, p=.016), but no significant difference was found between the most recently carried *relative* loads of the infantry respondents (*M*=59% BW, *SD*=20% BW) and those of the grouped 'other' corps (p=.12).

Recent Loads Carried, by Gender

With female soldiers constituting only 5% of respondents wearing Patrol Order on their most recent load carriage activity, gender variations in Patrol Order loads were excluded from further examination in this study. On the other hand, when dressed in Marching Order, female soldiers (6% of respondents) reported carrying significantly lighter *absolute* loads (*M*=31.1 kg, *SD*=10.3 kg) than male soldiers (*M*=44.0 kg, *SD*=15.8 kg: *t*(274)=-3.21, p=.001). However, no significant differences were found when the *relative* loads carried by female soldiers (*M*=48% BW, *SD*=16% BW) were compared to the *relative* loads carried by male soldiers (*M*=52% BW, *SD*=20% BW: *t*(274)=-0.72, p=.45).

---

[63] Artillery (*M*=49.02 kg, *SD*=18.96 kg), armoured (*M*=42.1 kg, *SD*=13.21 kg) and signals corps (*M*=44.33 kg, *SD*=14.73 kg).

[64] Respondent's load divided by respondent's weight multiplied by 100.

[65] Artillery (*M*=59% BW, *SD*=31% BW), armoured (*M*=49% BW, *SD*=16% BW), and signals corps (*M*=57% BW, *SD*=20% BW).

The nature of the loads was also reviewed, to examine differences in *absolute* loads between female soldiers and their male counterparts. As shown in Table 5, the key differences were significantly lighter *absolute* loads carried in the field packs [$t(274)=-2.51$, p=.006] and the lower number of female soldiers wearing the additional loads of body armour and helmet or carrying additional stores or weapon systems. Due to the small number of female respondents, no categorical analysis was conducted when reviewing differences in equipment and stores carried between genders.

Table 5: Distributions of loads and equipment by order of dress and genders.

		Female	**Male**
Webbing	Absolute load (kg) *M* (SD)	7.6 (3.6)	9.5(5.0)
	Relative load (% BW) *M* (SD)	12(5)	11(7)
Pack	Absolute load (kg) *M* (SD)	20.4 (7.1)	25.5*(7.8)
	Relative load (% BW) *M* (SD)	32 (11)	30(9)
% of cohort wearing or carrying listed equipment (n=number in cohort)	Wore body armour	6% (n=1)	20% (n=63)
	Wore helmet	6% (n=1)	24% (n=64)
	Carried stores	6% (n=1)	36% (n=76)
	Carried weapon	63% (n=14)	82% (n=259)

* Significantly different to female, p = .013

Recent Load Carriage Context – Activity

When describing the nature of their most recent load carriage activity, the majority of respondents reported undertaking unit training or physical training (PT) (48%), field training exercises (41%), or being on operational deployment (6%). The remaining respondents claimed to have been conducting other tasks (3%) or to have conducted no load carriage activity in the last 12 months (2%).

An ANOVA of Patrol Order load data identified significant differences in loads carried during different activities, ($F(2,45)=6.9$, $p=.002$). Patrol Order loads carried during military operations were significantly heavier ($M=50.1$ kg, $SD=16.0$ kg)[66] than field training loads ($M=23.7$ kg, $SD=13.4$ kg) and PT loads ($M=17.8$ kg, $SD=14.3$ kg). An analysis of Marching Order loads yielded similar results, with operational loads ($M=62.5$ kg, $SD=17.3$ kg) significantly heavier than field training loads ($M=47.2$ kg, $SD=16.0$ kg), which were in turn heavier than PT loads ($M=37.5$ kg, $SD=12.6$ kg), $F(2,259) = 28.0$, $p <.001$.

---

[66] These results should be viewed with caution as only three respondents reported carrying Patrol Order on operations during their most recent activity. See Section 4.3.1 and Figure 8 for more reliable operational Patrol Order data.

Furthermore, whereas the ratios of activity types in Patrol Order and in Marching Order were similar (rows 1 and 2 in Table 6), the ratios of respondents wearing body armour, helmets or carrying weapons differed between these activity types. Responses indicated that Army personnel on military operations were more likely to be wearing body armour or helmets or carrying weapons than those undertaking PT or field training exercises.

Table 6: Nature of load carriage dress by activity type.

Dress	**Activity**		
	PT	**Field Training Exercise**	**Operations**
Patrol Order	16%	17%	17%
Marching Order	84%	83%	83%
TOTAL	100%	100%	100%
In addition to Patrol Order or Marching Order			
body armour and helmet were worn by	8%	37%	83%
and weapons were carried by	68%	83%	100%

Recent Load Carriage Context – Tasks

Foot patrols or walking were the most commonly reported tasks recently undertaken while carrying loads (83% of respondents). This task was the task performed in 89% of recent PT sessions, 75% of field training exercises and 78% of operational duties. Following foot patrols or walking, administration (10%), mounted patrols (4%) and static tasks (3%) were the most common self-reported recently undertaken tasks.

Recent Load Carriage Context – Duration of load carriage tasks

Across all activities, 66% lasted for less than 3 hours, 12% lasted for 6 to 12 hours, 3% for 12 to 24 hours and 18% lasted for more than one day.[67] Among activities of less than 3 hours' duration, PT was the most dominant type. Among activities lasting longer than three hours, field training exercises were the dominant type (Table 7).

Table 7: Duration of load carriage activities by activity type.

Activity	**up to 60 min**	**>1-3h**	**>3-6h**	**>6-12h**	**>12-24h**	**>1- 3d**	**>3d**
PT	67%	69%	20%	14%	0%	0%	10%
Field training exercises	28%	26%	64%	64%	100%	80%	71%
Operations	1%	2%	16%	21%	0%	0%	17%
Other	3%	3%	0%	0%	0%	20%	2%
TOTAL	99%*	100%	100%	99%*	100%	100%	100%

* Total does not equal 100% due to rounding.

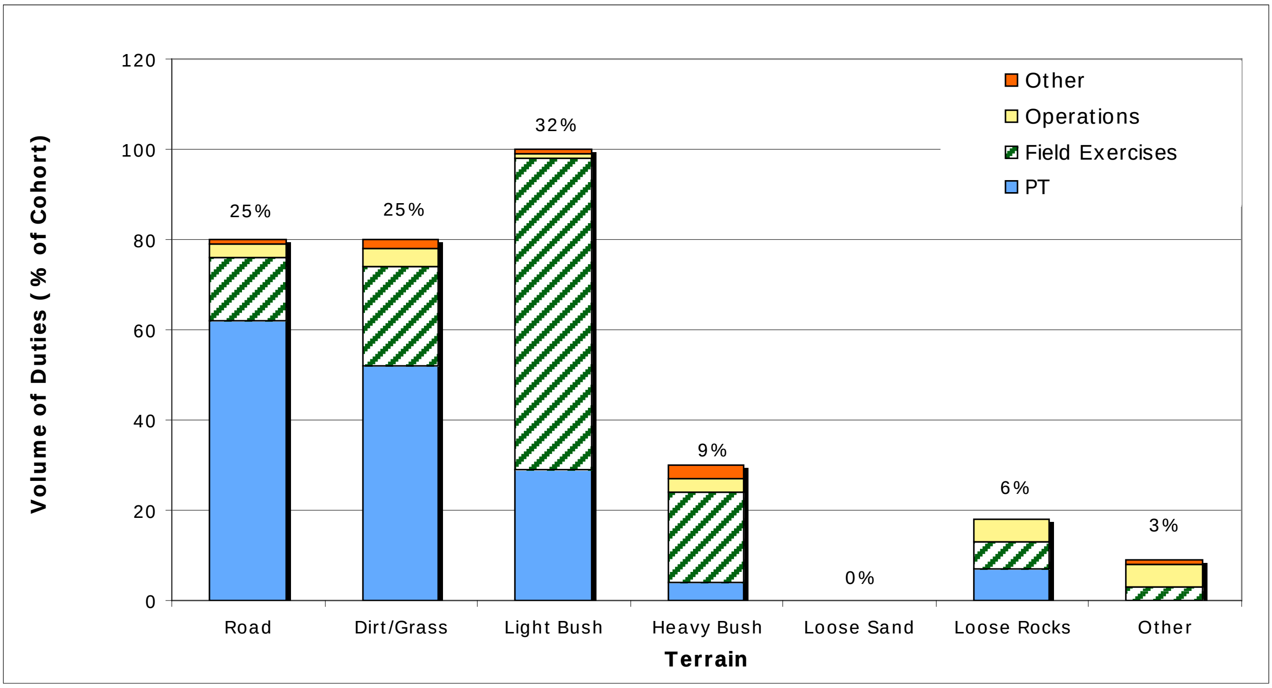
---

[67] Total does not equal 100% due to rounding.

Load Carriage Context – Nature of Terrain

Light bushland was reported as the most common terrain crossed during respondents' most recent load carriage activity, followed by roads and dirt or grass (Figure 7). Foot patrols or walking were the most common tasks conducted across all terrain types (road, 81%; dirt/grass, 78%; light bush, 80%; heavy bush, 97%; loose rocks, 89%). Over half of the load carriage activities conducted in light bush were part of field training exercises, with PT accounting for the majority of activities conducted on roads or over dirt/grass.

Figure 7: Frequency distribution histogram of the terrain crossed during respondents' most recent load carriage activity.



Recent Load Carriage Context – Grade of Terrain

Mild hills were reported as the most commonly traversed terrain grade (61% of reported most recent activities) with PT the most commonly conducted activity over mild hills (48% of activities over mild hills). PT was also the most commonly conducted activity over flat grades (60% of activities over flat grades), which was the terrain type in 22% of all recent load carriage activities. Field training exercises were the most commonly performed load carriage activities over steep hill grades (46% of activities over steep hills), which was the terrain type in 17% of all recent load carriage activities. Foot patrols or walking were the most common tasks carried out over all three grades of terrain, most notably on mild hills (84% of tasks over mild hills) and on steep hills (91% of tasks over steep hills).

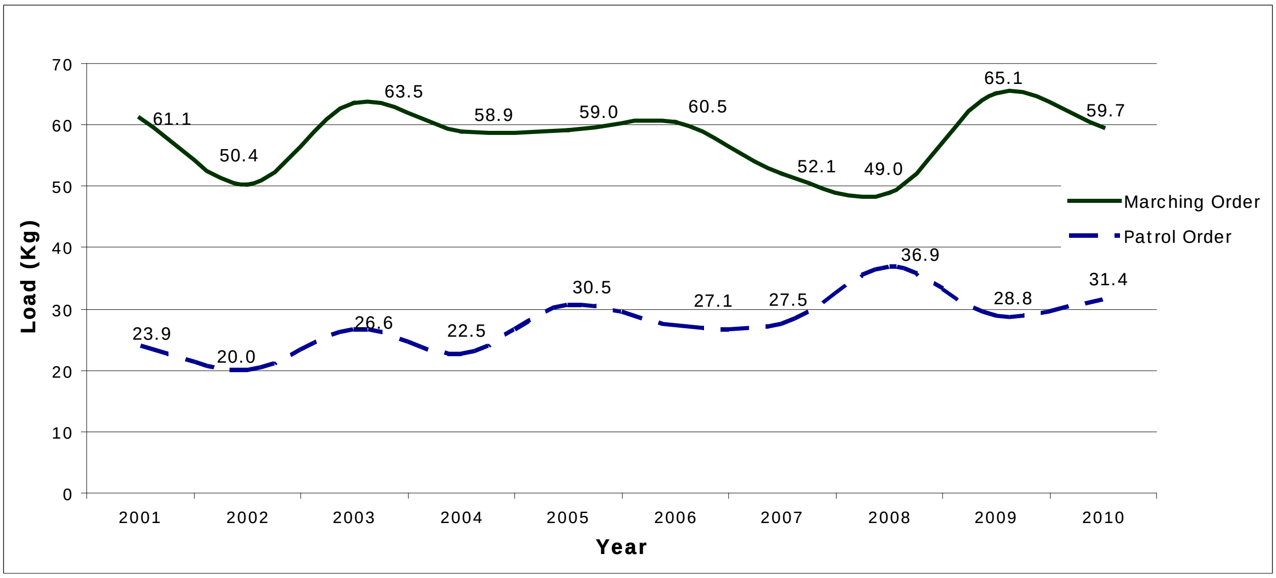
When the nature of the terrain (roads, light bush, etc.) was paired with the grade of terrain (flat, mild hills, etc.), activities conducted on roads or on dirt or grass were more frequently conducted over flat terrains (40% and 39% of activities conducted on roads or on grass, respectively) than over any other terrain grade. Activities conducted in light bush were more often conducted over mild hills (38% of activities in light bush) or steep hills (28% of activities in light bush) than over any other terrain grade.

Operational Load Carriage Context

Sixty-six per cent of respondents provided data regarding load carriage during military operations, with over 80% having seen operational service in the last decade. As over 50% of respondents had completed more than one operational deployment, a total of 411 reports of load carriage activity undertaken during operational deployments were provided by respondents over a period spanning more than two decades. As the research focus was on the current load carriage context, only data for the decade 2001 to 2010 (*n*=301 data sets) were included in the analysis.

When all responses relating to operational tours (first, second and third tours per individual) for the preceding decade were grouped by year of deployment, mean total loads per year (2001-2010) carried by respondents, dressed in either Patrol Order or Marching Order, ranged between 40.7 kg and 50.9 kg with a mean *absolute* load across years of 47.7 kg (*SD*=21.0 kg), representing 56% (*SD*=26%) of respondents' mean body weight (Figure 8).

Figure 8: Self-reported loads carried by Australian soldiers during military operations over the last decade (2001-2010).



When Patrol Order loads for each year of the full decade (*M*=28.4 kg, *SD*=10.0 kg) were viewed in isolation, mean loads ranged from the lightest mean load in 2002 (*M*=20.0 kg, *SD*=11.7 kg) to the heaviest mean load in 2008 (*M*=36.9 kg, *SD*=10.8 kg). Marching Order loads across the decade (*M*=56.7 kg, *SD*=15.3 kg) ranged from the lightest mean load in 2008 (*M*=49.0 kg, *SD*=12.1 kg) to the heaviest mean load in 2009 (*M*=65.1 kg, *SD*=16.3 kg).

Review of the validity of responses by triangulating results from different survey questions found no statistically significant difference in Marching Order loads reported by the seven per cent of respondents who reported carrying loads during military operations between 2009 and 2010 (*M*=63.2 kg, *SD*=8.6 kg) and the Marching Order loads reported by respondents (5%) who designated operational load carriage as their most recent activity (*M*=62.5 kg, *SD*=17.3 kg), *t*(36)= -0.13, p=.089.

Operational Loads Carried, by Corps

The differences in operational loads carried between corps were significant, *F*(5,396)=12.2, *p*=.001. When Marching Order loads were reviewed in isolation, significant differences between corps were found *F*(5,260)=11.8, *p*=.001. The average reported *absolute* Marching Order loads carried by Armoured corps (*M*=61.2 kg, *SD*=19.0: kg p=.006), Infantry corps (*M*=60.9 kg, *SD*=15.7 kg: p=.001), Engineer corps (*M*=59.4 kg, *SD*=15.0 kg: p=.001), and Artillery corps personnel (*M*=58.1 kg, *SD*=16.9 kg: p=.002) were significantly heavier than those carried by the grouped ‘other’ corps (*M*=42.4 kg, *SD*=15.6 kg). No significant differences in *absolute* Marching Order loads were found between respondents from Signals corps (*M*=54.4 kg, *SD*=19.0 kg) and those from the remaining corps represented in this program of research.

Australian female soldiers are currently excluded from serving in certain corps (Davison, 2007). Moreover, gender differences in absolute loads have already been identified in this study (see Table 5). For these reasons, an additional analysis of the data was performed with responses from female soldiers serving in the grouped ‘other corps’ and Signals corps removed. Even though the loads carried by the grouped ‘other’ corps (*M*=48.8 kg, *SD*=12.2 kg) and Signals corps (*M*=57.5 kg, *SD*=19.6 kg) were heavier with the female data removed, the significant differences in loads carried between corps (*F*(5,240)= 4.0, *p*=.002) remained consistent with those noted in the paragraph above.

A statistical analysis of *relative* (to body weight) operational Marching Order loads confirmed significant differences between corps (F(5,260)=7.6, p=.001). Infantry (*M*=71% BW, *SD*=20% BW: p=.001), Artillery (*M*=68% BW, *SD*=28% BW: p=.0028), and Engineers (*M*=68% BW, *SD*=19% BW: p=.003) were identified as carrying significantly heavier *relative* loads than the grouped ‘other’ corps (*M*=52% BW, *SD*=19% BW) (Table 8). Armoured corps personnel, while carrying the heaviest *absolute* loads, did not carry significantly heavier *relative* loads when compared to all other corps (*M*=63% BW, *SD*=18% BW).

Table 8: Bonferroni comparison of relative loads carried between specific ARA corps and grouped ‘other’ corps.

Corps	**Mean Difference (% BW)**
‘Other corps’ vs Infantry	19.31*
‘Other corps’ vs Artillery	16.44*
‘Other corps’ vs Engineers	16.07*

* Significant differences between corps p < .004

The loads carried for four different tasks were analysed in relation to each soldier’s corps in terms of both loads carried and frequency of performance of each task. As can be seen in Table 9, the patterns of tasks varied with corps.

Table 9: Operational task compositions and loads by corps.

Corps	**Admin**	**Static/Posts**	**Foot patrols**	**Mounted patrols**
	% of total reported corps time allocated to specific tasks Mean Load: kg (SD)			
Artillery	24%	12%	64%	-
	47.80 (4.7)	65.40 (7.2)	51.20 (25.5)	-
Armoured	-	-	16%	84%
	-	-	41.40 (33.8)	36.00 (17.9)
Infantry*	9%	1%	78%	13%
	47.70 (18.1)	31.40 (0)	52.80 (17.1)	46.60 (15.9)
Engineers*	35%	7%	35%	24%
	36.40 (14.0)	59.00 (18.1)	44.10 (19.0)	54.70 (24.8)
Signals	32%	5%	37%	26%
	41.80 (19.3)	38.40 (0)	30.60 (12.3)	25.10 (14.4)
Other*	38%	20%	25%	18%
	31.20 (15.1)	38.00 (21.4)	40.20 (14.6)	33.60 (14.1)

* Total does not equal 100% due to rounding.

As can be expected, the majority of the armoured corps tasks (84%) were performed in vehicles or 'mounted', whereas the majority of the infantry corps tasks (78%) were performed on foot. Analysis was performed of the absolute loads carried by corps on the single task type that was uniformly conducted task across corps, which was patrolling on foot. The results showed that, within this task type, different corps carried significantly different loads, (*F*(5,150)=3.31, p=.007). Post hoc analyses revealed that the only statistically significant difference in mean *absolute* loads existed between the heavier operational Marching Order loads of infantry (*M*=52.8 kg, *SD*=17.1 kg) and the lighter loads carried by signal corps (*M*=30.6 kg, *SD*=12.3 kg, p=.039). When mean loads *relative* to body weight were compared across corps, no statistically significant differences in mean *relative* loads carried when patrolling on foot were identified (*F*(5,150)=2.1, p=.07).

Operational Loads Carried, by Gender

Female soldiers (11% of responses), regardless of dress, reported carrying significantly lighter *absolute* loads (*M*=26.4 kg, *SD*=13.3 kg) during military operations than their male counterparts (*M*=39.0 kg, *SD*=17.5 kg), *t*(99)=-2.02, p=.045. Again, however, no significant differences were found when the *relative* load (*M*=43% BW, *SD*=21% BW) carried by female soldiers during military operations was compared to the *relative* loads (*M*=47% BW, *SD*=21% BW) carried by male soldiers during military operations over the same operational period (1998-2010),[68] (*t*(99)=-0.60, p=.55). The key difference in carried loads between male and female soldiers during military operations was the significantly heavier *absolute* loads carried by male soldiers in webbing (*t*(96)=-2.76, p=.006) (Table 10).

Table 10: Gender distribution of loads and equipment by order of dress during military operations.

		Female	**Male**
Webbing	Absolute load (kg) *M* (SD)	6.6* (1.6)	9.3*(3.3)
	Relative load (% BW) *M* (SD)	9(4)	11(4)
Pack	Absolute load (kg) *M* (SD)	19.0(9.0)	22.7(9.2)
	Relative load (% BW) *M* (SD)	29(14)	27(11)
% of cohort wearing or carrying listed equipment (n=number in cohort)	Wore body armour	67% (n=8)	87% (n=77)
	Wore helmet	58% (n=7)	84% (n=75)
	Carried stores	8% (n=1)	42% (n=37)
	Carried weapon	67% (n=8)	96% (n=85)

* Significantly different to female, p=.006

An analysis of the composition of tasks undertaken by soldiers of each gender while on deployment showed that, while the proportions of time spent on mounted patrols or static patrols were comparable between genders, a notably lower proportion of time was spent by female soldiers conducting foot patrols compared to male soldiers and a higher proportion of time was spent on conducting administration tasks (Table 11).

Table 11: Operational tasks compositions by gender.

	Female*	**Male***
Administration	44%	18%
Static patrols	11%	8%
Foot patrols	22%	54%
Mounted patrols	22%	21%

* Does not equal 100% due to rounding.

---

[68] No respondent data was available for female soldiers on operations prior to 1998.

Finally, a post hoc analysis was conducted to determine the potential for the observed differences in the *relative* loads carried by male and female respondents to be influenced by the average lighter body weight of females (which was identified in 'Survey Respondent Characteristics' above and in the literature review in Chapter 2). An analysis of the operational loads carried by the lightest 20% of male respondents and the heaviest 20% of male respondents (n=18 per group) yielded no significant differences in the *absolute* loads carried between the lighter group (*M*=34.7 kg, *SD* =17.00 kg) and the heavier group (*M*=35.47 kg, *SD*= 15.05 kg; *t*(34)=0.12, p=.902). Conversely, when *relative* loads were analysed, differences between the lightest 20% and the heaviest 20% of male respondents approached significance (*t*[29]=2.03, p=.0509, unequal variances) between the lightest and heaviest 20% of male respondents. The lightest respondents reported carrying loads that represented 49% of their body weight, while loads representing 36% of body weight were carried by the heaviest male respondents.

Operational Load Carriage Context – Tasks

When operational tasks were analysed across corps and gender, foot patrols or walking were still the most dominant task type (50% of tasks), mounted patrols were the second most commonly performed task type (25% of tasks) and administration (17%) and static patrols or standing at post (8%) were the least frequently performed task types. When assessed over two decades, responses suggest that the dominance of patrolling on foot or walking might be reducing (from 67% down to 45% of total tasks), with mounted patrols increasing (from 9% up to 29% of total tasks). This change in operational task composition must be considered in light of current ADF operational theatres (i.e. East Timor [1999-ongoing] versus Afghanistan [2001-2002, 2005-ongoing]) and the varying numbers of troops deployed to these regions (discussed in greater detail in the Discussion: Section 4.4).

When these different task types were analysed in terms of loads carried, statistically significant differences were detected in loads carried for different tasks, (*F*(3,303)=6.9, $p < .01$). Post hoc analysis identified that a 'patrolling on foot' task involved significantly heavier loads (*M*=49.2 kg, *SD*=19.2 kg) than 'mounted patrols' (*M*=40.2 kg, *SD*=19.4 kg; p=.007), or 'administration' tasks (*M*=38.1 kg, *SD*=16.2 kg; p=.001). No statistically significant differences in loads carried were found between 'static post' tasks (*M*=42.0 kg, *SD*=20.4 kg) and other tasks (p>.08).

Operational Load Carriage Context – Duration of load carriage tasks

Responses indicate that 26% of operational load carriage tasks lasted for over 3 days, with tasks lasting less than 60 min (17%), >1–3 hours (16%) and >3–6 hours (16%) the next most frequently reported operational load carriage tasks. Durations of >6–12 hours (11%), >13–24 hours (5%) and >1–3 days (9%) were the least frequently reported. Administration duties dominated the nature of load carriage tasks lasting less than 60 min (68%) while patrolling on foot was the major task type for events lasting from 1 to 24 hours (55%) and for three or more days (64%). Mounted patrols were the dominant task type for events lasting for one to three days (67%).

Operational Load Carriage Context – Nature of Terrain

Unlike the situation reported above for the ‘most recent’ load carriage tasks, roads, rather than light bushland, were identified as the most frequently traversed terrain type while conducting *operational* load carriage tasks (29% of tasks), with mounted patrols constituting 36% of all operational load carriage tasks conducted on road. Over terrains that were classified as light (13%) or heavy (18%) bush, the most dominant task type was patrolling on foot. Dirt and grass (15%) and rock (11%) were the next most frequently reported terrain types crossed during load carriage activities. No respondents reported traversing loose sand during their most *recent* load carriage task, but 7% of respondents reported traversing loose sand during load carriage while engaged in military operations, with 48% of these respondents reporting they were conducting a mounted patrol task at the time.[69]

With operational load carriage data divided into decades (1991–2000; 2001–2010), a difference between decades in the distribution of the natures of terrain was noted (Table 12). This difference would be consistent with changes in campaigns and theatres of operations as discussed earlier in this section (*operational load carriage context – tasks)* and detailed in Annex A.

Table 12: Differences in terrain covered during operational load carriage tasks 1991–2010 (% of reported tasks).

Period	**Road**	**Dirt/Grass**	**Light bush**	**Heavy bush**	**Loose sand**	**Rock**	**Other**
1991–2001 (n=110)*	20%	22%	20%	35%	0%	2%	2%
2001–2010 (n=301)*	31%	13%	12%	15%	8%	12%	8%

* Does not equal 100% due to rounding.

---

[69] The remaining 7% of respondents claimed to have traversed ‘other’ terrain types.

Operational Load Carriage Context – Grade of Terrain

Flat terrain was the most commonly reported terrain grade traversed during load carriage tasks while on military operations (41% of tasks across two decades), with mild hills reported least often (26% of tasks across two decades). The key task type conducted on flat ground was administration tasks (33% of tasks) followed by both foot patrols (27% of tasks) and mounted patrols (27% of tasks). Over hilly terrain, foot patrols were the most dominant operational task type, constituting 65% of reported operational load carriage tasks over mild hills and 69% of load carriage tasks over steep hills. The distribution of mounted patrols was relatively constant over all measured terrain grades (24% to 27% of task types).

When the nature of the terrain was analysed with the grade of terrain, it was apparent that almost half of all reported operational load carriage tasks conducted on flat ground were conducted on roads (49% of tasks). Conversely, almost half of all reported operational load carriage tasks conducted in heavy bush were conducted on steep terrain (48% of tasks). Commensurate with differences between the decades in the natures of terrain covered in load carriage, there were also differences observed in the grades of the terrain covered. Flat terrain was been the more dominant terrain in the most recent decade as opposed to the steep hills of the previous decade (Table 13).

Table 13: Differences in the grade of terrain covered during military operations over last two decades.

Activity	Flat	Mild hills	Steep hills
1991–2000 (n=110)	26%	21%	53%
2001–2010 (n=301)*	45%	27%	29%

*Total does not equal 100% due to rounding.

4.4. DISCUSSION

The aim of Study A was to characterise and examine the current load carriage context of the ARA soldier. From the published literature, it appears this study is the first to capture load carriage information, including both weight and context, in detail across several contexts at one time. Whereas previous studies have looked at operational loads in isolation (Bachkosky, et al., 2007; Task Force Devil Combined Arms Assessment Team, circa 2003), this study captured details of loads carried during physical training (PT), field training exercises and on operations, as well as details regarding the contexts in which these loads were carried.

4.4.1. What loads are currently carried by Australian Army soldiers, in training, during field training exercises and during military operations?

As a snapshot across a specific period of time (2001-2010), the current study found that ARA soldiers are typically carrying just over 20 kg in Patrol Order, or around 25% of their reported body weight. With only around 9 kg of this mean Patrol Order load coming from their webbing, the remainder of the soldier's Patrol Order load was comprised of body armour, helmet, weapon, and additional stores, carried collectively or in various combinations. Unexpectedly, the majority of the load reportedly carried by respondents during recent activities conducted in Patrol Order came from the additional stores. Respondents who reported load carriage activities involving Marching Order, while carrying heavier total loads (mean of 43 kg or 52% body weight), carried only slightly heavier webbing (approximately 1 kg). Even though approximately the same proportions of soldiers were carrying additional stores, soldiers carrying load in Marching Order, on average, carried approximately half the additional stores load of that carried in Patrol Order (mean stores loads of 8.7 kg versus 17 kg). The potential reason for this difference is the opportunity for the soldier in Marching Order to transfer stores, and hence load, from the hands or slung across the body into the backpack. Moreover, the nature of the tasks being undertaken may have contributed to the differences. As an example, soldiers undertaking defence works (e.g. sandbagging or establishing a machine gun post) would typically perform this task in Patrol Order and be required to carry additional stores essential for defensive tasks (e.g. shovels or wire).

When the reported loads were examined in relation to the activity being performed, differences were found, with reported loads carried by soldiers during PT (*M*=37.5 kg, *SD*=12.6 kg) lighter than those carried during field training (*M*=47.2 kg, *SD*=16.0 kg). Both these loads were lighter than loads reportedly carried on operations (*M*=62.5 kg, *SD*=17.3 kg). These reported operational loads were consistent with Australian operational loads reported in other literature. During the ADF's OPERATION CITADEL in East Timor, Paulson (2006) stated that Australian soldiers carried loads in excess of 45 kg. Survey respondents claimed that loads carried between 2002 and 2003, the period coinciding with this operation, averaged 45.6 kg (*SD*=22.3 kg). Similarly, McMahon (2010) claimed that while he was on military operations in Afghanistan as a member of the Engineer corps, a fellow member carried a Marching Order load of approximately 75 kg. The Marching Order data collected in this study which corresponds to this period indicated that core loads ranged from 68.6 kg to 86.4 kg (*M*=77.7 kg, *SD*=9.0 kg).

With operational loads identified as being significantly heavier than field and PT loads, an initial concern might be that Australian soldiers are carrying heavier loads than soldiers of other nations. This was not found to be the case in the current study. A review of loads carried by the U.S. Army in Afghanistan by the Task Force Devil Combined Arms Assessment Team (circa 2003) found that U.S. riflemen were carrying a mean load of 29 kg, or 36% body weight, in their ‘Fighting Load’.[70] Australian soldiers reported carrying similar absolute loads but slightly lighter relative loads during the same period, being a mean Patrol Order load of 27 kg or 30% body weight in 2003. Marching order loads were also remarkably similar, with the U.S. soldiers carrying loads of around 58 kg or 71% body weight and Australian soldiers carrying loads of around 63.5 kg or 72% body weight.[71]

A study conducted in 2007 of U.S. Marine Corps combat loads reported loads ranging from 34.5 kg in dress equivalent to Australian Patrol Order to 55.8 kg in dress equivalent to Australian Marching Order (Bachkosky, et al., 2007). For soldiers serving in the same theatre, Australian absolute loads were comparable, ranging from 31 kg in Patrol Order to 54 kg in Marching Order. Furthermore, these loads were similar to the 54 kg mean loads reportedly carried by British Riflemen in the same theatre in 2009 (Brown, et al., 2010). This finding of similar loads between nations supports the findings of Chapter 3, the Historical Review of Soldier Load Carriage, where loads carried by Australian soldiers were found to be similar in the corresponding time period to those carried by other allied nations. These similarities in load suggest that military forces of the U.S., U.K., and Australia were carrying similar operational loads and faced similar concerns regarding the loads carried by their soldiers during military operations (Bernton, 2011b; Brown, et al., 2010; Lowell Sun, 2010; Tyson, 2009). As such, an opportunity exists where a potential solution developed for one nation may be of benefit to several others.

A further consideration is the impact of the body weight of soldiers. The mean reported operational Marching Order load over the last decade was 56.7 kg with a standard deviation of 15.3 kg. Reported body weights from these respondents ranged from 52 kg to 126 kg (see Table 3). These results suggest a potential for some soldiers to be carrying over 100% of their body weight during load carriage tasks. This was found to be the case in several instances when individual loads were examined in the data. Conversely, even though respondents from Armoured corps were identified as carrying significantly heavier *absolute* Marching Order loads during military operations than the grouped ‘other’ corps, they were not carrying significantly heavier *relative* loads, due to the higher

---

[70] Fighting Load is akin to Australian Patrol Order (described in the Glossary and Annex A: ARA Load Carriage Systems Orders-of-Dress).

[71] The impact of differences in soldier body weight is discussed later in this section.

mean body weight of respondents (Table 3). Furthermore, the differences in mean body weight between U.S. soldiers who were considered in the Task Force Devil report (approximately 80 kg) (Task Force Devil Combined Arms Assessment Team, circa 2003) and Australian respondents in the current study[72] (88.2 kg), explain the previously reported finding where U.S. soldiers were carrying Marching Order equivalent loads of around 58 kg or 71% body weight whereas Australian soldiers were carrying loads of around 63.5 kg or 72% body weight.

With PT training and field training exercises being designed to physically condition soldiers and prepare soldiers for operations (Australian Army, 2002), the training gap in loads carried in the three activities may pose potential risks. Consider, for example, recent media releases highlighting the musculoskeletal injuries suffered by soldiers during military operations (Bernton, 2011b; Brown, et al., 2010; Lowell Sun, 2010; Tyson, 2009). If soldiers are not adequately conditioned for load carriage tasks their risk of injury may be increased (Knapik, et al., 2004; Knapik, et al., 1992). One key example of this training gap was highlighted in Table 6, where it was evident that less than 40% of soldiers wore body armour and helmet while conducting field training exercises compared to over 80% of soldiers wearing this protective equipment during military operations. Considering the weight of this protective equipment (Lowell Sun, 2010; McPhedran, 2009a; Whitworth, 2009) and its potential to cause injuries (Fargo & Konitzer, 2007), soldiers need to be conditioned to wearing this equipment if their physical resilience is to increase (Henning & Khamoui, 2010).

Furthermore, body armour and helmets may have implications for heat regulation during load carriage (Caldwell, Engelen, van der Henst, Patterson, & Taylor, 2011; Law & Lim, 2008). Law and Lim (2008) reported improved work duration and tolerance of participants while wearing body armour once they were acclimatised to the clothing and environmental conditions. Thus, failure to wear body armour during conditioning and training could reduce the capacity for the soldier to acclimatise to the micro-environment created when body armour is worn, which could in turn increase the soldier’s risk of heat-related illness during field exercises and operational deployments. Recent research by Caldwell, et al. (2011) suggests that the risk of sustaining a heat-related illness due to the thermoregulatory effects of body armour and helmet may be negligible, but the authors acknowledged that their study was limited to uneventful urban patrolling. Of note, the trials were conducted with participants walking on treadmills without webbing or pack in any of the conditions. As such, while that study provides some useful initial findings, more research is needed on the impact of load carriage with participants wearing webbing and pack, covering a variety of

---

[72] During Australian military operations over the corresponding period.

terrain types and grades and wearing body armour. However, lighter loads for soldiers undertaking PT are not surprising as the load carried would depend on the soldier's stage of training. For example, new recruits carry less load than fully trained soldiers (Orr, 2007). This is a requirement of load carriage conditioning as heavy loads introduced too soon have the potential to cause injuries (Pope, 2001). With this in mind, it is imperative that any physical conditioning activity undertaken, while progressive, is sufficient to prepare the soldier to carry heavy loads (Australian Army, 2005). On this basis, physical conditioning for load carriage within the ARA is examined in detail in Study C (Chapter 6).

The findings in the current study support four findings from the Historical Review of Soldier Load Carriage (Chapter 3). These four findings, discussed in greater detail below, are:

1. The loads reportedly carried by Australian soldiers in East Timor was around 45 kg;
2. Australian soldier load weights are aligned with those of other nations;
3. *Absolute* loads carried by soldiers since the Vietnam war are increasing; and
4. *Relative* loads carried by soldiers may be similar to those carried by soldiers of antiquity.

Paulson (2006)[73] cited loads carried by Australian soldiers in East Timor as being greater than 45 kg. This load weight figure was the only source of data available to the researcher at the time and therefore represented the sole reference to Australian soldier loads during operations in East Timor. The current study found that when all loads, including both Patrol and Marching Order, were averaged, the data supported the values provided by Paulson (M=45.6 kg, SD=22.3 kg).[74] In relation to other defence forces, the Historical Review of Soldier Load Carriage observed that, in general, the loads carried by Australian soldiers and soldiers of allied nations were similar. Soldier body weight was an influencing factor for relative loads, as discussed in detail later in this chapter. In regard to increases over time in the *absolute* loads carried by soldiers, the historical review (Chapter 3) supported the earlier findings of Knapik (1989, 2000; 2004) and found that the *absolute* loads carried by soldiers have been increasing in recent conflicts. In an Australian context, the review concluded that Australian soldier loads, carrying mean *absolute* loads of around 30 kg in the World Wars, 36 kg in Vietnam and over 45 kg in East Timor, have been increasing. The findings in the current chapter of Australian soldiers carrying loads of around 56.7 kg (SD=15.3 kg) over the last decade (2001–2010), support this conclusion. In regard to *relative* loads, in the current study respondents self-reported carrying *relative* loads which averaged 56% of their body weight (SD=26% body weight). These relative loads were akin to those thought to have been carried by Roman Legionnaires (56% body weight).[75] This finding of Australian soldiers carrying relative

---

[73] Chapter 3: A Historical Review of Soldier Load Carriage, Section 3.3.4.

[74] Although other operations over this period must be considered, the major operational task for Australian Army Soldiers over this period was in East Timor, with no Australian troops serving in Afghanistan.

[75] Chapter 3: A Historical Review of Soldier Load Carriage, Section 3.3.1.

loads of around 56% of their body weight also supports a previous statement that Australian soldier loads are similar to those of soldiers of allied nations with U.S. soldiers reportedly carrying *relative* loads of around 55% body weight in current operational deployments in Afghanistan. [76]

4.4.2. What are the characteristics (tasks, durations, terrains, etc.) that form the context of these load carriage activities?

Research investigating the impact of load carriage over different distances or durations and across different terrain grades and types was reported in the review of the literature on soldier load carriage (Chapter 2) (Abe, et al., 2008a; Crowder, et al., 2007; Epstein, et al., 1988; Lyons, et al., 2005; Morrissey & Liou, 1988; Patton, et al., 1991; Pimental & Pandolf, 1979; Santee, Allison, et al., 2001; Schiffman, et al., 2009; Scott & Ramabhai, 2000b; Soule & Goldman, 1972; Strydom, et al., 1966). In that review, no load carriage research was found to specifically investigate the types of tasks soldiers are required to complete when undertaking load carriage events, the durations for which soldiers undertake these load carriage events, or the types and grades of terrains on which they are required to carry loads. This is understandable, as even on a specific tour of duty, in one country (like Afghanistan), the terrain can vary markedly (Brown, et al., 2010). Therefore, contextual understanding of contemporary soldier load carriage tasks, the durations of these tasks, and the terrain traversed while completing these tasks needs to be established to enable future research into load carriage to provide results that are applicable to the soldier in the field.

Load Carriage Tasks

The current study identified foot patrols as the dominant task type while carrying loads. This result was consistent across all activity categories, these being PT, field training exercises and military operations. This finding supports the focus of load carriage research on locomotion tasks (For example, Attwells, et al. 2006; Blacker, et al. 2006; Knapik, et al. 1997). However, this study also identified an increase over the last decade in the frequency of load carriage tasks associated with vehicle mounted duties. This change may be due to several factors, including changes in operational theatres, equipment availability, and operational requirements. As an example of the impact of a change in operational theatres, certain areas on the outskirts of Kabul, Afghanistan, are only traversable by a mounted patrol as they are claimed to be associated with a high risk of harm from mines (Gimby, 2004). Changes in equipment availability to enable a shift from unmounted to

---

[76] Chapter 3: A Historical Review of Soldier Load Carriage, Section 3.3.4.

mounted tasks have also contributed. For example, the ADF Infantry Mobility Vehicle, or 'Bushmaster' was introduced mid-2004 (Hutcheson, 2003). Moreover, limited availability of air mobility assets increases the needed for land mobility and may have led to an increased need for vehicle mounted movement of soldiers (Coghlan, Gemmell, & Allen, 2008; Prince, 2009). Changes in operational requirements might also have contributed to the reported increase in the ratio of mounted to unmounted load carriage tasks: For example, in Afghanistan increased use of combined mounted and foot patrols as opposed to foot patrolling only has been used to move troops through mined areas and to provide protection from improvised explosive devices (Gimby, 2004). These factors may act in isolation or be interrelated. For example, the increased need for mounted patrols may be leading to the purchase of additional mobility vehicles, allowing for an increase in combined mounted and dismounted operations.

During vehicle mounted operations, soldiers could be expected to carry lighter loads. This was found to be the case in this study, where soldiers on mounted operations carried significantly lighter loads than dismounted soldiers on a foot patrol. However, while this research identified an increase in the frequency of vehicle mounted patrols, this trend may not be a significant influence on the load carriage context, as operational requirements are generally more important influences. As an example, Australian and coalition forces in the Iraq theatre predominantly conducted mounted operations, whereas the Afghanistan theatre has had a greater dismounted focus (Beidel, 2011; McPhedran, 2009b).

Duration

The durations of the load carriage tasks reported in this study varied widely. In general, the majority of recent load carriage tasks of less than three hours duration occurred as part of PT. Longer load carriage tasks occurred predominantly during field training or on military operations. During military operations, the majority of tasks lasting under an hour were of an administrative nature, whereas tasks lasting longer than an hour were predominantly foot patrols. Responses suggest that the majority of foot patrols last between 3 to 6 hours or for longer than 3 days, with the majority of mounted patrols likewise lasting for longer than 3 days. Available information on foot patrol durations in the current Afghanistan theatre (the key deployment region for the ARA) is that these last from several hours to several days, and in some cases for longer periods of up to 8 days (Beidel, 2011; Brown, et al., 2010; Montain, Koenig, & McGraw, 2005; US Army Sergeants Major Academy, 2007). These results demonstrate that, as noted in the historical review of soldier load carriage (Chapter 3), soldiers are still required to march for long periods while carrying load.

The current findings suggest that the significantly heavier operational loads (being heavier than PT and field training exercise loads) were being carried for long durations, sometimes up to several days. Furthermore, loads carried on foot for those long durations were significantly heavier than loads carried on mounted patrols. Conversely, during PT sessions, respondents reported carrying significantly lighter loads for less than 3 hours. These findings highlight the previously identified gap between load carriage preparation and operational load carriage requirements.

Terrain

Prior to discussing the terrains traversed during load carriage, it is important to note that, while respondents in the current survey identified the most common terrains traversed, this does not suggest that these were the only terrains traversed. It is possible that a variety of terrains were crossed over the duration of the operational deployment and even over a single load carriage event. As an example, foot patrols in Afghanistan have been reported to occur over a wide variety of terrains, within a single patrol (Brown, et al., 2010).

The reported nature of the terrain traversed while carrying loads varied. For the majority of respondents the most recent terrain traversed was light bush and mild hills. During PT, load carriage activities were more frequently conducted on roads or on dirt or grass over flat terrain or mild hills. Field training exercises were more frequently conducted in light bush over mild or steep hills. During military operations, foot patrolling was the dominant activity over mild to steep hills and through light to heavy bush and over rock. In the last decade, 24% of reported operational foot patrols while carrying loads traversed not only through heavy bush but also up steep hills. With the intent of PT being to physically condition the soldier to conduct field exercises and, together with field training exercises, to physically prepare the soldier to conduct military operations, these disconnects in load carriage terrains between the three activities are of importance. The literature review (Chapter 2) provided moderate evidence demonstrating the increased impact of both terrain type and level of incline on the physiological costs of load carriage on the soldier. As such, when comparing soldier load carriage during PT and on operations, it is clear that soldiers on operations typically have to contend with an increased physiological cost resulting from the increase in terrain grade (Crowder, et al., 2007; Lyons, et al., 2005), as well as the increased energy cost of moving through heavy bush (Soule & Goldman, 1972), whereas those undertaking load carriage in a PT context frequently do not. Potential causes of this training gap are discussed in Study C (Chapter 6).

The current study suggests that a further discrepancy existed between research protocols and soldier load carriage practices. Of the 145 original research papers meeting the inclusion criteria for the literature review (Chapter 2), only two (Soule & Goldman, 1972; Strydom, et al., 1966) had load carriers traversing terrains similar to those identified above. These two papers (Soule & Goldman, 1972; Strydom, et al., 1966) evaluated the impact of terrain types on energy costs specifically in order to establish predictive equations. As such, load carriage research into the impacts of soldier load carriage while negotiating some of the types of terrain that soldiers experience during training and operational tasks (like thick bush and loose sand) is lacking, with research typically conducted on treadmills(Abe, Muraki, & Yasukouchi, 2008b; Bhambhani & Maikala, 2000; Charteris, 2000; Stuempfle, et al., 2004), roads and dirt paths (Beekley, et al., 2007; Evans, Zerbib, Faria, & Monod, 1983; Knapik, et al., 1999; Patterson, et al., 2005; Ren, Jones, & Howard, 2005).

4.4.3. Does the current load carriage context vary in regard to corps or genders?

Corps Differences

This study highlights the fact that different corps carry out different primary tasks and as such different load carriage tasks as well. For instance, Infantry corps' load carriage tasks consisted predominantly of foot patrols whereas for Armoured corps respondents the majority of tasks were mounted patrols. The grouped 'other' corps most often were involved in administration tasks. There were some elements of crossover, whereby respondents from all corps reported conducting some load carriage associated with patrol or administration tasks. These findings support the view that different corps, although having some common duties, generally performed different ranges of tasks (Defence Science and Technology Organisation, 2009; Reynolds, 2002).

During field training exercises and on operations, differences were found between corps in both *absolute* and *relative* loads carried. Infantry and Engineer corps respondents reported carrying significantly heavier *absolute* loads than the grouped 'other' corps, both in general and during field training exercises. However, only Infantry respondents were found to be carrying a heavier *relative* load than the grouped 'other' corps. A potential reason for these differences in loads between corps lies not only in the differences in their core tasks, but also in the differences in field training exercises that each corps undertake to train for their core tasks. Conversely, no significant load differences were found between Artillery, Armoured, Infantry, Engineers, and Signals corps. This lack of differences may be due to the performance across these corps of common general tasks, like 'all corps training', or to the enforcement of set loading limits, whereby policy dictated a maximum load that could be carried within any of these corps. This latter possibility is considered in detail in Study D (Chapter 7).

During military operations, significant differences in *absolute* loads were found between the Combat Arms corps (Infantry, Engineers, Artillery and Armoured) and collective 'other' corps. However, in terms of *relative* loads, only Infantry, Engineer, and Artillery corps carried significantly heavier loads than the collective 'other corps' during operations. Once again, no significant differences in *absolute* or *relative* loads carried during military operations were found between respondents from the Infantry, Engineers, Artillery, Armoured, and Signals corps. A statistically significant difference was observed between loads carried on foot patrols and those carried during mounted patrols or administration tasks. On this basis, the differences in loads carried in Combat Arms corps and the grouped 'other corps' may stem in part from differences in the activities conducted by each corps. For example, infantry respondents, who generally reported carrying statistically heavier *absolute* loads than the grouped 'other corps', conducted the highest reported percentage of foot patrols. Thus the nature of the activity might influence the loads carried by each corps. In contrast, Armoured corps respondents reported carrying significantly heavier *absolute* loads than the grouped 'other' corps on operations, even though the majority of their tasks (mounted patrols) were associated with significantly lower *absolute* loads when compared to foot patrols. Based on these findings, different corps carried different loads, with Infantry consistently carrying heavier *absolute* and *relative* loads than the grouped 'other corps'. Corps-specific activities (for example foot patrols) could play a role in the differences in corps' loads.

Gender Differences

Female respondents reported carrying statistically lighter *absolute* loads than male respondents. However, when the *relative* loads were considered (that is, in relation to the respondent's body weight), no statistical differences were observed between the genders. The findings in the current study coincide with those of Lobb (2004). Lobb observed that male recreational backpackers self-reported carrying heavier *absolute* loads than female recreational backpackers. However, when the loads were considered in *relative* terms, no differences in loads were found, with both genders carrying similar mean *relative* loads of around 19% body weight. An analysis comparing the loads carried by the heavier 20% of male respondents with the loads carried by the lighter 20% of male respondents removed the potential for the differences to be due to differences in gender body weights.

Two reasons may explain why the *absolute* external loads carried by female respondents were lighter than those carried by male respondents. These reasons are (a) differences in tasks performed and (b) differences in equipment worn or carried. First, as previously determined, loads carried during administration tasks and mounted patrols while on military operations were significantly lighter than those carried on foot patrols, and notably more female respondents identified the former activities as their primary tasks. This difference between genders in task allocations is likely to have been due to a combination of differences in the main tasks of their respective corps and, as identified in the literature review (Chapter 2), government policies restricting the employment of women in combat roles. Second, fewer female respondents wore body armour or helmets, or carried a weapon. Most notably, only 8% of female respondents reported carrying additional stores in their hands, compared to 42% of male respondents. This lower frequency of stores carriage, and hence incidental load carriage, in female respondents may have been due to differences in the context in which the tasks were being performed. Administration tasks performed in a secure location might reduce the need for combat body armour and helmets to be worn, in contrast to administration tasks performed in a forward operating base location, which may be more exposed to enemy activity. Likewise, stores are more likely to be in situ. A final consideration may lie in the possibility that, when loads were distributed amongst soldiers, consideration was given to gender differences and, where possible, additional loads (like stores) were not distributed to female soldiers. This load selection process might be due to the previously identified male assumption that female soldiers are less capable of performing load carriage tasks due to physiological gender differences (Attwells & Hooper, 2005) or due to load carriage policy (explored in Study D). However, although this load selection process might be a factor in determining carried loads, it is potentially only a minor factor as, regardless of gender load carriage capability concerns, it is highly unlikely that the need to wear body armour and helmet or carry a weapon would be circumvented in order to address potential gender-related loading concerns. Neither of these two reasons would, however, account for the similar findings of Lobb (2004) in recreational backpackers and, on this basis, more research into this field may be of benefit.

The finding in the current study of no statistically significant difference in the reported *relative* loads carried by male and female soldiers is important, as it demonstrates that even though female soldiers are in general carrying lighter *absolute* loads, they are still carrying *relative* loads commensurate with their male counterparts. Increasing the *absolute* loads carried by the average female soldier to approximate the *absolute* loads being carried by male soldiers would impose a significantly heavier *relative* load on many female soldiers, and as such require a higher work effort (Gordon, et al., 1983; Quesada, et al., 2000). This is an issue that was already identified in the lightest 20% of male respondents. A final caution is that, even though current carried *relative* loads might be similar between genders, it does not mean that potential gender differences in energy costs are entirely negated. Scott and Ramanhai (2000a) observed that female participants, who were taxed 27% more in terms of heart rate than male participants when carrying an equivalent *absolute* load, were still taxed 24% more than their male counterparts when the loads were adjusted to be equivalent to a percentage of body weight. These female participants had a greater mean body fat mass (around eight kilograms greater) than their male counterparts. In other words, the average female soldier was carrying an additional eight kilograms of non-functional mass compared to the average male soldier in that study.

4.5. LIMITATIONS

This study had several limitations that merit discussion, these being (a) that data were limited to dominant features and averages, (b) low survey response rates, (c) self-reported load weights, and (d) the relatively small number of female respondents.

The goal of this study was to investigate the current load carriage context of the ARA. As such, data (like that of load carriage on a 9-month deployment) were captured in terms of the most dominant features (e.g. terrain) or in terms of averages (e.g. load, duration), and so some detail and variation in these features and measures would have been undetected. This limitation arose from the intention of the study being to capture a large volume of data across a variety of contexts, and over a specific period of time. With this current load carriage context now established by the current study, additional objective research might be warranted to enhance the field of knowledge with respect to further detail and variations in the load carriage context of ARA soldiers.

To reach a wide range of military personnel, an electronic online survey was used. Due to the nature of unit duties and the unit work rhythms, a relatively low overall survey response rate and particularly low survey response rates from some corps were experienced. This could have affected the representativeness of the data. While unit participation rates and survey response rates were sufficient to enable the study to establish an overview of the current load carriage context of the ARA, ideal unit participation rates and individual response rates would be higher. However, the nature of the population and its occupations does make this difficult.

Data were based on self-report. In regard to load weights, research has suggested that respondents tend to under-estimate actual load (Rice, Sharp, Williamson, & Nindl, 1992) and may find it difficult to estimate differences between heavy loads in lifting tasks (Karwowski, Shumate, Pongpatana, & Yates, 1989). To mitigate potential concerns of this nature, responses in this study were compared to other data and information derived from similar time frames and contexts, in order to enable consideration of response validity. No specific information regarding what constituted reported loads for specific corps was captured, nor information as to the nature of the specific duties performed by different corps during generic tasks. For example, with this study limited to four generic tasks, detailed differences in duties performed by Infantry and Engineer respondents during a foot patrol were not examined. For this reason, the findings regarding load differences between corps derived from this study, while constituting initial findings, would be enhanced by further research or alignment with ongoing studies in this area.

Finally, the results for gender, while providing some insights into gender-related impacts of load carriage and potential new directions for research, should be viewed with caution due to the relatively small number of female respondents (n=22; 7%).

4.6. SUMMARY AND CONCLUSION

Unlike other studies reported in the available literature, the current study was able to capture information regarding contemporary military loads carried during PT, field training exercises, and on military operations. Furthermore, information regarding the general context in which these loads were carried was captured. On this basis, future load carriage studies can now be better informed in relation not only to the loads currently carried by soldiers, but also to the context in which these loads are carried.

In the context of *relative* loading (that is, load relative to the carrier’s body weight), this study identified that some soldiers carried loads in excess of their body weight. This was found in several instances when individual loads were examined in the data. On this basis, the body weight of the load carrier might serve as a risk factor when heavier loads are carried. The risk potential is discussed in greater detail in Chapter 8.

With the loads currently carried by ARA soldiers now identified, the consequences of carrying these loads and questions regarding whether these loads pose a problem can be explored. The need to determine the impact of the Australian Army load carriage context, presented in this study, on the Australian soldier provides the impetus for Study B, Load Carriage and its Associated Risks for the Soldier (Chapter 5).

The current study also identified a potential training gap, whereby the loads carried and the context in which they were carried during PT, field training exercises, and on operational duties varied significantly. With PT used to prepare personnel for field training exercises and operational duties, and field training exercises likewise used to prepare personnel for operational duties, it is important that these load carriage training and development processes align. In this study, differences were found between the load weights, the natures of the loads carried, and the load carriage contexts (most notably durations and terrains) that characterised each process. To determine whether deficiencies in training do indeed exist, further research on PT was conducted and is reported in Study C, Soldier Load Carriage and Physical Training (Chapter 6).

This study also raised questions regarding load carriage doctrines and policies and their impact on the loads carried by soldiers, most notably for different corps and genders. These questions are addressed in Study D, Soldier Load Carriage and Policy (Chapter 7).

5. STUDY B: LOAD CARRIAGE AND ITS ASSOCIATED RISKS FOR THE SOLDIER

5.1. INTRODUCTION AND BRIEF REVIEW OF THE LITERATURE

As described in Chapter 1, risk can be defined as the chance of something happening that will have an adverse impact on objectives (Standards Australia Working Group MB-002-01, 2004b). In this instance, the objectives of interest are objectives of military load carriage events as well as the broader objectives of the ARA. Risk is often portrayed in terms of an event (e.g. load carriage) and the consequences that might flow from it (e.g. injury). Risk for an event can be measured as a combination of the potential consequences of the event and their likelihood of occurrence (Standards Australia Working Group MB-002-01, 2004c) or algebraically as 'Risk equals Severity multiplied by Likelihood' (Hughes & Ferrett, 2009).

The *event* described in the current program of research is contemporary military load carriage, the contexts of which are described in earlier chapters (Chapters 2 through 4). Evidence gathered in the historical review (Chapter 3) and Study A (Chapter 4) suggests that soldiers are now carrying more *absolute* load[77] than ever before during the event and that these loads are increasing. This raises the risk potential for load carriage events to impact on the soldier. Even though *relative* loads[78] have remained stable (around 55%)[79] this may still be excessive and have negative impacts on soldiers. History suggests that this might be the case. The Historical Review of the Soldier Load Carriage (Chapter 3) showed that soldiers undertaking load carriage activities over three millennia have incurred injuries. Moreover, historical evidence links load carriage to decreases in capability (Lothian, 1921; Marshall, 1980).

Current literature (Chapter 2) identifies load carriage tasks as having the potential to cause a variety of injuries to soldiers and potentially reduce their combat effectiveness (Knapik, et al., 2004).[80] It appears, therefore, that load carriage could increase risk both to the individual soldier and to other members of a unit. Injuries to soldiers during load carriage tasks have the potential to increase

---

[77] Load weight regardless of the body weight of the carrier.

[78] Load weight in relation to the body weight of the carrier, determined by load divided by body weight multiplied by 100%.

[79] Discussed in the Historical Review of Soldier Load Carriage (Chapter 3) and Study A (Chapter 4).

[80] Discussed in detail in the literature review (Chapter 2).

logistical workload (e.g. medical evacuation), and to reduce unit fire-power through loss of personnel. In combination with reduced performance (e.g. in mobility and marksmanship), load carriage has the potential to reduce both a unit's fighting strength and the combat effectiveness of remaining unit members. This in turn creates risks for mission success and may increase the risk of sustaining casualties.

The aim of the study reported in this chapter was to determine whether contemporary military load carriage is a source of injury and performance risk to the ARA. Consequently, this study informs the *Risk Identification* process of the Risk Management Framework (RMF).[81] The study aim was embodied in the following research questions:

- What are the frequencies, body sites, and mechanisms of load carriage injuries and what activities are commonly being performed at the times when these injuries occur?
- What impacts do soldiers perceive load carriage has on their combat performance?
- What are the consequences of injuries and performance impairments induced by load carriage on the soldier?

5.2. METHODS

5.2.1. Setting

The setting for this study was described in Study A (Chapter 4, Section 4.2.1.).

5.2.2. Research Design

The RMF, described in Chapter 1, forms the framework for this program of research. This study informs the second step in the RMF, being *Risk Identification* (Standards Australia Working Group MB-002-01, 2004a, 2004b, 2004c); in this instance, risks associated with the conduct of current Australian military load carriage tasks. The study reported in this chapter aimed to explore the risks associated with this load carriage context, which is described in Chapters 2 through 4 and Appendix A.

The survey research design employed in the current study and in Studies A, C and D was described in Study A (Chapter 4, Section 4.2.2). As well as the survey data, the cross-sectional design

---

[81] Discussed in detail in Chapter 1.

employed in this study also involved collection of injury data sourced through the Australian Defence Force Occupational Health, Safety and Compensation Analysis and Reporting (OHSCAR) database.

5.2.3. Approvals

Command approvals and ethics approvals for this research were described in Study A (Chapter 4, Sections 4.2.3 and 4.2.4).

5.2.4. Data Collection

As noted above, data for the findings reported in this chapter arose from two sources: survey data and reported injury data. Survey data were collected through the methods described in Study A (Chapter 4), as a component of the same survey that informed Study A. Injury data were sourced through the OHSCAR database.

Participants

The units and participants recruited for the survey to inform this study were described in Study A (Chapter 4, Section 4.2.5). OHSCAR data was drawn from the Australian Army population as described in Appendix A.

Survey Data

The Survey Design and Distribution

The survey design and distribution were described in Study A (Chapter 4, Section 4.2.5). The current study reports the findings from Questions 10, 19, 20 and 21 (Appendix G) of the survey, as they relate to the survey demographic data (Questions 1 and 2: Appendix G). The findings from Questions 4 and 6 (Appendix G) of the online survey questionnaire, which seek details of the respondent's most recent load carriage experience, were used as internal checks to confirm responses, a method described by Oppenheim (2001) to improve survey response reliability. In this instance, responses to Question 6 (Appendix G) regarding task performance in respondents reporting 'operational service' as their most recent load carriage activity (Question 4; Appendix G) were compared to data entered in response to Question 10 (Appendix G).

Injury Data

The ADF OHSCAR database was searched to identify all reported injuries sustained during load carriage over the period 01 January 2009 to 31 December 2010. This database is designed to capture all forms submitted in the notification and reporting of Occupational Health and Safety (OHS) incidents (Department of Defence, 2011b). An OHS incident is here classified as any accident or event that arises from the performance of Defence work (Department of Defence, 2011b). OHS incidents involve a wide range of qualifying classifications, ranging from '*dangerous occurrences which could have, but did not injure any person*' to '*serious personnel injury*' (Department of Defence, 2011b). Depending on the severity of the incident, legislated reporting time frames range from 1 to 28 days (Department of Defence, 2011b). The incident report form (titled AC563; Appendix I) is completed by the injured soldier or activity supervisor, and submitted to Defence OHS representatives who may add additional details such as medical assessment results (Department of Defence, 2011b).

Two mechanisms may be used to search the OHSCAR database: a search of the free text narrative fields in the database records, and searches of fields in the records which contain the Type of Occurrence Classification System (TOOCS) codes that best describe each incident. Within each incident record, the free text fields include descriptions of how the incident occurred, the nature of the injury or illness, and comments added by the supervisor. The TOOCS fields allow for searches to find all incident records containing specific TOOCS codes. Trained personnel manually code information relating to each incident and enter the resulting TOOCS data on the OHSCAR database.

In the current study, the free text field was used as the search medium to identify OHSCAR records of interest, rather than the TOOCS data fields. The TOOCS data fields were disregarded for two reasons. First, the TOOCS protocol codes incidents by the '*most serious injury or disease sustained*'(Australian Safety and Compensation Council, 2008). For example, an incident where a soldier trips over while carrying a heavy load and lacerates his hand on a rock would be coded as a laceration. In that instance, searching the TOOCS field codes would fail to identify injuries in which load carriage played a causal role. Second, the TOOCS activity field lacks the specificity (no load carriage oriented codes) required for this study, and searches of this field were likely to return results that were misleading or not valid. As an example, the TOOCS activity code 'marching' includes incidents arising during 'military drill', 'marching on parade', 'marching as a formed body', and 'endurance marching'. For these two reasons the free text of incident records was searched, both to improve the data capture of incidents in which load was carried but not recorded as the causal factor within the TOOCS-related fields and to minimise misleading and invalid results.

As access to the OHSCAR database is restricted, the database search was conducted by a third party database search operator following the submission of relevant request forms by the investigator. This process is considered to have improved the accuracy of the data extraction and minimised bias, as the third party was specifically qualified to conduct, and had experience in, interrogations of the OHSCAR database. The search terms used to search the free text fields were those commonly associated with contemporary military load carriage in the ARA. These terms were; ‘pack’, ‘webbing’, ‘patrol’, ‘patrol order’, ‘march’, ‘marching order’, ‘route march’, ‘endurance march’, ‘Combat Fitness Assessment’, ‘CFA’, ‘load’, ‘load carriage’ and ‘carry’. Discussions were held between the investigator and the trained third party database search operator to determine optimal search terminology to ensure maximal data capture. Data were collected for a 24-month period (2009 and 2010). Total ARA injury figures reported over this period were also requested.

5.2.5. Data Extraction

Survey Data

Data were extracted from the online survey by following the protocols described in Study A (Chapter 4, Section 4.2.6). Responses to questions 1, 2, 4, 6, 10, 19-21 were downloaded from the associated *SurveyMonkey* database as a Microsoft Office Excel (Microsoft, WA:USA, 2003) spreadsheet in order to address the research questions that underpinned this particular study.

Reported Injury Data

The raw OHSCAR incident data (with no identifying personal information) were manually cleaned by the investigator to ensure that only records of incidents relating to contemporary military load carriage were retained. Each line of data was reviewed by the investigator, who removed duplicate entries (same record entered twice) and records unrelated to load carriage (e.g. the term ‘load’ used to describe degree of weapon readiness). The remaining incident records were then subjected to the inclusion and exclusion criteria detailed in Table 14.

Table 14: OHSCAR Injury data inclusion and exclusion criteria.

	Inclusion Criteria	**Exclusion Criteria**
Service Type	ARA	Cadets Army Reserve Navy Air force Defence civilian
Incident Description	Injury occurred during a load carriage event, immediately after a load carriage event, or the day following a load carriage event, with no indication of intervening activity	Load carriage identified but injury associated with other mechanisms (e.g. running)
Casualty type	Serious personal injury Incapacity Minor injury	Exposure[82] Dangerous occurrence[83]

All TOOCS code fields (e.g. 'body location', 'mechanism') in the included injury records were then cleaned by comparing allocated TOOCS codes with free text descriptor data. When discrepancies were identified, precedence was given to the free text descriptors, as descriptions provided by incident reporters were considered more detailed and accurate than data entered by a third party using a finite coding system. Data were then recoded into the TOOCS data fields or amended TOOCS data fields (discussed below).

To increase data accuracy, brevity and sensitivity, two TOOCS fields were recoded, these being *body location* and *mechanism of injury*. Common *body locations* were grouped and generalised to region. For example, following review of the free text descriptors, 'neck and shoulder', 'neck bones, muscles and tendons', 'neck and trunk', and 'shoulder' were all coded under 'neck and shoulder'. This process was performed to improve data accuracy by removing some ambiguity over precise body locations of injuries. As an example, one injury coded under 'neck bones, muscles and tendons' was described as '*pain along the shoulder into the side of my neck'* in the free text descriptor field. By recoding the TOOCS data as 'neck and shoulder', data accuracy was presumed to increase. Additional categories were added following review of the free text descriptors to increase data specificity. These specific categories were added in instances where a specific body region, previously categorised under a general TOOCS code ('lower leg' for example), was mentioned in the free text descriptor fields in two or more separate incident records. Two examples are 'shin' (20 entries) and 'gastroc-soleus complex' (4 entries), each of which was previously listed under the more general term 'lower leg' in the TOOCS field. Overall, *body locations* were reduced

---

[82] Exposure data were removed as this information is used to describe exposure to workplace hazards (like noise or radiation) that does not immediately or shortly afterward lead to incidents of injury meeting the inclusion criteria for casualty type.
[83] Dangerous occurrence data were removed due to the data's subjective nature and failure to meet inclusion criteria for casualty type.

from 32 categories to 20 categories in the OHSCAR data set. The original TOOCS body location categories and the corresponding modified *body location* data categories used in this study are tabulated in Appendix J.

Several original TOOCS *mechanisms of injury* categories were also merged. Although this change decreased data specificity, merging the ‘mechanism’ categories into broader categories increased data accuracy and removed ambiguity. As an example, a data descriptor stating that a soldier had fallen with a pack and complained of an ankle injury was classified as a ‘fall from height’. By classifying incidents such as that example in a general ‘fall’ classification, uncertainty as to whether the fall was on the same level or from a height (which the available data could not elucidate) was removed. The original and the modified TOOCS *mechanisms of injury* categories used in this study are tabulated in Appendix J.

5.2.6. Data Analysis

Unit cooperation and survey response rate calculations were conducted using the methods reported in Study A (Chapter 4, Section 4.2.7) and were based on methods recommended by the ISER and AAPOR protocols (as described in Study A and Appendix H). Descriptive and inferential statistical analyses were employed to examine and identify the consequences of load carriage injuries, the frequencies of injuries sustained during load carriage across respondents’ military careers, the body sites of injury from load carriage tasks, the natures of load carriage injuries, the mechanisms of injuries, the activities being conducted at the times injuries occurred, and the relationships between loads carried and perceived impact on task performance. Before any comparative analyses were conducted, consideration was given to the assumption of normality by using the Kolmogorov-Smirnov test and the assumption of homogeneity of variances by using Levene’s test. Student t-tests were used to compare continuous data between two groups (e.g. load weight by activity) and a Chi-square test for independence was employed for comparing frequencies of nominal data across data sets (e.g. proportional representations of particular body sites of injury for survey injury data compared to those for OHSCAR injury data). Analysis of variance (ANOVA) was employed to compare continuous data between three or more groups or categories (e.g. load weight by site of injury). An analysis of variance (ANOVA) was employed to compare data between three or more groups (e.g. load weight by corps group) and if significant, Bonferroni post-hoc tests for multiple comparisons were used to determine where the differences lay. When there were significant differences in variances between samples being compared, t-tests assuming unequal variances or Dunnett’s C comparisons were used.

Response data from the 5-point Likert Scales (Questions 6 and 10) of the survey questions used in the current study were recoded into scores ranging from -2 (notable reduction) to +2 (notable improvement), with a score of zero assigned to a response of *no change*. This allowed representation of mean data per performance category to reflect either a negative or a positive impact, or no impact.

Data were analysed using the IBM Statistical Package for the Social Sciences (SPSS) Statistics Version 19.0 for Macintosh and Windows (SPSS Inc., Delaware:USA, 2010) with the level of statistical significance set at 0.05.

Measure for reporting the level of injury

Two common measures for reporting the level of injury are injury *incidence* and injury *prevalence* (Whyte, Harries, & Williams, 2005). Injury incidence refers to the number of injuries per unit of exposure (typically time) in a given cohort size, for example 20 injuries per 1000 soldiers per 1000 hours of engagement in a specific activity type (Caine, Caine, & Maffulli, 2006; Whyte, et al., 2005). The number of injuries may be restricted to new injuries (Turnock, 2009), may include both new and recurrent injuries (Whyte, et al., 2005) or may represent an overall number of injuries (Caine, et al., 2006). Injury prevalence refers to the percentage of a population injured at a specific point in time, for example an injury prevalence of 20% (6 of 30 personnel are carrying injuries) (Caine, et al., 2006; Whyte, et al., 2005).

For the current study, the frequency of load carriage injuries sustained by soldiers across their military careers was estimated from the survey data, rather than using a pure measure of injury incidence or injury prevalence, in order to provide a clear picture of soldiers' experiences of load carriage injuries across their careers. Pure injury incidence rates could not be calculated from the available data, due to inability to capture reliable measures of exposure to the source of the injury risk (load carriage in this instance). The capture of load carriage frequency and duration data for all soldiers was beyond the scope of this study and would have depended, unrealistically, on accurate recall by soldiers of load carriage events in which they had participated over many years. The aim of this study was to inform the *Risk Identification* process of the Risk Management Framework (RMF)[84] by determining whether contemporary military load carriage was a source of injury and performance risk in the ARA. Therefore, pure injury prevalence measures were less useful than a measure of career-long injury experience from load carriage. On this basis, a clear picture of load

---

[84] Discussed in detail in Chapter 1.

carriage injury experiences across the respondents' careers was more useful than a point-in-time measure.

The formula for estimating load carriage injury frequency per 1000 person-years of military service (LCIF per 1000yrs), across survey respondents, was adapted from the method used by Whyte, et al. (2005, p. 3) to calculate injury incidence, and can be expressed as:

> LCIF per 1000yrs=total number of injuries reported by all survey respondents / sum of the number of years of military service of survey respondents x 1000

One acknowledged source of error in this estimate was recall bias in respondents (Coughlin, 1990), who were likely to have forgotten some of the injuries they might have suffered during their military careers. However, this error ensured that the load carriage injury frequency estimates derived from the formula were conservative, and the resulting estimate remained valuable as it provided an estimate of the frequency of significant load carriage injury events which had occurred over the military careers of the survey respondents.

The ability to calculate injury prevalence or injury experience prevalence from the OHSCAR reported injury data was severely limited by fluctuations in ARA and individual unit sizes over the data capture period (2009 and 2010), with the ability to capture detachment to other services, transfers to and from reserve units, rates of joining and discharge and periods of leave being beyond the scope of this study. These difficulties meant that reasonably accurate denominator (population size) data was not available to inform such calculations. For this reason, OHSCAR injury data were analysed and reported descriptively, in terms of total numbers of reported injuries and percentages of total reported injuries represented by a particular category of injury in the defined populations in a given time period, for example 8% of all reported body stressing injuries reported by the population in the period 2009 and 2010.

To calculate the percentages of all injuries represented by injuries to particular body sites, the numbers of injuries reported for a specific body site were divided by the total number of injuries reported in the respective study and then multiplied by 100%. The use of these percentages permitted comparison of injury body site profiles between studies, catering for differences in research approaches. For example, the current study reported ARA soldier injuries based on the soldiers' experiences of injury across their whole career whereas the studies of Knapik (1992) and Reynolds, et al. (1999) reported injury incidents associated with a single load carriage event lasting either 1 or 5-days.

5.3. RESULTS

5.3.1. Survey Results

Unit Participation and Survey Response Rates

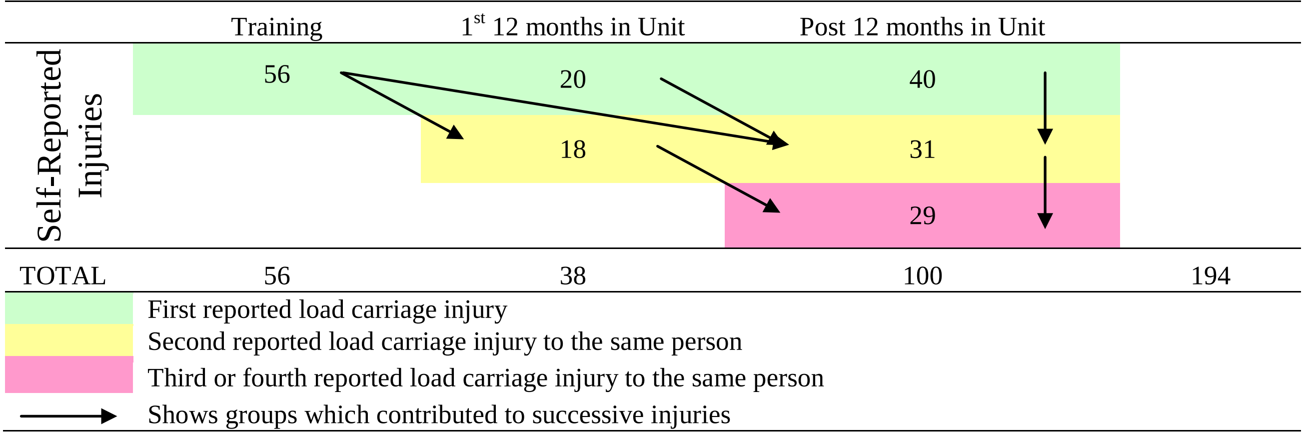
Unit participation and survey response rates were described in Study A (Chapter 4, Section 4.3.1). The demographic characteristics of survey respondents were described in Study A (Chapter 4, Section 4.3.1, Table 3).

Self-Reported Load Carriage Injuries

Frequency and Distribution of Self-Reported Load Carriage Injuries

Of the 338 survey respondents, 116 (34%) reported sustaining at least one injury during a load carriage event at some stage during their military career.[85] With some of these survey respondents sustaining more than one injury, 194 injury records were captured in the survey, giving an estimated load carriage injury frequency (LCIF) of 104.1 load carriage injuries per 1000 respondent-years of military service. The distributions across time of the self-reported load carriage injuries sustained by survey respondents are shown in Figure 9.

Figure 9: Self-reported injuries by time period.



---

[85] Reported career spans in this population group ranged from 1 year to over 30 years. Based on the age of the oldest respondent [56 years] and the minimum recruiting age of the Australian Army [17 years], the maximum possible period of service was considered to be 39 years.

Among the 116 respondents reporting load-carriage injuries:

- 8% (*n*=9) were female soldiers and 92% (*n*=107) were male soldiers. This gender distribution of those reporting injuries was similar to the gender distribution of all survey respondents (female=7%, *n*=22; male=93%, *n*=316).
- 48% (*n*=56) of respondents reporting having suffered at least one load carriage injury during initial training. Of these respondents:
  - 52% (n=29) reported sustaining an additional injury (to the same or another body site).
  - 32% (*n*=18) reported sustaining an additional injury (to the same or another body site) within the first 12 months of unit service.
- 42% (*n*=49) of respondents reported sustaining more than one load carriage injury:
  - Of these respondents, 43% (*n*=21) reinjured the same body site, 31% (*n*=15) reinjured a different site, and 27% (*n*=13) reinjured both the same site and another body site.
- Mean self-reported loads were 29.5 kg (*SD*=13.6 kg) or 35% BW (*SD*=12%).

Body Sites of Self-Reported Load Carriage Injuries

Overall, 61% (*n*=118) of the self-reported injuries were to the lower limbs, 27% (*n*=52) of injuries were to the back, 9% (*n*=18) of injuries were to the upper limbs, 3% (*n*=5) were to the abdomen and hip and 1% (*n*=1) was to the head.[86] Of these injuries the lower leg[87] (*n*=46, 24%) and lower back (*n*=45, 23%) were the leading body sites of self-reported injury, followed by the ankle, and foot (see Figure 10).

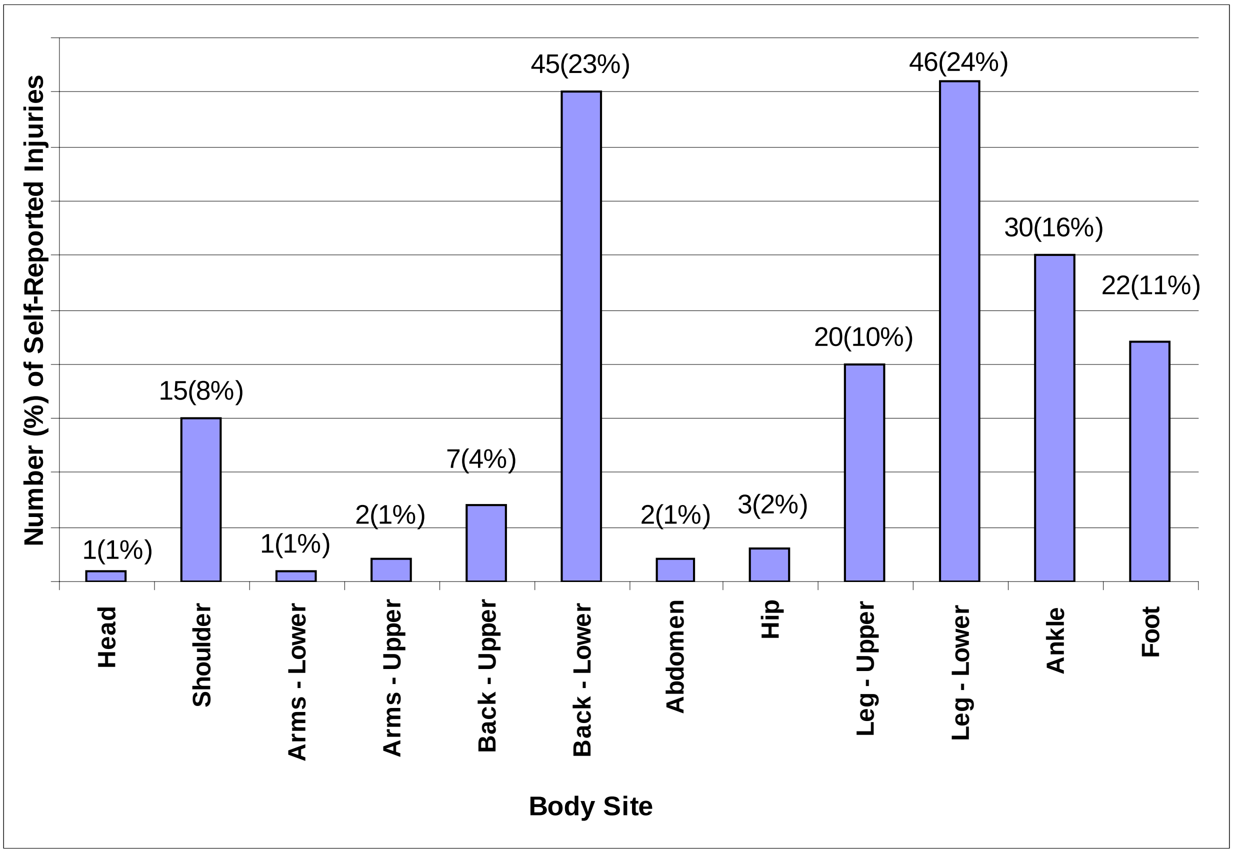
Nature of Self-Reported Load Carriage Injuries

Bones and joints were the most frequently injured body structures (39% of injuries, *n*=76), and another third of injuries were reportedly to muscles and tendons (36%, *n*=70). Ligaments accounted for an additional 15% of injuries (*n*=29), followed by ‘other’ structures (6%, *n*=12). Skin (being foot blisters) accounted for the remaining injuries (4%, *n*=7). Overall, soft tissue injuries accounted for 55% of the self-reported injuries (*n*=106). An ANOVA found no significant differences between groups of injuries formed on the basis of which structures were injured in the mean self-reported loads carried by the injured respondents at the time of injury (F(4,186)=2.03, p=0.92).

---

[86] Total does not equal 100% due to rounding.
[87] In this instance, lower leg refers to the shank and excludes the ankle or foot.

Figure 10: Histogram of self-reported load carriage injuries by body site.



Activities Conducted at the Time of the Self-Reported Load Carriage Injuries

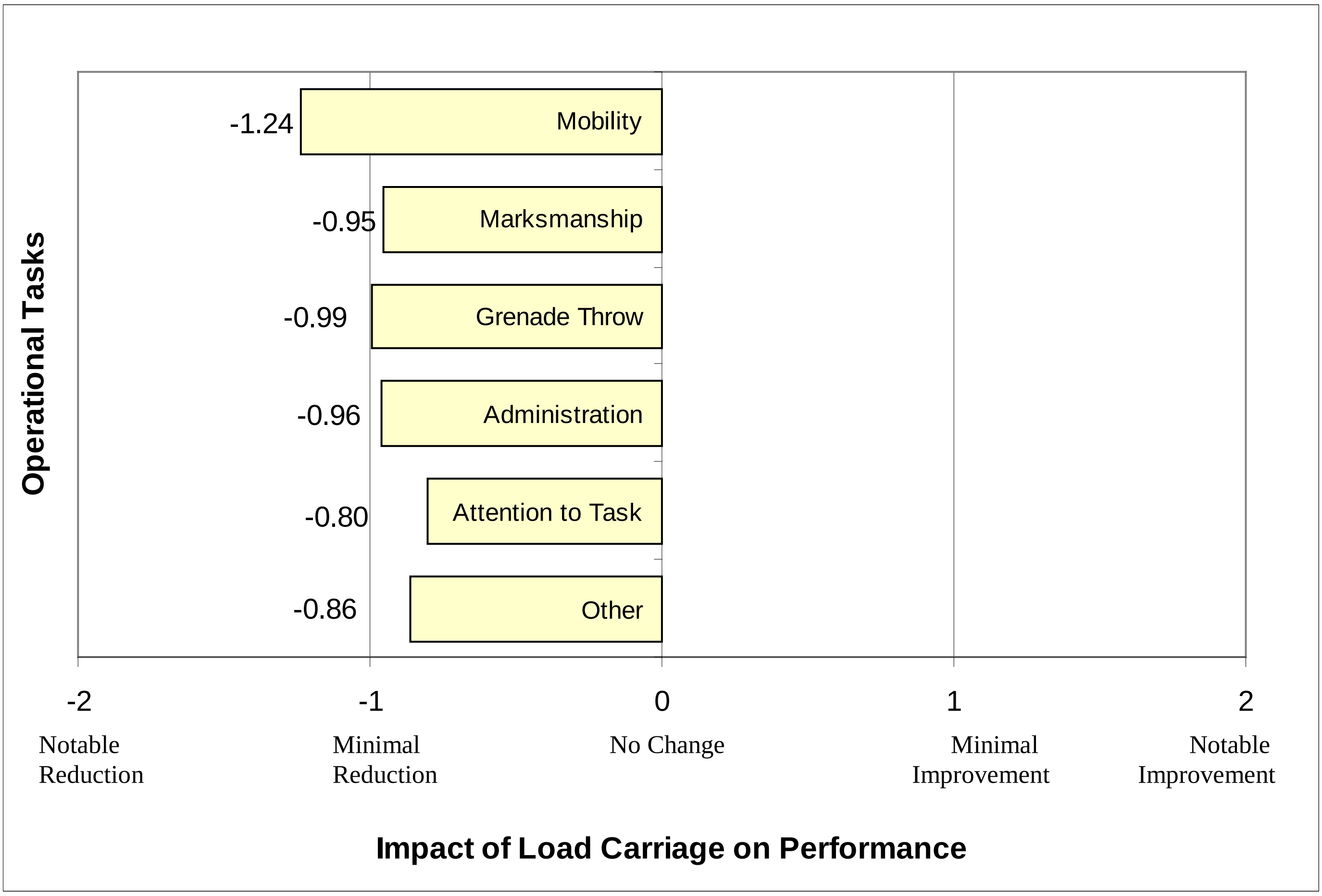
Field training exercises reportedly accounted for 28% (*n*=55) of load carriage injuries and physical training (PT) a further 14% (*n*=27). Endurance marching, which can be conducted as part of PT or a field training exercise, accounted for the highest frequency of load carriage injuries (38%, *n*=73). ‘Other’ activities accounted for the remaining 20% of injuries (*n*=39). Further analysis revealed:

- 86% (*n*=6) of foot blisters occurred during endurance marching.
- Field exercises accounted for 40% (*n*=12) of ankle injuries occurring during load carriage.

Self-Reported Impact of Load Carriage on Operational Performance

Load carriage was reported as having a negative impact on all five operational tasks (mobility, marksmanship, grenade throw, administration and attention-to-task) about which survey respondents were specifically questioned. When mean scores for each task were determined, mobility was the activity to which respondents assigned the greatest negative impact score of -1.24, indicating that respondents perceived load carriage to cause more than a minimal reduction in performance capability for this task. While still recording a negative impact score, attention to task was assigned the lowest negative impact score, at -0.80. The mean load carriage impact scores for all five tasks are graphically represented in Figure 11.

Figure 11: Self-reported mean ratings of the impact of load carriage on operational task performance.



Of the five described tasks, mobility was considered to be the task most affected by load carriage. Forty-two percent of the respondents who provided a rating for this task considered load carriage to have caused a *notable reduction* to their mobility with a further 37% claiming a *minimal reduction*. The majority of remaining respondents (16%) claimed that load carriage had no negative impact on their mobility, with less than 1% claiming that load carriage led to a *minimal improvement* in their mobility.[88]

For both lethality tasks (marksmanship and grenade throwing performance), respondents most frequently considered that load carriage caused a *minimal reduction* in performance (37% and 30% of respondents, respectively) with a *notable reduction* being the second most common response (24% and 20%, respectively). A slightly higher percentage of respondents reporting perceived impacts of load carriage on lethality task performance, when compared to responses regarding mobility task performance, considered that load carriage had no impact on their lethality skills (24% and 18% respectively). Again, less than 1% of respondents reported that load carriage tasks

---

[88] Four percent of respondents answered that the mobility task performance was not applicable. This might be the case in soldiers who performed the majority of their tasks in vehicles, aircraft or in a command post.

improved their marksmanship, and no respondents reported perceived improvements in their grenade throwing ability. Of note, grenade throwing ability was associated with the highest number of respondents (31%) to mark this task as ‘not applicable’.[89]

As with previous task ratings, the majority of respondents considered load carriage to have a negative impact on their performance of administration tasks, with 50% claiming a *minimal reduction* and 24% a *notable reduction* in their capacity to perform this task. Twenty-three percent considered load carriage to have no impact on their administration task performance. Among all the tasks surveyed, administration tasks had the highest number of respondents reporting that load carriage had a positive impact on their performance, though the numbers were still very low (2%, *n*=5).

In relation to ‘attention to task’, responses were again similar. The majority of respondents reported that load carriage had a negative impact on their attention to task, with 43% claiming a *minimal reduction* and 18% a *notable reduction.* Meanwhile 1% claimed a *minimal improvement* in task performance and 5% considered this task *not applicable*. This task had the highest number of respondents (33%) claim that load carriage had no impact on their performance.

Of the 107 responders provided a rating for the ‘other’ category, 70 (65%) considered the impacts of load to be negative with a mean rating of -0.86. Comments supplied listed driving, moving in and out of vehicles and performing tasks in narrow spaces (like searching, operating vehicle mounted weapon systems, and repairing vehicles). Of the remaining responders, 32% (n=34) considered that any ‘other’ tasks were unaffected by load carriage while 3% (n=3) considered their ability to perform ‘other’ tasks improved. None of these responders (‘no change’ or improved performance) provided any comments regarding the tasks they were performing.

5.3.2. OHSCAR-Reported Load Carriage Injuries

Numbers and Distributions of Recorded Load Carriage Injuries

A total of 1, 954 injury records were extracted from the OHSCAR database using the predefined search terms, for the chosen period of 1 January 2009 to 31 December 2010. Manual cleaning removed 16 repeated entries and 112 records for persons from an unknown military service. Implementation of the planned inclusion and exclusion criteria to ensure that only load carriage related injury records were retained resulted in a total of 404 such records being retained. These 404

---

[89] Fourteen percent of respondents answered that marksmanship performance was not applicable. This may be the case for soldiers who did not engage the enemy with small arms fire (rifle, machine gun etc) while on operations.

load carriage related injury records represented 8% of the total 5, 188 OHSCAR injury records that represented ARA injuries sustained between 1 January 2009 and 31 December 2010 which resulted from *body stressing.*[90]

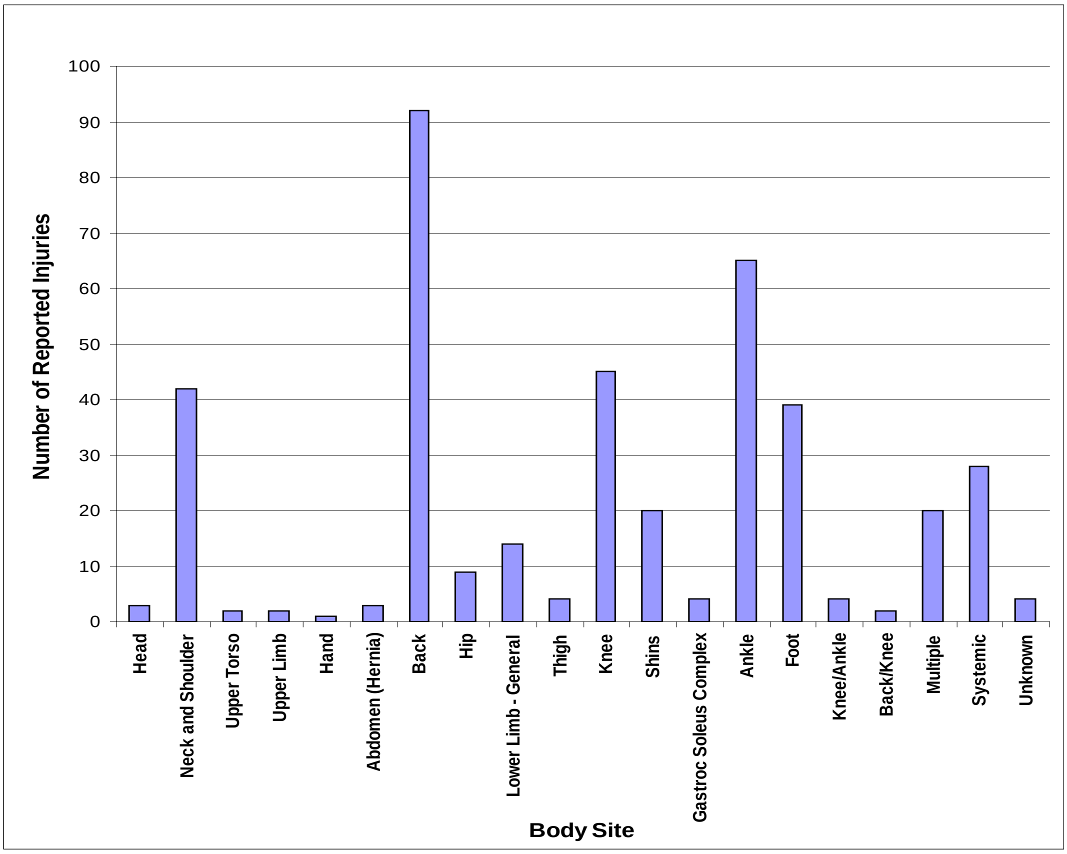
Among the 404 load carriage injuries reported on the OHSCAR database:

- 10% (*n*=38 of 392[91]) were sustained by female soldiers and 90% (*n*=354 of 392) were sustained by male soldiers. This ratio is commensurate with the gender ratio across the ARA population as a whole (2007–2009), being 10% female and 90% male (Khosa, 2010).
- 91% (*n*=369) were classified as *minor injuries*,[92] 1% (*n*=6) as *incapacity*,[93] and 7% (*n*=29) as a *serious personal injury* (SPI).[94]

Body Sites of OHSCAR-Recorded Load Carriage Injuries

The distribution of these injuries, by body sites, is shown in Figure 12.

Figure 12: Histogram of OHSCAR-reported ARA load carriage injuries (2009-2010) by body site.



---

[90] In this instance *body stressing* relates to injuries caused by physical stress to the body.
[91] 12 data records did not include gender.
[92] Non-emergency treatment, every injury not a 'serious personal injury'.
[93] Unable to work for more than 30 consecutive days.
[94] Requiring emergency medical treatment, includes all fractures.

The back was the leading site of injury (*n*=92, 23%) followed by the ankle, knee, and neck and shoulder. Of these reported injuries:

- 57% (*n*=52) of back injuries were specifically noted to be lower back injuries. This equated to 13% of all included load carriage injuries.
- When common body sites were aggregated in a manner comparable with that used in reporting the survey results (e.g. lower limb–general, thigh, knee, etc.), 56% (*n*=195) of injuries were noted to affect the lower limbs, 26% (*n*=92) affected the back, and 13% (*n*=45) were to the upper limbs. In addition, 3% (*n*=9) were to the pelvis, 1% to both the head and abdominal region (*n*=3) and less than 1% (*n*=2) were to the upper torso.[95]
- A Chi-Square test for independence to assess differences between survey respondent injury data covering the period 1990 to 2010 and OHSCAR injury records over the period 2009 and 2010 in distributions of the body sites of injuries found no significant difference in the distributions of aggregated body injury sites, $\chi^2(6)=3.90$, $p=0.31$.[96]

Nature of Recorded Load Carriage Injuries

Numerous inconsistencies between the TOOCS-coded 'nature of injury' data items and associated free text descriptors were identified in the OHSCAR dataset. Furthermore, the detail of information provided in the free text was insufficient to enable 'recoding' of the data. As an example, one entry, which was TOOCS-coded as a fracture, had the free text descriptor report that the pain in the patient's legs dispersed after an hour and the member continued the activity. That incident was classified as a minor injury caused by muscular stress. The majority of the TOOCS 'nature of injury' data were excluded from analysis on the basis that analysis results would possess limited reliability. One reliable data subset could be retrieved, however, that being for foot blisters, which accounted for 54% (*n*=21) of foot injuries and 5% of load carriage injuries overall.

Mechanisms of Recorded Load Carriage Injuries

The reported mechanisms of load carriage injury incidents in records extracted from the OHSCAR database are shown in Table 15, using modified categories.

---

[95] The following sites were not included in the comparison as they had no comparable survey equivalent: 28 systemic injuries, 20 multiple sites of injuries, 5 unknown injuries and 2 back and knee injuries (i.e. multiple sites).

[96] Systemic injuries from OHSCAR were not included in the analysis as this injury choice was not available to the survey respondents.

Table 15: OHSCAR-reported mechanisms of load carriage injuries for the period 2009 and 2010.

Mechanism of Load Carriage Injuries	Number of reported injuries
Muscular stress	251
Fall	85
Exposure to environmental heat	28
Rubbing and chafing	21
Stepping kneeling or sitting on objects	9
Unspecified mechanisms of injury	3
Contact with moving or stationary object	4
Other and multiple mechanisms of injury	2
Being trapped between stationary and moving object	1
TOTAL	**404**

Among the reported load carriage injuries:

- 77% (*n*=50) of ankle injuries were classed as 'rolled' or 'twisted' ankles due to misstep and tripping. Of these injuries, 78% listed 'fall' as the principle mechanism of injury.
- 100% (*n*=21) of 'rubbing and chafing' injuries were foot blisters.
- 4% (*n*=16) of the load carriage injuries were attributed to putting on or taking off load carriage equipment.
- 100% (*n*=28) of heat-related injuries, constituting 7% of all injuries and 31% (*n*=9) of SPIs, were reportedly caused by 'exposure to environmental heat' during a load carriage event.

Activities Conducted at the Time of the Recorded Load Carriage Injuries

Marching was reported as the most common activity being conducted at the time when load carriage injuries occurred (62%, *n*=249), followed by patrolling (13%, *n*=54), combat training (12%, *n*=47)[97] and PT (6%, *n*=23). Of the remaining injuries, 5% (*n*=19) were attributed to manual handling, and 1% to boarding a vehicle and walking (*n*=3), respectively. 'Unknown' or 'other' activities constituted 1% (*n*=6) of the activities being conducted at the time of injury.[98]

5.4. DISCUSSION

Load carriage activities performed by ARA soldiers have led to self-reported and recorded injuries and were perceived by soldiers to reduce soldier combat performance. The majority of the load carriage injuries discussed in the results section of this chapter involved either lower limb or back, with bones and joints accounting for the most frequently reported injured body structures. Field and operational activities were the leading activities being performed at the time that load carriage

---

[97] Together *patrolling* and *combat training* constitute field training and equated to 25% (*n*=101) of reported injuries.

[98] Total does not equal 100% due to rounding.

injuries occurred, and muscular stress was identified as the mechanism of injury for over half of reported load carriage injuries. The survey responses from soldiers also indicate a clear soldier perception that the loads they carried reduced their ability to perform five key tasks (attention to task, marksmanship, grenade throwing, general duties and mobility) while on operational duties.

5.4.1. What are the frequencies, body sites, and mechanisms of load carriage injuries and what activities are commonly being performed at the times when these injuries occur?

The study found that load carriage had the potential to cause a variety of soldier injuries. ARA load carriage accounted for 8% of all OHSCAR-recorded ‘body stressing’ injuries over the 2009 to 2010 period. In addition, just over a third (34%) of survey respondents reported suffering at least one injury while undertaking load carriage activities during their military careers. The mean self-reported load carried by the survey respondents at the times when load carriage injuries occurred was 29.5 kg or 35% body weight. The lower limbs were the leading sites of reported injuries, and the overall reported distribution of body sites of injury was commensurate with the distributions noted in the literature review (Chapter 2) to be typical of load carriage events and in the general military population (Lobb, 2004; Reynolds, et al., 1999; Knapik, et al. 1992).

In the study, 116 (34%) of the 338 survey respondents reported having experienced at least one load carriage injury during their military careers, and a total of 194 injuries were experienced by these 116 respondents. These numbers are proportionally lower than the lifetime injury experiences reported by Lobb (2004) when she surveyed hikers in New Zealand. In the study by Lobb (2004), 520 (74%) of the 702 survey respondents reported having experienced an injury while hiking, at some time in their lives. A potential reason for this higher lifetime frequency of reported injuries in the hiking population might be their exposure to load carriage events, as measured by total years of exposure, and frequency and duration of events within exposed years. The survey of Australian Army soldiers reported in Study A (Chapter 4) identified that 66% of respondents reported participating in load carriage events that lasted for less than 3 hours, 12% lasted for 6 to 12 hours, 3% for 12 to 24 hours and 18% lasted for more than one day. Conversely, the hiking population surveyed by Lobb (2004) included 2% of respondents who claimed to carry their loads for less than 2 hours per day when hiking, 39% for 2 to 5 hours per day and 59% for over 5 hours per day. Of these hiking respondents, 43% reported carrying loads for a single day when hiking, and 47%

reported carrying loads for 2 to 3 days and 10% for 4 to 8 days.[99] Despite these differences, in the absence of further comparable data on the exposure of both military respondents and hikers to load carriage over their lifetimes, it is impossible to estimate the level to which differential exposure might have contributed to the difference between these populations in load carriage injury frequencies. Differences between the two populations in distribution of demographic factors (such as nationality, age, and fitness) and the nature of the activity (terrain and speed of movement as examples) may have also contributed to the differences in injury findings. Finally, the mean *relative* load reported in this study as carried by Australian Army soldiers at the time of injury was 35% of body weight. This mean *relative* load is higher than the mean *relative* load of 19% of body weight reported for hikers by Lobb (2004), although it must be noted that the loads reported by Lobb (2004) were generalised to the hiking activity and were not necessarily the loads being carried at the time of injury. Nevertheless, the aforementioned differences between the two groups in load carriage contexts and carrier characteristics (including factors like age, fitness and terrain), together with possible differences in levels of load carriage exposure, may have contributed to the lower lifetime frequency of injuries reported in this study despite the heavier mean *relative* loads.

The injury frequency figures from this study were reasonably consistent with the figures reported for military load carriage events in other nations (in this instance the United States of America) by Knapik, et al. (1992) and Reynolds, et al. (1999). It is acknowledged that the observed frequency of injury experiences during military load carriage in this current study (34%; 116 respondents of the 338 survey respondents) was based on soldier experiences of injury across their whole career. On the other hand, Knapik, et al. (1992) reported a 24% injury incidence rate (79 soldiers of 335 soldiers injured) for infantry soldiers carrying a load of 46 kg on a 20-km maximal effort load carriage march, and Reynolds, et al. (1999) reported an injury incidence rate of 36% in infantry soldiers (78 soldiers of 218 soldiers injured) carrying a load of 47 kg while marching 161 km over a 5-day period. These injury frequencies, each based on a single load carriage event, would seem to be high in comparison to the career-long injury frequencies reported by Australian soldiers in the current study. Several potential reasons for the higher injury frequencies reported in the studies of Knapik, et al. (1992) and Reynolds, et al. (1999) exist, including reporting practices and study methods, which might affect the reporting of certain injuries, like foot blisters (discussed in greater detail in the paragraphs below).

---

[99] 1% of hikers reported carrying loads for over 8 days.

With no significant difference observed in the distributions of body sites of injury between the survey data (across respondent careers, which ranged up to more than 20 years) and OHSCAR records (a 2-year period), the distributions of load carriage injuries in ARA soldiers across the body suggest a consistent trend over time. Furthermore, injury body site data from the survey and OHSCAR database in the current study corresponded with injury body site findings within both specific load carriage studies (Knapik, et al., 1992; Reynolds, et al., 1999) and studies of general military training (Almeida, et al., 1999; Jennings, et al., 2008; O'Connor, 2000), suggesting consistency across contexts of load carriage, as well as across time. In the current study, the lower limbs were attributed with the highest reported proportions of both self-reported (61%) and formally reported (56%) injuries. A high proportion of lower leg injuries is consistent with studies of single load carriage events (Knapik, et al., 1992; Reynolds, et al., 1999), of military personnel in general (Almeida, et al., 1999; Jennings, et al., 2008; O'Connor, 2000), of ADF personnel specifically (Defence Health Services Branch, 2000), and of recreational hikers (Lobb, 2004).

In the aggregated injury body site data, the back was associated with the second highest proportion of reported injuries. In the survey data, the lower back was the site of 23% of all injuries and was identified as the second most frequently reported site of injury (after the lower leg). In the OHSCAR data, the back presented as the leading site of injury (followed by the ankle), with 57% of back injuries (13% of all injury cases) attributed to the lower back specifically. Given the biomechanical impacts of load carriage on the spine, such as increased lumbar compression and shear forces, changes to thoraco-pelvic rhythm and increased forward lean (Attwells, et al., 2006; Fowler, Rodacki, & Rodacki, 2006; Majumdar & Pal, 2010; Meakin, et al., 2008), the high proportion of lower back injuries was not unexpected. Differences between the results of the current study and those of other injury studies (Lobb, 2004; Knapik, et al., 1992; Reynolds, et al., 1999) are also evident, most notably in the proportions of ankle injuries, foot blisters, and environmental injuries.

Ankle injuries in this study represented 16% of all reported injuries (for both survey data and for OHSCAR records), with 77% of these injuries described as ‘rolled’ or ‘twisted’ ankles in the OHSCAR free text narratives. Conversely, studies by Knapik, et al. (1992) and Reynolds, et al. (1999), reporting injuries sustained during a specific load carriage event, observed lower proportions of ankle injuries. In the study of Knapik, et al. (1992), 6% of all injuries were determined to be ankle and knee sprains. Similarly, Reynolds, et al. (1999) reported 5% of all injuries to be injuries to the ankle. From a non-military perspective, 28% of all injuries reported by New Zealand hikers in the study by Lobb (2004) were to the ankle. A potential reason for these differences in injury site proportions comes from the contextual environments of the studies. Whereas the studies of Knapik, et al. (1992) and Reynolds, et al. (1999) observed load carriage on formed roads or dirt paths during a single marching event, the results of the current study captured incidents across all terrains during events ranging from endurance marching to patrolling. This hypothesis regarding the potential role of terrain and task type in determining ankle injury rates is strengthened by the fact that 77% of the ankle injuries observed in the current study were attributed to a 'trip' as the mechanism of injury. Lobb (2004) did not provide any information regarding the terrain covered by the hikers she surveyed.

The literature review (Chapter 2) identified blisters as the primary concern for military marching (Knapik, et al., 1995; Reynolds, 2000). In the current study, 4% of injury self-reports and 5% of OHSCAR injury records were due to foot blisters. These proportions of foot blister injuries are similar to those observed by Lobb (2004) (6.8%) although notably lower than the proportions reported by Knapik, et al. (1998; 1992) and Reynolds, et al. (1999), being between 32% and 48% of all reported injuries. Several potential reasons for these differences in blister proportions exist, including reporting practices, differences in the nature of load carriage activities and study methods, and additional risk factors. Data capture in the current study was achieved through both self-reports of load carriage injuries and formal injury records. OHSCAR injury surveillance is based on OHS incidents and, as such, not all injuries may be reported. For example, a soldier who suffers foot blistering from an endurance march during a PT session might self-manage the incident or seek treatment without ever completing an injury report form (AC 563 form). Furthermore, soldiers themselves might not consider blisters to be an injury or an injury serious enough to seek medical attention (Knapik, et al., 1992) and, as such, few soldiers might have listed foot blistering as an injury in the current survey or when proactively reporting an injury. The same reasoning could apply to the lower proportion of blister injuries identified by Lobb (2004). Finally, the study methods of Knapik, et al. (1992; 1998) and Reynolds, et al. (1999) provided a greater opportunity to capture data on blister injuries, with their studies including some measure of active medical assessments following the assessment. Medical staff documented injuries during or immediately following the march; thus respondents were not asked to remember suffering a blister at some time during their military career (as in the current study) or during their years of hiking (Lobb, 2004).

Differences in military demographics might also have contributed, albeit in a limited capacity, to differences in blister injury proportions between studies. Variability in equipment (boots, sock type, etc.) has the potential to confound comparisons of blistering injuries (Knapik, et al., 1995), as do cultural differences. The respondents in this study were Australian whereas the participants in the studies of Knapik, et al. (1992) and Reynolds, et al. (1999) were American. On this basis, other risk factors associated with blister injuries (detailed in Chapter 2), which include ethnicity and smokeless tobacco (Knapik, et al., 1999; Reynolds, et al., 1999), might have contributed to differences in blister presentation rates.

The notable number of environmental heat-related injuries observed in the current study was unexpected. No other studies were found to have reported this injury type associated with load carriage (Chapter 2). Although accounting for only 7% of reported injuries, heat-related injuries accounted for 31% of all reported SPIs in the data captured. With heat-related injuries having previously caused fatalities in military personnel in the ARA (Rudzki, 2009) and foreign defence forces (Carter III, Cheuvront, Williams, et al., 2005), this finding is of particular concern and is discussed in greater detail subsequently.

Mechanisms of Reported Load Carriage Injuries

Although muscular stress was identified in the current study as the leading mechanism of injury during load carriage (62%), several other mechanisms were associated with injuries identified in this study. In the 7% of injuries that constituted the heat-related injuries discussed in the previous paragraph, all 28 cases listed exposure to environmental heat as the causal mechanism. However, the literature suggests other mechanisms which contribute to heat-related injuries, such as metabolic heat production and clothing insulation, can be a causal factor (Goldman, 2001; McDermott, Casa, Ganio, et al., 2009). As the OHSCAR database can list only a single mechanism of injury, these findings on heat injury from that data source must be interpreted with caution.

Among the 5% of injuries reportedly caused by rubbing and chafing, the injury sustained in all of these 21 cases was friction blisters to the feet. These results concur with the mechanisms of injury associated with foot blisters reported in the literature review (Chapter 2). Finally, of the 21% of injuries reportedly caused by a fall in the OHSCAR data, 53% (45 of 85) were ankle injuries. Of these ankle injuries, 78% were described as ‘rolled’ or ‘twisted’ ankles reportedly caused by falls. The findings in this study suggest the potential consequences of the findings of Park, et al. (2010), who observed an increasing risk of trips and falls associated with obstacle negotiation when carrying increasing loads.

Activities Performed at the Times When Load Carriage Injuries Occurred

Field training exercises, rather than PT, was the activity type most often associated with load carriage injuries. Overall, 28% of survey injury records and 25% of OHSCAR injury records identified field training exercises as the activity type at the time of injury. PT was identified in 14% of the survey injury records and 6% of the OHSCAR injury records as the activity performed at the time of injury. Potential reasons for this higher frequency of injury occurring during field training exercises include differences between the two activities in the amounts of time that soldiers were exposed to them[100] and in the respective load carriage contexts. Moreover, PT lessons are commonly conducted by PT Instructional (PTI) staff, trained in depth in the safe conduct of physical activity. PTI staff are trained to monitor participants for signs of fatigue, illness and injury, monitoring that forms part of the ARA's injury prevention strategy for injuries sustained during physical activity (Defence Health Services Branch, 2000). As such, PTIs may have anticipated and prevented some instances of potential load carriage injuries during PT sessions.

Both this current study and Study A (Chapter 4) also observed significantly heavier loads reportedly carried during field training exercises compared to those carried by soldiers during PT. Furthermore, Study A (Chapter 4) identified differences in the nature of the terrain covered during these two activities, with field training exercises conducted through light bush over mild or steep hills whereas PT was more frequently conducted on roads or on dirt or grass over flat terrains. On this basis, both the heavier loads and the more challenging terrain may have induced the higher frequency of injuries reported for field training exercises. The differences in terrain may also account for the higher frequency of ankle injuries reported for field training exercises (40%) than for PT (10%), given that uneven terrain is a risk factor for ankle injury (Chan, Yuan, Li, Chien, & Tsang, 1993).

It is nevertheless important to recognise that, although the frequency of injuries reportedly sustained during field training exercises was greater than that during PT in the current study, the higher frequency of injury field training exercises might be a result of inadequate preparation of the soldiers for load carriage tasks during field training exercises. The findings of differences in load weights and load carriage contexts between PT and field training exercises identified in Study A (Chapter 4) suggest that the load carriage contexts of PT might not adequately progress to meet the load carriage contexts of field training. Consequently, when soldiers are required to carry heavier loads during field training exercises they might be more susceptible to injury, resulting in the higher frequency of injuries during field training exercises. This potential gap in physical conditioning for load carriage activities is investigated in Study C (Chapter 6).

---

[100] Typically, a PT session would last around 60 minutes (Australian Army, 2005) whereas a field training activity would last several hours to several days(Australian Army, 1984, 2003, 2009a).

5.4.2. What impacts do soldiers perceive load carriage has on their combat performance?

In this study, soldiers reported that load carriage had a negative impact on task performance while on operational duties. In particular they identified that mobility was reduced during load carriage tasks. These findings support those reported in the literature review (Chapter 2: Johnson et al., 1995; Harper, et al., 1997; Knapik, et al., 1997: Pandorf, et al., 2002) and Study A (Chapter 4). Research by Johnson, et al. (1995), Harper, et al. (1997), Knapik, et al. (1997) and Pandorf, et al. (2002) has identified the negative impact of load carriage on the ability of soldiers to cover a given distance in a given time. Moreover, studies by Frykman, et al. (2000), Polycn, et al. (2000) and Park, et al. (2008) have identified decrements in obstacle course performance with increasing loads carriage. These studies basically concluded that as loads increased, mobility generally decreased. The results of the current study extend these prior findings in two ways, namely transfer to the operational environment and enhancement of our knowledge of soldier awareness of the impacts of load carriage on task performance. First, while the prior studies identified above captured performance measures in a controlled environment, the results of the current study, where respondents provided feedback based on operational experience, were drawn from an operational environment. Although objective measures of the impact of soldier load carriage on task performance during operational engagements would be preferred (cognitive testing during an operational patrol or weapon fire accuracy and movement speed during an engagement with an enemy as examples), the nature of these engagements makes scientific study extremely hazardous. On this basis, although based on soldier perceptions, the current study provides some indication of the transferability of findings from research in controlled environments to operational and combat environments. Second, while the prior research provided evidence that load carriage reduced mobility, the current study suggests that soldiers are aware of the mobility decrements caused by the loads they carry. As such, the findings of this study may provide insights into the findings of the Historical Review of Soldier Load Carriage (Chapter 3), where the historical evidence suggested that soldiers will take measures to reduce their loads. Now, the findings of the historical review, which identified a trend for soldier load carriage to reduce mobility, are extended into the current ARA environment. In particular, support is given to Breen’s (2000) statement on the mobility limitations of Australian soldiers during operations in East Timor. Breen (2000) claimed that Australian soldiers were so encumbered by their loads that they could not give chase to militia fleeing into the bush.

The results of the current study suggest that the majority of soldiers consider both their marksmanship and grenade throwing ability to be reduced as a result of the loads they carry. Previous research discussed in the literature review (Chapter 2), which investigated the impact of load carriage on lethality skills (like marksmanship and grenade throwing ability), provided mixed results. Several studies observed reductions in marksmanship and grenade throwing ability to be associated with load carriage (Harman, et al., 1999; Harper, et al., 1997; Knapik, et al., 1997; Knapik, et al., 1991; Sharp, et al., 1999) but others observed no change in performance of these lethality skills (Knapik, et al., 1997; Patterson, et al., 2005). Potential reasons for the differences in lethality findings between the studies lie in differences in marksmanship and grenade throwing practices, performance measurement approaches or task design (e.g. shooting and throwing grenades from different positions; measuring grenade throw distance versus throw accuracy; completing the march as fast as possible versus at set sub maximal speed). These differences may help explain the findings in the current study where, although the majority of respondents reported a perceived reduction in lethality skills,[101] some[102] claimed that the loads they carried had no impact on their lethality skills.

These results extend beyond providing mere subjective support for prior research that objectively showed diminished performance with load carriage. They raise the potential for soldiers to adopt strategies to compensate for perceived deficits. For instance, soldiers in an operational environment might increase their application of lethal force (expend more ammunition) to overcome what they perceive to be a shortfall in their performance following load carriage. This is important, as it indicates that the soldier’s perception of a decrement in lethality due to load carriage could have a greater impact on a soldier’s application of lethality than scientifically measured decrements might warrant.

Of all the five performance indicators against which respondents reported their perceptions of load carriage impact, attention to task was perceived by respondents to be the least affected by load carriage. Whereas studies by Johnson (1995) and Mahoney, et al. (2007) identified reductions in alertness and vigilance to be associated with load carriage, over a third of respondents in the current study considered load carriage to have no detrimental impact on their attention to task. These findings suggest that if, as research suggests, cognitive impairment is associated with load carriage, soldiers carrying heavy loads might not realise that their attention to task is diminishing during long patrols. The implication of these findings is that, following or during load carriage, soldiers might

---

[101] 70% of marksmanship respondents; 72% of grenade throw respondents.

[102] 28 % of marksmanship respondents; 26% of grenade throw respondents.

be more prone to miss important, potentially life threatening visual clues, such as signs of an improvised explosive device or a partially concealed weapon on a person approaching their patrol or check-point. On the basis of the discussions above, load carriage may have a negative impact on soldiers' operational performance, thereby increasing risk of injury while on military operations and increasing the risk of mission failure.

Finally, although the perceived negative impacts of load carriage on task performance in this study were similar to those measured objectively in other research (Chapter 2: Knapik, et al., 2004), the correlation between perceived impacts and actual impacts (objectively measured) is not known. As such, soldiers may under-appreciate, over-appreciate or accurately appreciate the impact of the loads they carry on their ability to perform tasks. On this basis, further research correlating perceived and actual impacts of load carriage on soldier task performance may be of benefit.

5.4.3. What are the consequences of injuries and performance impairments induced by load carriage on the soldier?

The current study, together with the findings in the literature review (Chapter 2) and Historical Review of Soldier Load Carriage (Chapter 3), suggest that load carriage can have negative consequences for the individual soldier. In this study, load carriage activities were reported by soldiers and identified by the ADF OHSCAR injury surveillance system as causing injuries. Among the respondents who reported experience of load carriage injuries, more than 50% reported suffering additional injuries during successive load carriage events. Furthermore, soldiers reported that load carriage negatively impacted on their task performance ability when on military operations, reducing their mobility, lethality, general task performance and attention to task. Both of these factors, injury and reduced task performance, have the potential to negatively affect the soldier and the force generation[103] and force maintenance[104] capability of a defence force.

With regard to ARA force generation, nearly half (48%) of the self-reported injuries occurring during load carriage activities occurred during initial training. Indeed, the literature suggests that rates of musculoskeletal injuries are higher during the earlier weeks of military training, when untrained recruits are adapting to an increase in exercise (Bush, et al., 2000; Greaney, et al., 1983; Milgrom, et al., 1985; Pester & Smith, 1992; Sheehan, et al., 2003). Proposed causal mechanisms

---

[103] In this context, force generation relates to the training of soldiers to meet operational needs.

[104] In this context, force maintenance relates to the maintenance of operationally ready soldiers employed in operational units.

for these injury patterns vary. Stein, et al. (1989) considered the onset of basic training to be the key causal injury factor, rather than a cumulative effect of marching mileage. Considering this, Orr and Moorby (2006) found that Australian Army recruits marched over seven km/day at the commencement of basic training, excluded distancing covered in physical training sessions and drill lessons. Similarly, Knapik, et al. (2007), who observed all activities completed during training days, found that US Army Basic Combat trainees covered an estimated 11 km/day during the first of three training phases. Thus, the commencement of training itself can be linked with cumulative loading. Further evidence has found trainee injury rates to be highest during training weeks with the highest volume of physical training (Almeida, et al., 1999). With basic military training typically escalatory in nature, both the sudden commencement of training and the continuous and progressive volume of conditioning as part of the training may combine to over-tax the musculoskeletal system to a point where any additional increases in volume dramatically increase the chance of injury.

The findings, in this study and the literature, do not suggest that load carriage is the sole or even major cause of trainee injuries but rather one of many. Rudzki (1989) compared the fitness and injury rates of two platoons, with one platoon on a running program and the other on a load carriage endurance walking program, and found the injury rates of both platoons to be similar. Of note, while Rudzki (1989) did not compare working days lost between the two groups, the study did identify that the endurance marching platoon sustained two back injuries while the running platoon did not report any back injuries. Unfortunately, the low number of back injuries observed in Rudzki’s (1989) study and confinement of this finding to a single study limit the transferability of these findings to the broader population. This finding of Rudzki (1989) does, however, warrant further investigation in light of the findings of Knapik, et al. (1992) who observed that back injuries were the leading cause of failure to complete a load carriage event. A final force generation consideration lies in the impact of load carriage injuries. Even if the severity of a load carriage injury does not warrant a medical discharge from training for the soldier and the loss of a potential future soldier for the ARA, an injury during training has the potential to delay the soldier’s training while rehabilitation occurs and, due to lost training time, to reduce force generation capability (Almeida, et al., 1999).

The consequences of injuries sustained during initial training flow on to impact upon soldiers in their unit and on ARA force maintenance. The current study identifies that force maintenance is at risk due to load carriage injuries. Of the personnel who reported sustaining an injury during initial training, 52% reported at least one additional injury (32% suffered an additional injury within 12 months). In total, 42% of respondents reported suffering subsequent injuries during load carriage activities, either to the same body site (43%), an additional body site (31%), or both the same and an additional body site (27%). These results suggest that soldiers who suffer an injury during a load carriage activity are at a notable risk of sustaining additional load carriage injuries. These injuries impact directly on the soldier’s readiness and on force maintenance through the reduction in available deployable personnel (Almeida, et al., 1999).

A study by Jennings, et al. (2008), discussed in greater detail in the literature review (Chapter 2), identified that 80% of soldiers suffering an injury were unable to undertake load carriage activities. On this basis, soldiers who have suffered an injury (be it from a load carriage activity or another mechanism) may be unable to carry load while they recover. In an ARA context, injury may prevent the soldier from being able to complete force readiness assessments (Australian Army, 2008a; Defence Science and Technology Organisation, 2009). For soldiers, such limitations in ability to carry load and to pass force readiness assessments have downstream effects on their ability to deploy. For the ARA, this will result in a reduction in deployable force size, and hence also in force maintenance capability.

In the face of the resulting reduction in deployable force size, deployed soldiers may be required to conduct additional patrols to fill the capability gap created by injured soldiers who cannot be replaced due to reduced deployable force reserves. Thus, their exposure to the load carriage *event* would be increased. Alternatively, the patrol size could be reduced in order to limit the requirement for soldiers to undertake additional patrols. In that case, with the remaining soldiers still required to carry all the additional stores required of a patrol (like radios, batteries, specialist weapons), these remaining soldiers would be required to carry heavier loads. This increased load in turn increases the risks to the soldier associated with the carriage of heavier loads (Knapik, et al., 2004). Furthermore, if injured soldiers are not on patrols, unit fire power may be reduced as each soldier is effectively a weapon platform. Thus, the remaining soldiers on patrol may be more vulnerable to enemy action. This vulnerability may be increased by the reduction in mobility, lethality and attention to task incurred by heavy load carriage (Knapik, et al., 2004).

The findings of the current study suggest that load carriage presents a credible source of risk to soldiers by increasing their vulnerability to injury, combat wounding and even potential fatality during military operations due to reduced personnel numbers and reduced combat performance. A notable number of injuries are attributed to soldier load carriage. These injuries have consequences that range from lost working days for recovery and rehabilitation to increased risk of future injury and hence an ongoing pattern of injury, recovery and rehabilitation. Further, generation and maintenance of the ARA workforce may be impaired, with fewer soldiers able to carry loads and able to meet with the physical requirements for operational deployment. During military operations, reduced force numbers, through load carriage injuries, can increase the load carriage exposure of other soldiers, through requirements to increase patrols to fill in for a missing capability. The negative impact of load carriage on task performance has the further potential to increase soldiers' vulnerability to combat wounds and even fatalities through reduced mobility, fire power and, most concerning, inattention to tasks like scanning for the enemy or signs of improvised explosive devices.

5.5. LIMITATIONS

Although the OHSCAR data was useful in capturing the current load carriage injury context and as a further data source for triangulation with survey data, two key limitations are presented: inability to accurately determine exposure rates, and difficulty in accurately identifying causal factors. First, based on OHSCAR data, reported injuries sustained during load carriage activities constituted 8% of all ARA body stressing injuries over a 2-year period. Unfortunately, this figure does not take into account activity exposure rates. Consider, for example, the differences in context and implications if 8% of body stressing injuries arose from an activity conducted once per year as opposed to the same 8% of injuries arising from an activity conducted daily for a year. Second, there is potential for load carriage activities to be causal factors in the 'deformation' of tissue, where tissue is degraded and weakened, yet not the 'yield point' where the injury occurs (Nordin & Frankel, 2001). As an example, a soldier might conduct load carriage tasks for several weeks yet only begin to feel shin pain from a stress fracture while running. Running, rather than the continuous structural overloading caused by load carriage, might then be identified as the causal mechanism. On this basis, the results reported in this study are considered to under-represent load carriage injuries in the ARA.

5.6. SUMMARY AND CONCLUSION

This study, confirming the findings of the historical review (Chapter 3) and review of the current literature (Chapter 2), suggests that load carriage presents a credible source of risk to the ARA soldier. A notable number of injuries were attributed to ARA load carriage practices. These injuries have consequences that range from potential lost working days for recovery to an increased risk of future injury and hence an ongoing pattern of injury and recovery. ARA soldiers also self-reported reduction in their ability to conduct specific military tasks, including mobility, lethality (marksmanship and grenade throwing ability) and administration tasks, as well as reduction in their attention to tasks, when carrying loads. These negative impacts of load carriage on task performance likewise have the potential to increase the vulnerability of soldiers and members of their team to combat wounds and even fatalities through reduced mobility, fire power and, most concerning, attention to tasks such as scanning for enemy or signs of improvised explosive devises.

The review of the current literature (Chapter 2) and the findings of the historical review (Chapter 3) suggested that physical conditioning through PT might provide a means of reducing the negative impacts associated with load carriage discussed above. Considering this suggestion, Study A (Chapter 4) identified a potential training gap, whereby the loads carried and the contexts in which they were carried during PT, field training exercises, and on operational duties differed significantly. This current study found that the injuries reportedly sustained during field training exercises were more numerous than those reportedly sustained during PT. Other factors notwithstanding, a potential cause for this higher number of injuries sustained during field training might be that PT fails to prepare soldiers for load carriage tasks during field training exercises. In conclusion, the findings of Study A and the current study suggest that a potential gap may exist between the physical conditioning conducted during PT to prepare soldiers for load carriage activities and the load carriage requirements of field training exercises and operational duties. This potential gap in physical conditioning forms the basis for Study C (Chapter 6).

6. STUDY C: SOLDIER LOAD CARRIAGE AND PHYSICAL TRAINING

6.1. INTRODUCTION

The literature review (Chapter 2) associated soldier load carriage with a risk of injury and with impairments in the performance of some military tasks (Knapik, et al., 2004). Study B (Chapter 5) confirmed associations between soldier load carriage and injury risk in the ARA context. That study also identified soldier perceptions of performance reduction in some military tasks.

With low levels of aerobic fitness associated with an increased risk of injury during load carriage tasks (Jones, 1983; Knapik, 2000), physical conditioning to increase fitness levels may be one means of limiting load carriage injuries. Likewise, as fatigue is associated with reduced task performance, increased fitness may delay and reduce fatigue (Murphy, 2002) and so reduce the impacts of load carriage on the performance of some military tasks. The need to condition soldiers to carry loads is not new; it can be traced back as far as the Roman Legionnaires and Macedonian foot soldiers (Chapter 3) (Campbell, 2004; Renatus, 1996). If physical conditioning is to provide a means of mitigating load carriage risk, the physical training (PT)[105] conducted by soldiers must prepare them for the contexts in which the loads will be carried during field training exercises and during military operations. An insufficient training dose could fail to train the soldiers to the standard required to withstand occupational load carriage demands (National Academy of Sports Medicine, 2009). This in turn could leave them susceptible to injury through insufficient conditioning preparations. Alternatively, if the load carriage training stimulus is excessive, the susceptibility to injury, particularly overuse injury, increases (Pope, 2007). Thus, to avoid becoming a risk source and to be effectively employed as a risk treatment, load carriage conditioning must follow established best training practice. However, to asses whether load carriage conditioning follows best training practice, best training practice for load carriage conditioning must first be determined. Before reviewing the literature presented in Chapter 2, several principles of physical conditioning that may influence best training practice for load carriage conditioning require consideration, most notably the principles of specificity, reversibility, recovery and overload (Katch, Mc Ardle, & Katch, 2011).

---

[105] In this text, PT provides a means of conditioning the soldier. That is, load carriage PT is a means through which soldiers are conditioned to carry load.

The principle of specificity suggests that the conditioning stimulus should approximate the nature of the task (Baechle & Earle, 2008; Katch, et al., 2011; Powers & Howley, 2012) in this case load carriage. The need to conduct load carriage conditioning to optimise load carriage performance has been established in the literature (Knapik, et al., 2004) and forms the premise of the Specific Adaptation to Imposed Demands or SAID principle (Baechle & Earle, 2008). Consequently the principle of reversibility suggests a detraining effect once a given stimulus is no longer received (Katch, et al., 2011; Powers & Howley, 2012). In short, failure to conduct load carriage conditioning may lead to a loss of load carriage specific conditioning. Again research confirms this principle with soldiers found to be at a higher risk of injury when returning to load carriage tasks after taking a respite from load carriage tasks (Knapik, et al., 1992). The principle of overload revolves around the need for the body and its systems to be placed under a stress that it is not accustomed. This training effect causes a response from the body requiring it to adapt and develop (Katch, et al., 2011; Powers & Howley, 2012).

Considering these principles of conditioning, the F.I.T.T. (frequency [how often], intensity [how hard], time [how long] and type of training) principle was used in this study to guide the evaluation of the reviewed load carriage conditioning programs. The F.I.T.T. principle was selected for three reasons. First, the principle provides a common framework for describing a physical conditioning training dose (Bompa & Carrera, 2005; Ehrman, et al., 2008; Mc Ardle, et al., 2006; Sharkey & Gaskill, 2006) and is used by the American College of Sports Medicine (ACSM) to detail the training requirements for health (Australian Army, 2005; Ehrman, et al., 2008; Haskell, Lee, Russell, et al., 2007; Wilmore, et al., 2008). Second, this principle is used by PTIs to develop and describe ARA training programs. Third, the principle has been used in other research fields to discuss physical conditioning standards and requirements (Hansen, Bicknase, VanSickle, & Bogenreif, 2008; Mottola, 2009; Somarriba, Extein, & Miller, 2008)

Frequency describes how often the physical conditioning sessions are to take place (Ehrman, et al., 2008; Haskell, et al., 2007; Wilmore, et al., 2008). As a result of their findings, Knapik, et al. (1993, 2004) recommended that weight load marching be conducted at least two times a month with loads that soldiers are expected to carry in a unit on operations. Visser, et al. (2005) however found greatest improvements with sessions conducted weekly versus fortnightly. On this basis, the optimal training frequency for load carriage could be considered as between two and four load carriage sessions per month or one session every seven to fourteen days (Knapik, et al., 2004; van Dijk, 2009). A lower training frequency may not only limit development but may lead to injury when the load carriage sessions occur (Knapik, et al., 1992).

Intensity relates to how hard the training effort is (Ehrman, et al., 2008; Haskell, et al., 2007; Wilmore, et al., 2008). In the load carriage context, intensity is influenced by the weight of load, speed of movement, and terrain being traversed (Knapik, et al., 2004). To ensure that load carriage PT sessions stimulate aerobic fitness adaptation, the load carriage intensity needs to be sufficient to elicit a cardiovascular and metabolic response (Rudzki, 1989). Even though research by Rudzki (1989) and Visser, et al. (2005), presented in the literature review (Chapter 2), has shown higher intensity training to be of particular benefit for improving load carriage task performance, the potential for injury following a long period of high intensity load carriage (Pope, 2001) must be considered. Ultimately, soldiers' conditioning stimulus needs to be designed to ensure that load carriers are being conditioned to carry loads at the intensities (load, speed, terrain) required for field training exercises and operational tasks (Leslie, 2007).

For load carriage conditioning, the time or duration of the PT session must be considered against both the intensity of the PT session and the outcome requirements. Just as short duration, high intensity PT sessions can be used to develop the ability to move rapidly for short durations (under direct or indirect fire, for example) (Bompa & Haff, 2009; Wilmore, et al., 2008), longer duration PT sessions are needed to develop the physical and mental stamina to endure tasks of long duration (dismounted patrols, for example) (Bompa & Haff, 2009; Whyte, 2006). Noting that the ACSM recommends a minimum of 20 to 30 minutes of exercise per session for general health, or the equivalent duration made up in 10 minute intermittent bouts (Haskell, et al., 2007), for the load carrier the duration of the load carriage conditioning session is ultimately determined by the occupational requirements of the load carrier (Marshall, 1980).

Given the principle of specificity, it is not surprising that the literature review (Chapter 2) found load carriage activities to be a recommended exercise for load carriage conditioning (Genaidy, et al., 1989; Henning & Khamoui, 2010; Knapik, et al., 2004; Vitiello & Pollard, 2002; Williams, et al., 2004). Furthermore, the results of the reviewed research suggest that exercises which stimulate upper body strength and increase aerobic fitness, in particular, may be of benefit for load carriage (2010; 1996; Kraemer, et al., 2001; Kraemer, et al., 2004),

Acknowledging that research into load carriage conditioning programming is limited, the review of the literature suggests that an optimal load carriage conditioning program would consist of: A load carriage specific PT session once every 14 days; at intensities (being load weight, speed and terrain) and durations (being time or distances) progressing to meet occupational requirements; with supplemental training (including upper body strengthening and aerobic conditioning) of potential benefit. As a final note, while a PT program may be consistent with industry best practice for load carriage conditioning, it does not ensure that the program meets with the training need. This concept is typified by O'Connor and Bahrke (1990) who, in a professional trade journal, stated that *'Training soldiers to carry 80 pound will not prepare them to carry 120 pounds when they are alerted to deploy'*. Whether it be progressing from initial training to an operational unit, or unit training in preparation for deployment, if the program is designed to meet a load carriage requirement that differs from the actual requirement, the training intent will not be realised. Thus the potential risk of injury and decrement to soldier performance due to loads carried may increase (Knapik, et al., 1992; Pandorf, et al., 2002; Ricciardi, et al., 2008).

The aim of this chapter was to continue to inform the *Risk Identification* process of the Risk Management Framework (RMF), commenced in Study B (Chapter 5) and described in Chapter 1, by exploring the role of PT as a load carriage risk source and potential risk treatment. This was achieved by answering the following research questions:

- Does the load carriage PT currently undertaken in ARA training institutions and in operational units reflect evidence-based guidelines for optimal load carriage conditioning?
- Is there a gap between current load carriage conditioning practices and load carriage requirements?

6.2. METHODS

6.2.1. Setting

The setting for this study is that described in Study A (Chapter 4, Section 4.2.1).

6.2.2. Research Design

The RMF, detailed in Chapter 1, forms the framework for this program of research. This study, continuing the work commenced in Study B, informs the second step in the RMF, *Risk Identification* (Standards Australia Working Group MB-002-01, 2004a, 2004b, 2004c), and aims to explore the role of physical training as a load carriage risk source and potential risk treatment.

The survey research design employed in the current study and Studies A, B and D is that described in Study A (Chapter 4, Section 4.2.2). Besides using the survey data, the cross-sectional design employed in this study also involved the collection of participating training institution and operational unit load carriage PT programs gathered from key ARA training units.

6.2.3. Approvals

Command approvals and ethics approvals for this research were the same as those described in Study A (Chapter 4, Sections 4.2.3 and 4.2.4), which encompassed this and the other studies reported in this thesis.

6.2.4. Data Collection

Data for the findings reported in this chapter arose from two sources: survey data and textual data. Survey data were collected through the methods described in Study A (Chapter 4). Textual data, namely PT programs, were sourced from key Army training institutions and units.

Participants

The ARA units and participants who agreed to participate in the survey used in this study were described in Study A (Chapter 4, Section 4.2.5). In the current study, additional specific textual data (in the form of PT programs) were requested from the initial (basic or entry-level) training institutions of soldiers and officers and the corps training institutions of the five corps investigated in the survey (Infantry, Artillery, Armoured, Engineers, and Signals).[106] These training institutions were specifically selected in order to investigate load carriage conditioning from initial training, through corps training, to service within a unit.

Survey Data

The Survey Design and Distribution

The survey design and distribution were described in Study A (Chapter 4, Section 4.2.5). This study reports the findings from Questions 11, 13-16 and 18 of the online survey questionnaire (Appendix G) as they related to the demographic data gathered in the online survey questionnaire (Questions 1 and 2: Appendix G). Findings from Questions 4 and 5 (Appendix G), which detailed respondents' most recent load carriage experience, were used as an internal check to confirm responses – a

---

[106] The five corps were selected via purposive sampling as described in Study A (Chapter 4, Section 4.2.5).

method described by Oppenheim (2001) to improve survey response reliability. In this instance, load weight data from Question 5 (Appendix G) in respondents reporting ‘physical training’ as their most recent load carriage activity (Question 4; Appendix G) was compared to load weight data entered in response to Question 16 (Appendix G) by the same respondents.

Textual Data

The textual data for this study were derived from military PT programs. Military PT programs are developed by specially trained Army PTIs and are designed to meet the individual training needs of a training institution or unit (Australian Army, 2005). The programs can vary in length from several weeks to several months to accommodate unit commitments. The PT programs are generally described in a document, with training dose following the F.I.T.T. principle, this being *frequency* (how often), *intensity* (how hard), *time* (how long), and *type* of training, or a derivative thereof (Ehrman, et al., 2008; Haskell, et al., 2007; Wilmore, et al., 2008). The *frequency* of PT is indicated by the dates, days and times of the training sessions. *Intensity* descriptions (e.g. Rating of Perceived Exertion, speed of movement, load, percentage of heart rate, light-medium-hard) may or may not be provided, depending on the intent of the session. Generally, the PTI controls the session intensity based on internal factors (e.g. stage of training) and external factors (e.g. ambient temperature). The *times* or durations of the sessions are listed either alongside the start times (e.g. 0800 to 0840) or in a separate column (e.g. 40 minutes). The *types* of PT undertaken form the basis of the program and are often described in common fitness terms (e.g. swim session, circuit, run) or more militarised (although formalised) nomenclatures (e.g. Battle PT, Lift and Carry). Information regarding the type of session typically includes the dress requirements of the session (e.g. Patrol Order, PT gear, etc.). These programs, constructed in these ways, are distributed to units for inclusion in orders and displayed in relevant notice areas for attention of the military personnel to whom they pertain.

The PT programs at military training institutions form part of an overall Training Management Plan and as such are more rigid in structure and detail than is typically the case for PT programs within operational units (Australian Army, 2005). With each phase of training, be it initial training or corps training (described in Appendix A), following a controlled, audited, and continually re-cycling[107] program, PT sessions are formulated, sequenced and scheduled to meet the training focus of the Training Management Plan (Australian Army, 2005). With dedicated lesson plans for each session, these PT programs from ARA initial and corps training institutions are generally more detailed in

---

[107] A recycled program is a set program employed for each successive training course. These courses could be run concurrently or consecutively.

presentation than the PT programs of operational units (e.g. providing more detail on the number of PTI staff and training staff to attend each session) (Australian Army, 2005).

Points Of Contact (POCs) from the units selected for the survey were contacted via email and requested to provide their unit PT program. In instances where unit POC did not have copies of the PT programs, the PTIs responsible for the conditioning of the unit were contacted and the PT program requested from them. For PT programs from training institutions, the Chief Instructors or PTIs were approached and requested to provide the institution's formal PT programs.

6.2.5. Data Extraction and Analysis

Survey Data

Data were extracted from the online survey by following the protocols described in Study B (Chapter 4, Section 4.2.6). Responses to questions 1, 2, 4, 5, 11, 13-16 and 18 were downloaded in a Microsoft Office Excel (Microsoft, WA:USA, 2003) spreadsheet in order to address the research questions that underpinned this particular study.

Unit cooperation and survey response rate calculations were based on methods recommended by the ISER and AAPOR protocols, as described in Study A (Chapter 4, Section 4.2.7) and Appendix H. Descriptive and inferential statistical analyses were employed to examine the load carriage conditioning dose (frequency, intensity, type, type) and context, and self-reported satisfaction of load carriage conditioning as a means of preparing for load carriage tasks within a unit and on military operations. Before any comparative analyses were conducted, consideration was given to the assumption of normality by using the Kolmogorov-Smirnov test and the assumption of homogeneity of variances by using Levene's test. Frequency distributions and descriptive statistics were generated for all data sets, with means and standard deviations calculated for interval data and modal responses identified for categorical data. Student t-tests were used to compare data between two groups (e.g. load weight and order of dress). An analysis of variance (ANOVA) was employed to compare data across three or more groups (e.g. load weight and various activity groups). As discussed in Study A (Chapter 4, Section 4.2.7), Bonferroni post-hoc tests for multiple comparisons were used to compare estimated marginal means. In instances where there were significant differences in variance between two samples being compared, t-tests assuming unequal variances were used. The methodology for determining relative loads, where loads were expressed as a percentage of body weight, was described in Study A (Chapter 4, Section 4.2.7).

Data were analysed using the IBM Statistical Package for the Social Sciences (SPSS) Statistics Version 19.0 for Macintosh and Windows (SPSS Inc., Delaware:USA, 2010) with the level of statistical significance set at 0.05.

Textual Data

On receipt of training institution or unit PT programs, the investigator extracted relevant data for transfer to a Microsoft Office Excel spreadsheets (Microsoft, WA:USA, 2003) dedicated either to training institutions or units. During data extraction, each PT session was rated from 1 to 4. Ratings were based on the session's specificity and potential value to load carriage conditioning in accordance with considered best practice for load carriage conditioning described in the literature review and the introduction to this chapter. A rating for each PT session was determined by reviewing the PT session title, dress, nature of the PT activity, and any clarifying comments to describe the lesson. The criteria for each rating, and examples (provided in Table 16) were reviewed by two independent army Physical Training Instructors from units not involved in the study.

Table 16: Criteria for rating PT sessions in relation to industry best practice for the type of conditioning undertaken for load carriage conditioning.

Rating	Criteria	Examples
1	A dedicated load carriage physical training session with participants dressed in load carriage equipment and with load carriage as the session focus	1. Pack march in Marching Order 1 with 15 kg (pack and webbing) 2. Lift and Carry session with Patrol or Marching Order
2	Other physical training activity dressed in a minimum load carriage ensemble of webbing	1. Rating 3 activity but dressed in Patrol Order or Marching Order 2. Rope climbing session dressed in Patrol Order 3. Battle PT dressed in Patrol Order
3	Other physical training activity that may be of supplementary benefit to load carriage ability	1. Run or Circuit training 2. Cardio boxing 3. Military Self Defence
4	Physical training session with unknown benefit to load carriage ability	1. Swim session 2. Team games 3. Sport

Rating 1 sessions were considered to be most closely aligned with established best practice for load carriage conditioning. Considering this, all Rating 1 sessions were further scrutinised in relation to the *frequency, intensity*, and *time* or length of the session extracted. The total numbers of sessions that were assigned each rating were also extracted. Once all data were extracted, the collated textual data were analysed using descriptive statistics and compared to current literature regarding optimal load carriage conditioning. In addition, results from this study were compared to the load carriage results from Study A (Chapter 4) examining loads carried during PT, field training exercises and on operations to determine whether a gap between current load carriage conditioning practices and load carriage requirements existed.

6.3. RESULTS

6.3.1. Survey Results

Unit Participation and Survey Response Rates

Unit participation and survey response rates were described in Study A (Chapter 4, Section 4.3.1). The demographic characteristics of survey respondents were described in Study A (Chapter 4, Section 4.3.1, Table 3).

Self-Reported Load Carriage PT

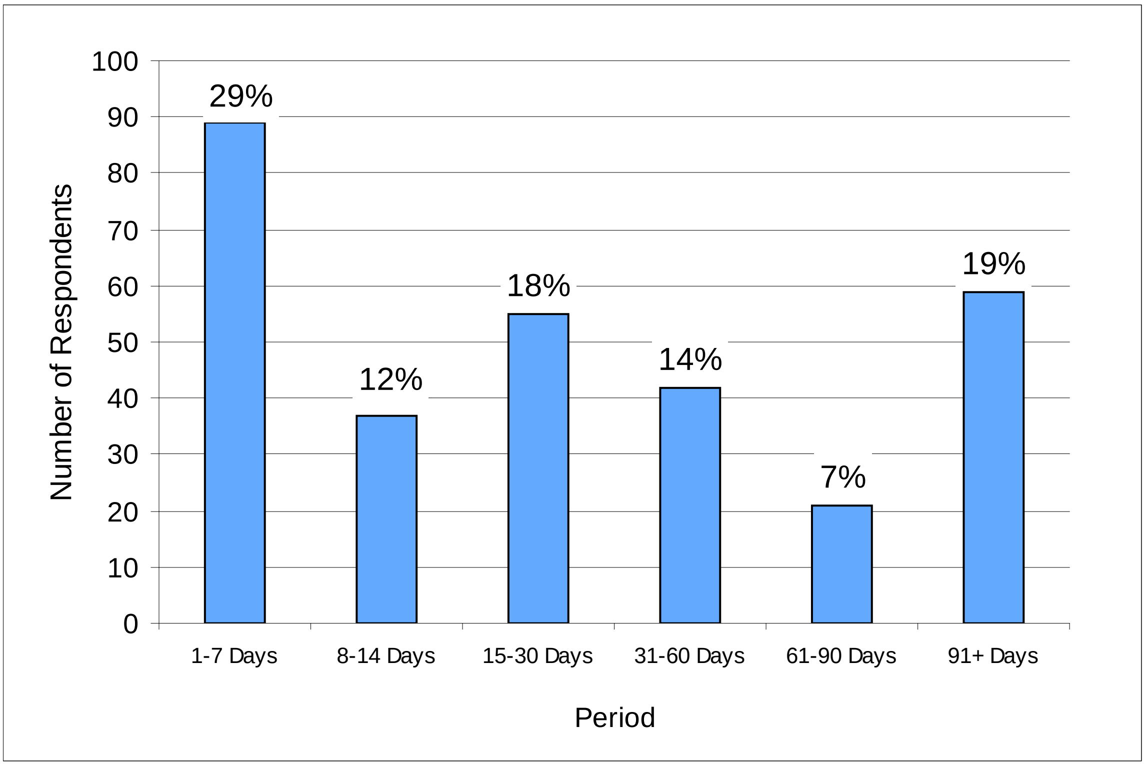
PT Frequency

When asked to describe their most recent load carriage PT session, 41% (*n*=126) of respondents reported participating in a session in the preceding fortnight. Conversely, over 19% (n=59) reported having not participated in a load carriage session within the last 3 months (91+ days). The frequency distribution of self-reported days since the respondent's most recent load carriage PT session is shown in Figure 13.

PT Intensity (Load)

Describing their most recent load carriage PT session, respondents reported engaging in load carriage PT wearing Patrol Order and Marching Order (described in detail in Appendix A). Patrol Order mean loads were 15.5 kg (*SD*=10.8 kg) or 18% body weight (*SD*=12% BW) whereas Marching Order mean loads were 36.3 kg (*SD*=12.0 kg) or 43% body weight (*SD*=14% BW). Marching Order was the most commonly reported form of dress for the load carriage PT sessions (69%). When these loads were compared to the self-reported loads for most recent load carriage activity (Study A) no significant differences in Patrol Order loads (t(33)=0.74, *p*=.47 unequal variances) or Marching Order loads (t(325)=0.89, *p*=.37) were found.

Figure 13: Frequency distribution histogram of self-reported days since most recent load carriage PT session.



During load carriage PT sessions performed while wearing Patrol Order, just over 10% of respondents reported wearing body armour and 26% reported carrying additional stores.[108] Among the respondents wearing Marching Order only 5% wore body armour, although considerably more (40% of respondents) carried stores compared to those wearing Patrol Order (26% of respondents). A greater tendency towards carrying a weapon was also found in Marching Order (74% of respondents who wore Marching Order) compared to Patrol Order (43% of respondents who wore Patrol Order). In total, 12% of respondents reported wearing body armour during PT sessions, and 40% carried stores in some form. The distribution of the reported loads and equipment is shown in Table 17.

Table 17: Distribution of loads and equipment by order of dress in PT sessions.

Dress		**TOTAL**	**Webbing**	**Pack**	**Body Armour***	**Helmet***	**Weapon***	**Stores***
Patrol Order	Respondents (%)	30%	100%	N/A	11%	7%	43%	26%
	Absolute load (kg) *M* (SD)	15.3 (10.6)	7.4 (3.4)	N/A	11 (0)	1.8 (0)	3.6 (0.2)	14.4 (11.8)
Marching Order	Respondents (%)	70%	100%	100%	5%	13%	74%	40%
	Absolute load (kg) *M* (SD)	36.3 (12.0)	8.0 (3.0)	23.0 (7.5)	11 (0)	1.8 (0)	3.7 (0.5)	9.6 (8.3)

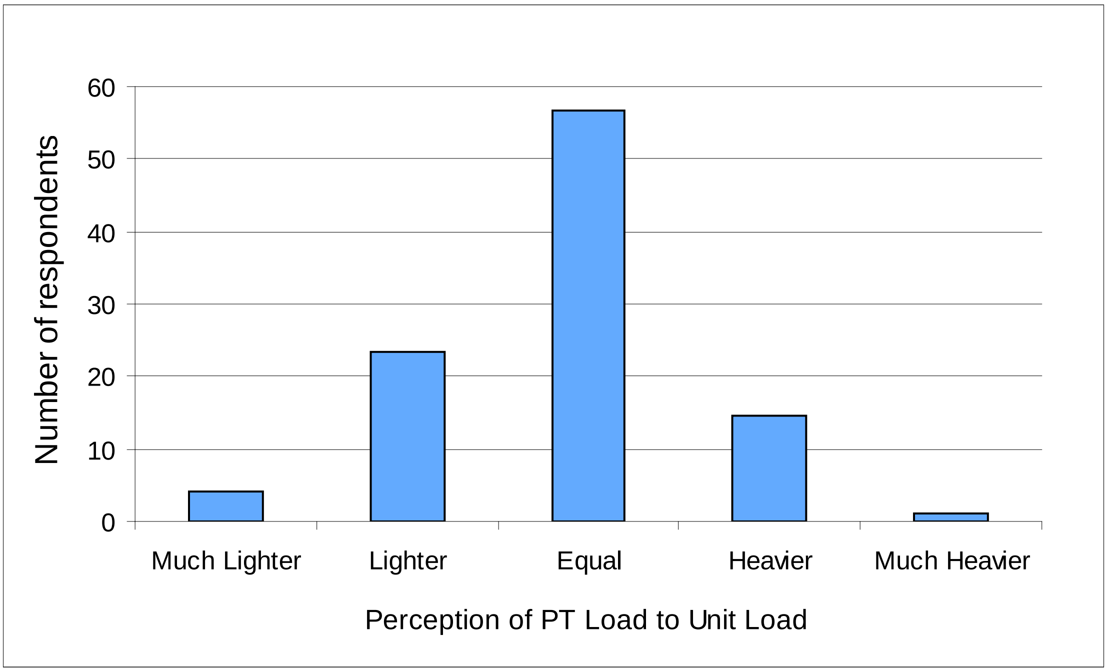
* If worn or carried

---

[108] Additional stores traditional to ARA PT sessions include ammunition boxes, stretchers, Unimog truck tyres, ropes, Koppers' logs, and torsion bars.

The majority of respondents (57%) considered the loads carried during PT to be *equal* to unit requirements[109] (Figure 14).

Figure 14: Histogram of self-reported perceptions of how PT loads compared to unit load requirements.



PT Intensity (Terrain)

Respondents reported covering a variety of different terrains during their most recent load carriage PT session. Roads (42%) and dirt or grass (39%) constituted the predominant terrains traversed, with light bush (16%) making up the majority of the remaining terrain types. Heavy bush, loose sand, and loose rocks constituted less than 4%[110] of the remaining terrain types traversed. Well over 90% of all recent load carriage PT sessions (Endurance Marching, Lift and Carry, etc.) were conducted on terrain that was either flat or characterised by mild hills. Activities on steep hills (7%) were limited to endurance marching sessions or combination sessions (sessions comprising a mixture of activities like endurance marching with periods of lifting and carrying a stretcher).

PT Duration (Time)

The majority of respondents' PT sessions (79%) lasted for no more than 2 hours, although sessions lasting up to three or more hours were reported (5%). For PT sessions lasting up to 6 hours, Endurance Marching was the most common activity, followed by PT sessions combining several

---

[109] Unit requirements refer to the equipment and stores that units require their soldiers to carry to meet with unit objectives.

[110] Does not equal 100% due to rounding.

activities (44%). Among the 79% of PT activities which lasted for 2 hours or less, 49% lasted no more than 60 minutes. H These durations were consistent with those identified by survey respondents in Study A (Chapter 2) when considering their most recent load carriage activity (Survey Question 4), as part of establishing the ARA load carriage context.

PT Type

An explanation of the different types of PT session can be found in Appendix K. Endurance Marching was the most common activity (60% of nominated activities) with the majority of these sessions (88%) conducted in Marching Order. Few respondents reported wearing body armour (4%) or carrying stores (16%) during these PT sessions.

Lift and Carry PT sessions involved the highest number of respondents (71%) carrying stores. Only 10% wore body armour and the majority of the Lift and Carry sessions were conducted in Patrol Order (94%). The orders of dress reportedly worn by respondents for these sessions are described in Table 18.

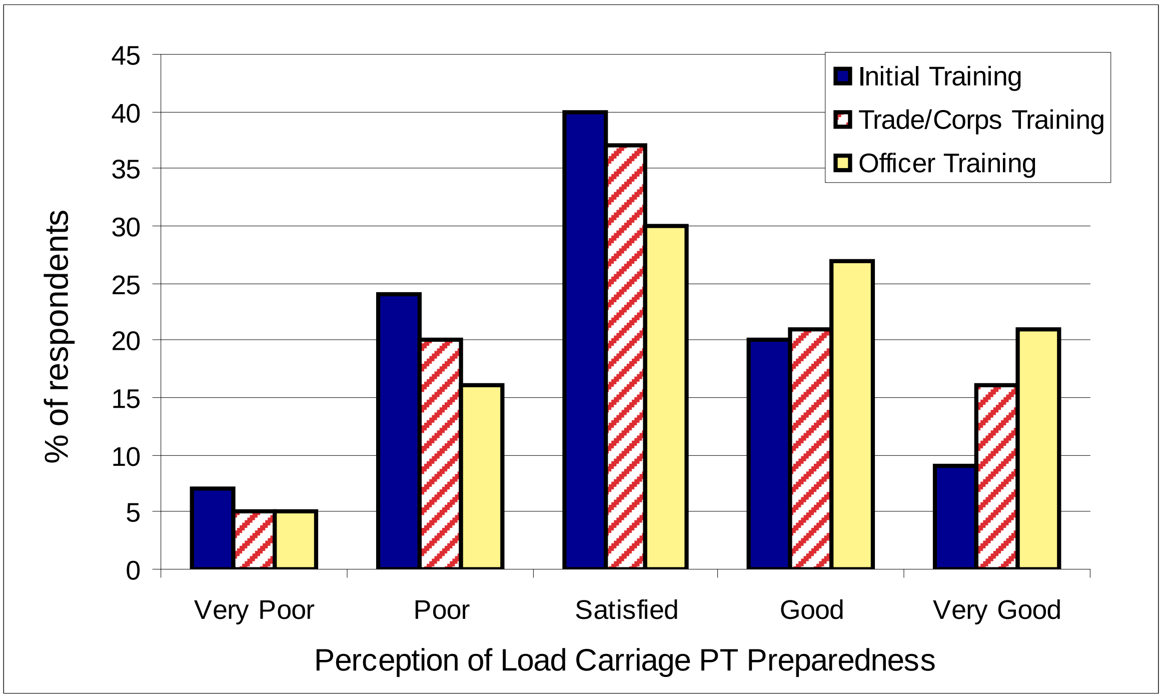
Table 18: Different PT sessions involving load carriage and the orders of dress reportedly worn by respondents.

	Patrol Order (PO)			**Marching Order (MO)**		
	Load (kg) ***M (SD)***	**Relative Load (% body weight)** ***M (SD)***	**Sessions dressed in PO (%)**	**Load (kg)** ***M (SD)***	**Relative Load (% body weight)**	**Sessions dressed in MO (%)**
Endurance March	11.5 (5.2)	14 (7)	12	35.8 (12.3)	43 (15)	88
Obstacle Course	12.5 (4.1)	15 (6)	74	38.0 (7.0)	45 (8)	26
Lift & Carry	20.8 (15.0)	24 (16)	76	37.1 (10.7)	44 (11)	24
Combinations	17.0 (11.7)	20 (12)	47	36.4 (11.1)	41 (14)	52
Other	15.0 (12.1)	17 (14)	66	48.5 (10.4)	56 (12)	33

Self-Reported Rating of Load Carriage PT

Respondents were generally *satisfied* with the load carriage training they received on joining the ARA (Figure 15). Approximately 70% of respondents considered the load carriage training conducted at initial employment and corps training to be *satisfactory*, or better, at preparing them for service in their first unit. For officer training, the proportion of respondents satisfied with their load carriage training was nearly 80%.

Figure 15: Histogram of self-reported rating of preparedness for load carriage within units following training.



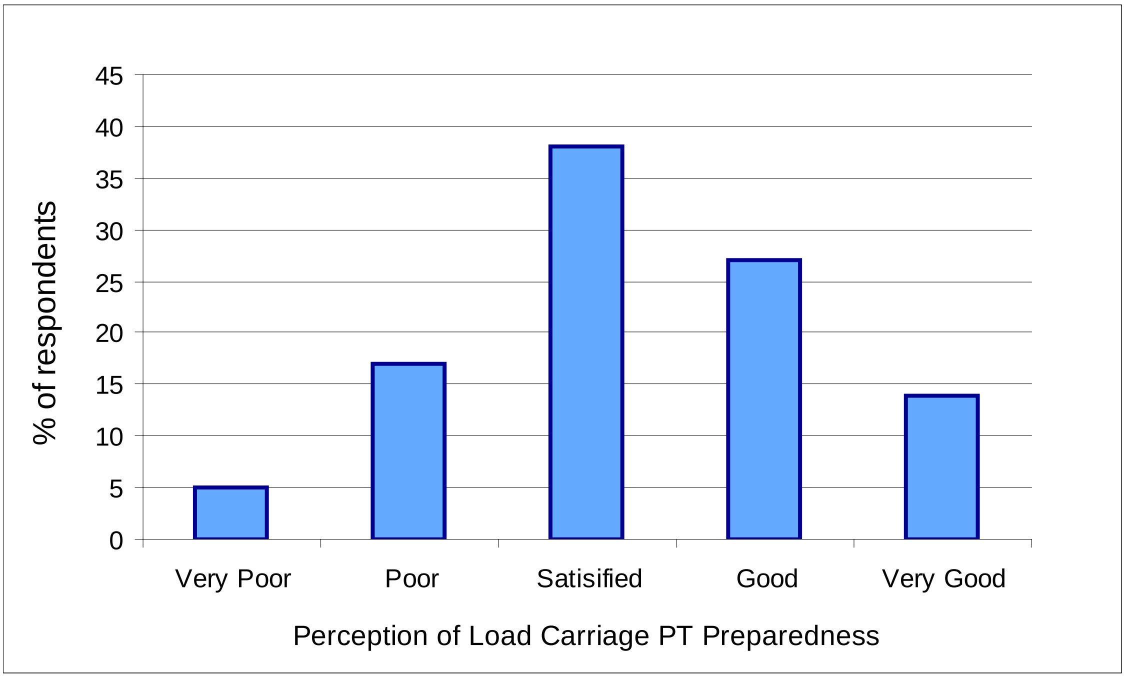
Similar results were obtained when respondents were asked to rate the amount of load carriage training received in their units, with 70% stating that the amount of load carriage PT conducted in their units was *satisfactory* or better (Figure 16). The majority of respondents (80%) considered themselves to have been suitably prepared for the load carriage requirements of operations. An ANOVA of the respondents' ratings of load carriage preparedness for operations and the load weights carried during military operations found no significant differences between rating groups (*F*(4,210)=1.29, p=.275).

6.3.2. Textual Data

Training Institution and Unit Participation Rates

Participating training institutions and operational units provided textual data in the form of training programs. Six of the seven training institutions approached provided their training programs. No responses from the remaining institution were received by the investigator. This represents a training institution cooperation rate of 86% (*n*=6). As described in the methods section, POCs for the operational units selected for the survey were contacted via email and requested to provide their unit PT program. The resulting unit participation rate was that described in Study A, being 27% (*n*=8).

Figure 16: Histogram of self-reported rating of preparedness for load carriage during military operations.



PT Programs

Training Institution PT Programs

The data extracted from the training institution PT programs, indicating the relative prominence and context of Type 1 load carriage training sessions, are shown in Table 19. The initial training institution for enlisted soldiers provided a dedicated load carriage PT program for load carriage conditioning, progressively increasing load to a defined outcome. However, only one of the four reviewed corps training institutions built on this initial load carriage conditioning and extended it. The remaining three corps training institutions failed to maintain or build on the load carriage conditioning developed during initial training. The outcome of training from the sole corps-training institution with the more dedicated load carriage PT program was soldiers conducting sessions carrying a load of 32 kg for up to 165 minutes during endurance marching sessions.

Table 19: Descriptive breakdown of data from training institution PT programs, indicating relative prominence and context of Type 1 load carriage training.

Program[111]	**Length of Program (number of sessions)**	**Number of sessions per type of training**[112]				**Load carriage training (Type 1)** (See footnote 89)		
		1	**2**	**3**	**4**	**Freq (per week)**	**Intensity (minimum to maximum load)**	**Time (min to max)**
A~	11 weeks (38 sessions)	8	7	13	10	Approx 1x week	9.5 kg – 27.5 kg	22 – 77 min
B~	69 weeks (105 sessions)	18	24	43	20	Inconsistent (e.g. 2 in one week, nil for 2 months)	Up to 47% Body weight	60 – 165 min
C	8 weeks (17 sessions)	0	2	10	5	No load carriage PT sessions		
D	12 weeks (20 sessions)	0	1	9	11	No load carriage PT sessions		
E	12 weeks (34 sessions)	3	2	21	8	Inconsistent (weeks 2, 6,8)	PO (load not specified)	60 – 100 min
F~	14 weeks (50 sessions)	11	16	11	12	Approximately 1x week for the first 11 weeks	25 kg – 32 kg	60 – 165 min

~ During these programs trainees spent time conducting field training exercises while dressed in load carriage equipment

Of note, trainees from three of six training institutions (Programs A, B and F) were required to participate in field training exercises during their training. During these field training exercises, the trainees were required to carry loads, as part of their field duties. More detailed data on the load carriage context during these field training exercises was unavailable to the investigator. On this basis, although Table 19 represents the frequency of load carriage in which PT trainees were participating, it may under-represent the actual amount of load carriage conducted during the training period for three of the training institutions identified above (Programs A, B and F).

The officer training institution (Program B) that was reviewed had a well-developed and structured PT program for load carriage conditioning. One shortcoming was that the load carriage conditioning was inconsistent in training dose, most notably training frequency. Interestingly, however, this shortcoming was due to the absence of PT sessions when soldiers undertook field-training exercises, which routinely included load carriage tasks. Soldiers therefore received load

---

[111] Program owner names have been replaced with alphabet characters to preserve institution anonymity.

[112] Types of training: 1 = Dedicated load carriage PT session; 2 = Other PT activities dressed in load carriage equipment; 3 = Other PT that might be of supplemental benefit to load carriage ability; 4 = PT with unknown benefit to load carriage ability. See Table 17.

carriage training at these times, even though it was not recorded as part of PT. The training goal for load carriage conditioning in the officer training institution involved soldiers carrying a load of 47% of body weight during sessions lasting up to 165 minutes.

Only one training instruction (Program A) discussed the terrain to be covered during the associated PT sessions. This initial training institution stated that all load carriage PT sessions were to be conducted on ‘relatively flat’ terrain. No other contextual information was provided by training institutions.

Unit Programs

The PT programs of the units which participated in this study ranged in length from 6 weeks to 15 weeks and varied in training frequency from twice per week to five times per week. Among the unit PT programs obtained, 50% (*n*=4) included load carriage oriented PT. Of these units, three units were currently undergoing specific training for their annual Combat Fitness Assessment (CFA).[113] The longest scheduled load carriage PT session, excluding the actual CFA on the basis that the CFA was an assessment rather than a PT session, was 120 minutes in duration with a maximum load of 31 kg (this weight excluded the 3.5 kg weight of personal weapons). The only PT program that included endurance marching, but not training for the CFA, had a maximum load carriage PT achievement of 60 minutes with a load of no more than 20 kg. There was no indication that this PT program was conditioning soldiers for any specific load carriage event. The key data extracted from participating unit PT programs are shown in Table 20.

---

[113] The CFA consists of a run, dodge and jump course (RDJ), followed by a 15 km road march event over 165 minutes (2 hours, 45 mins). As the RDJ must be conducted within 24 hours of the walk, most units conduct the RDJ the afternoon before the 15 km endurance march on the day of assessment. The assessment, undertaken at commander’s direction, may occur once a year.

Table 20: Descriptive breakdown of participating Unit PT programs.

Program [114]	**Length of program (number of sessions)**	**Number of sessions per type of training**[115]				**Load carriage training (Type 1)** (See footnote 92)		
		1	**2**	**3**	**4**	**Freq (per week)**	**Intensity (minimum to maximum load)**	**Time (min to max)**
A*	6 weeks (12 sessions)	12 100%	0 0%	0 0%	0 0%	2x/1 week	7 kg to 31 kg	40-120 min
B	6 Weeks (18 sessions)	3 17%	1 6%	13 72%	1 6%	1x/2 weeks	15 kg to 20 kg	60 min
C*+	15 weeks (75 sessions)	13 17%	3 4%	43 57%	16 21%	1 per week first 12 weeks	No information	up to 60 min
D*~	11 weeks (33 sessions)	8 24%	9 27%	10 30%	6 18%	1 per week first 8 weeks	Patrol Order+	up to 60 min
E	10 weeks (49 sessions)	0 0%	10 20%	28 57%	11 22%	No load carriage PT sessions		
F	10 weeks (42 sessions)	0 0%	9 21%	19 45%	14 33%	No load carriage PT sessions		
G	8 weeks (31 sessions)	0 0%	8 26%	18 58%	5 16%	No load carriage PT sessions		
H	6 weeks (18 sessions)	0 0%	0 0%	12 67%	6 33%	No load carriage PT sessions		

*Training for Combat Fitness Assessment
~Included carrying additional stores like ammunition boxes
+No additional load weight provided

6.4. DISCUSSION

In comparing the results of this study to best practice as determined from the research presented in the literature review (Chapter 2) and the introduction to this chapter, the F.I.T.T. principle was used. For load carriage, the optimal training frequency was considered to be between two and four load carriage sessions per month or one session per fortnight (Knapik, et al., 2004; van Dijk, 2009). Only one in four corps training institutions and no more than half of participating units reported participating in load carriage PT at the frequency recommended above for load carriage conditioning. Only 42% of survey respondents claimed to have participated in a load carriage PT session within the preceding fortnight. Apart from an increased potential for these soldiers to sustain a future injury when required to again conduct a load carriage activity (Knapik, et al., 1992), soldiers may lose fitness (in this case potential load carriage fitness) through non-use (Mc Ardle, et

---

[114] Program owner names have been replaced with alphabet characters to preserve unit anonymity.

[115] Types of training: 1 = Dedicated load carriage PT session; 2 = Other PT activities dressed in load carriage equipment; 3 = Other PT that might be of supplemental benefit to load carriage ability; 4 = PT with unknown benefit to load carriage ability. See Table 17.

al., 2006; Wilmore, et al., 2008). The principle of reversibility suggests that, following cessation of training, an individual's body 'detrains' over a period of time, to a level of fitness consistent with the current lower work rate (Hoffman, 2002; Wilmore, et al., 2008). While this principle is supported by research demonstrating a decrease in aerobic fitness measures following periods of training cessation (Frederiks, Swenne, Bruschke, et al., 2000; García-Pallarés, Carrasco, Díaz, & Sánchez-Medina, 2009; Nirmalendran & Ingle, 2010), it is acknowledged that further research specific to the load carriage context is required.

The Intensity of Load Carriage Conditioning Sessions

In the load carriage context, intensity is influenced by weight of load, speed of movement, and terrain being traversed (Knapik, et al., 2004). For best practice, a progression in load carriage intensity to meet with occupational demands was considered optimal (Leslie, 2007) The current study identified a gap between the intensity of the load carriage conditioning occurring in PT programs and that required in both field training exercises and military operations. The load weight outcomes for the majority of training institution PT programs fell notably short of operational load carriage requirements (see Table 19). In particular, the loads carried by soldiers at the end of their PT program while undergoing corps training or officer training (see Table 19) were generally below the mean field exercise loads and operational loads carried by soldiers in units[116]. Of note, one of these corps training institutions was responsible for training a corps identified in Study A (Chapter 4) as carrying some of the heaviest loads. Considering this load carriage training gap between training institution PT and the requirements of field exercises and operations, it is notable that the intensities of load carriage PT in training institutions were aligned with the loads carried during load carriage PT within operational units. This may provide for effective load carriage conditioning, if the load carriage conditioning in units accommodated this level of conditioning and progressed to operational requirements. However, this finding may be of concern if the load carriage training intensity of *unit* PT programs did not align with the load carriage requirements of unit field training exercises and operational duties. This was found to be the case with unit load carriage conditioning programs failing to align with field training or operational load carriage requirements – a surprising finding given that units might be expected to have a good understanding of operational load carriage requirements.

---

[116] Data from Chapter 4; Study A: Patrol Order loads carried were a mean 23.7 kg (*SD*=13.4 kg) during field training exercises and 50.1 kg (*SD*=16.0 kg) during military operations. Marching Order loads were a mean 47.2 kg (*SD*=16.0 kg) during field training exercises and 62.5 kg (*SD*=17.3 kg) during military operations.

The maximum load carried during PT in one unit was identified as approximately 20 kg, and in another unit 35 kg. These loads fell short of the mean loads identified in Study A (Chapter 4) for field exercises and during military operations, these being mean Marching Order loads of 47 kg and 57 kg respectively. Three of the four units which conducted load carriage PT were preparing for their annual Combat Fitness Assessment (CFA), the guidelines of which require soldiers to carry no more than 35 kg and to complete the 15 km march in 165 minutes. The CFA load carriage limit might have influenced and limited or reduced the weights of the loads carried in PT and the durations of the PT sessions, if commanders viewed this limit as guidance as to what constitutes a safe load weight. This possibility requires further research. Conversely, the requirement to complete the CFA might have increased the amount of load carriage PT conducted by a unit, beyond what would otherwise have occurred, especially in light of three programs stating that their PT programs were CFA conditioning programs.

The observed gap in load carriage intensity between PT sessions and those of field training exercises and operational duties could be due to several factors, including differences in the nature of the loads carried and lack of awareness of unit load carriage requirements. The nature of the loads carried provided a potential cause for the significant differences between PT loads, identified in this study and Study A (Chapter 4), and the loads carried as part of unit training (see Table 20) and during military operations (See Figure 8). In the current study 7% of respondents wore body armour and 67% carried a weapon during their PT sessions. Likewise, in Study A (Chapter 4) 8% of respondents, detailing their most recent load carriage activity as PT, wore body armour and 68% carried weapons. However, Study A (Chapter 4) also found that during field training exercises 37% of respondents wore body armour and helmet and 83% carried a weapon, whereas during military operations 83% wore body armour and helmet and 100% carried weapons. Together, these results suggest a potential cause for the differences in loads carried during PT and loads carried during field training exercises and on operations is the nature of load carriage dress, in particular the numbers of personnel wearing body armour and helmet and carrying a weapon. With over half of respondents stating that the loads they carried met with unit load carriage policy, the potential disconnect might lie with either a lack of appreciation of the unit policies or with the unit policies under-representing what is actually carried during field training exercises and during military operations. These possible discrepancies between soldier perceptions and unit policies, and between unit policies and field and operational requirements, are discussed in Study D (Chapter 7).

Considering these shortfalls in load carriage load weight intensity, it could be argued that the PT programs for the four units that conducted load carriage training were still progressing in their in their conditioning continuum to meet the load carriage requirements of either field training exercises or operational requirements, and that their load weights and session intensities were not yet equivalent to those required on field training exercises or on operations. However, all four of the associated army units were identified as having spent at least one, and up to 4 weeks away on field training exercises during the survey data collection period. Therefore, these units were required to carry field training exercise loads at this point in their conditioning continuum, and the load carriage conditioning contexts of the unit's PT program should have been commensurate with the field training exercise requirements of the unit (Australian Army, 2005; Leslie, 2007; Mayville 1987; Porter, 1992). Of note, around 80% of survey respondents considered themselves to have been prepared satisfactorily or better for operational load carriage requirements. This might be due to mission specific training, typically undertaken prior to operational rotations of units. Data to elucidate this issue was not captured in this research; that aspect warrants further investigation.

A final consideration lies in the loads carried when expressed as a percentage of respondents' body weight. The mean load reportedly carried by respondents was 36.3 kg (*SD*=12.0 kg), representing a mean 43% of body weight (*SD*=14%). However, examination of individual respondents' data revealed notable differences in the individual *relative* loads that contributed to this mean relative load. In the cases of two respondents who both reported carrying *absolute* loads of 36.6 kg, one respondent carried a *relative* load of 58% of body weight (body weight of 63 kg) and the other 39% of body weight (body weight of 94 kg). Given these difference in *relative* loads identified, if load carriage training intensity is to be structured to elicit a given individual training response, consideration needs to be given to not only to the *absolute* load carried but also to the *relative* load. Nevertheless, although that approach might optimise unit load carriage conditioning programs for individuals, the load carriage requirements of field training exercises and on military operations must also be taken into consideration, since the above example demonstrates that, unless changes are made to load carriage practices, lighter individuals will carry heavier relative loads than heavier individuals in these field and operational contexts.

The Time / Duration of PT Sessions for Load Carriage Conditioning

Akin to the parameter of 'intensity', best practice for the duration of load carriage PT conditioning was considered as progressing to meet with occupational demands (Marshall, 1980; Leslie, 2007). The duration of load carriage PT sessions in the initial officer training institution and one of the corps training institutions observed in the current study aligned with unit PT load carriage practices. However, unit PT load carriage practices failed to align with load carriage requirements of field training exercises and operational requirements. The progression in duration of load carriage tasks from soldier initial training to one of the corps training institutions could be considered well-structured, with initial training institution programs including load carriage PT sessions of up to 77 minutes in length with loads of up to 27.5 kg and the corps training institution commencing its load carriage PT with sessions of 60 minutes duration with loads commencing at 25 kg. Both this corps training institution and the officer training institution employed endurance marching load carriage sessions of up to 165 minutes in length, a duration coinciding with the length of the CFA conducted in units. The PT programs from the participating units involved a maximum load carriage time (regardless of PT type) of 120 minutes. Two units specifically listed the 165 minute CFA in their program (Table 20: Programs A & C). Of note, 5% of self-reported sessions in the current study were longer than 180 minutes in duration. The reason may lie in soldiers conducting their own personal training. This often occurs when a soldier is training for a specific event like the Special Forces Selection Course or an endurance marching event (e.g. William Hovell Trail).

The findings of this study, when compared to the findings of Study A (Chapter 2), again suggest a disconnect between unit load carriage conditioning characteristics and unit load carriage requirements, with load carriage PT sessions notably shorter (the majority under three hours) than the load carriage durations of field training exercises and during military operations (the majority over three hours) (Chapter 4, Table 7). Conversely, although the majority of corps training institutions were not conducting load carriage sessions of a duration commensurate with unit load carriage requirements, the PT session durations of the officer training institution and one of the corps training institutions were aligned with those observed in unit PT.

Type of PT Sessions for Load Carriage Conditioning

The type of training required to improve load carriage performance varies. A review of the literature (Chapter 2: Introduction to this chapter) suggests that optimal conditioning for load carriage requires specific load carriage PT to be conducted, that is, load carriage marching (Genaidy, et al., 1989; Knapik, et al., 2004; Vitiello & Pollard, 2002; Williams, et al., 2004). However, with load carriage performance associated with metabolic fitness (Henning & Khamoui, 2010) and muscle strength (Ling, et al., 2000), training to improve these fitness characteristics has the potential to increase load carriage ability. Activities that increase muscle strength (strength training, circuits, etc.) and metabolic endurance (running, cycling, etc.), may indirectly enhance load carriage task performance and may increase injury resilience (Harman, Gutekunst, Frykman, Nindl, et al., 2008; Kraemer, et al., 2004). However, further research to validate this hypothesis is required.

There was poor alignment of the PT programs reviewed in this study with the type of conditioning established as best practice to improve load carriage performance. Evidence exists, however, that improvements in load carriage ability may be achieved without including specific load carriage training in the conditioning program (Kraemer, et al., 2001; Kraemer, et al., 2004). All units reviewed in the current study did conduct some form of physical conditioning. However, the principle of specificity states the need for the conditioning context to be similar to the performance context (Ehrman, et al., 2008; LeBoeuf & Butler, 2007; Wilmore, et al., 2008). This principle is typified by the research finding that performance on a load carriage marching activity is considered a good predictor of load carriage marching ability (Simpson, et al., 2006; Williams & Rayson, 2006; Williams, et al., 2004), and justifies the claims that load carriage tasks need to be included in a conditioning program designed to improve load carriage ability (Genaidy, et al., 1989; Knapik, et al., 2004; Vitiello & Pollard, 2002; Williams, et al., 2004). On this basis, load carriage endurance marching best approximates patrolling on foot, the task identified in Study A (Chapter 4) as the most common load carriage task on field training exercises and military operations. Both of the initial training institutions observed in the current study conducted load carriage endurance marching as part of their load carriage conditioning program. Conversely, only two of the four corps training institutions included endurance marching for load carriage conditioning in their PT programs. Likewise, only 50% of the observed army units conducted endurance marching with load as part of their conditioning programs. On this basis, half of the corps training institution PT programs and half of the PT programs from units participating in this program of research employed *types* of PT sessions considered best practice for load carriage conditioning.

This study also identified differences in the specifics of the load carriage context of PT programs and those of field training exercises and military operations. The findings in this study, supporting those Study A (Chapter 4), suggested that roads or dirt paths over mostly flat terrain or mild undulating hills constituted the most common terrain traversed during load carriage conditioning. In contrast, load carriage activities during field training exercises were more frequently conducted over mild or steep hills, through light bush. During military operations, although foot patrols were often conducted on roads over flat terrain, recent operations have also required soldiers to traverse mild to steep hills through heavy bush, and loose sand and rocks – terrains not identified in any of the load carriage PT programs reviewed in this study. On this basis, the PT programs of units which otherwise conducted the appropriate *types* of load carriage activity for load carriage conditioning were generally unsuccessful in using terrain similar to that encountered in field training exercises and military operations.

In summary, a disconnect in the *type* of PT for load carriage conditioning has been identified. Half of the corps training institutions and units reviewed did not conduct load carriage endurance marching as a conditioning activity, even though foot patrols constituted over three-quarters of the load carriage tasks during field training exercises and during military operations. Those units which did conduct endurance marching load carriage PT were carrying loads over terrains that differed from those reportedly traversed on field training exercises and during military operations.

The differences in terrain traversed during PT, when compared to terrains traversed during field training exercises and on military operations, present a potential injury risk. Reid (1992, p. 215), discussing ankle injury frequency in the general and sporting populations, stated that '*the number of traumatic injuries are easily accounted for if one considers the tremendous force generated when the whole body weight is superimposed on the inverted foot.*' With limited load carriage conditioning occurring in heavy bush and over loose sand and rocks, soldiers may be inadequately prepared for load carriage tasks across these terrains, terrains traversed during contemporary field training exercises and military operations (Chapter 4). Noting that insufficient activity specific conditioning may present as a risk source for musculoskeletal injury (Brukner & Khan, 2011; Griffin, 2003), failure to condition soldiers to carry loads through heavy bush, and on loose sand and rocks, may be a plausible reason for the high incidence of ankle injuries ('rolled' ankles) observed during load carriage tasks identified in Study B (Chapter 5).

6.4.1. Does the load carriage PT currently undertaken in ARA training institutions and in operational units reflect evidence-based guidelines for optimal load carriage conditioning?

The PT programs of training institutions and units participating in this research achieved limited success in meeting established evidence-based guidelines for load carriage conditioning when viewed under according to the F.I.T.T. principle (frequency, intensity, time and type of training). Deficiencies were found, to some degree, across all four components. Only 50% of corps training and unit PT programs included load carriage conditioning at a suitable training frequency. Even when the training frequency met evidence-based guidelines, the training intensity (load weight and terrain traversed), duration of the sessions, and specific type of training (terrain traversed) were limited in the extent to which they complied with the various elements of the F.I.T.T. principle.

The loads carried during PT, which contribute to determining the intensity of the session, were significantly lower in this study than those required for field training exercises and during military operations. An identified potential cause for these load differences was the differences in PT dress requirements, most notably the absence of body armour and helmet, and fewer sessions which included the carriage of personal weapons. In regard to session durations, the durations of PT sessions which involved load carriage were notably shorter than the durations identified in Study A (Chapter 4) as required for field training exercises and during military operations. Differences between the types of terrain traversed for PT and during field training exercises and military operations (Chapter 4) limited alignment of the *type* of training with load carriage evidence-based guidelines, even though several training institutions and units did conduct load carriage specific activity as part of their PT programs. The limited amount of load carriage conditioning training conducted on terrains typical of those traversed, with loads, during field training exercises and during military operations, is a plausible reason for the high number of ankle injuries from ‘rolled’ ankles identified in Study B (Chapter 5).

Finally, both the initial training institutions and one corps training institution, although failing to meet evidence-based guidelines for optimal load carriage conditioning for field training exercises and operations, met evidence-based guidelines (i.e. F.I.T.T.) for conditioning soldiers to undertake load carriage as part of a PT program within units. This finding is discussed in greater detail in the next section of this chapter.

6.4.2. Is there a gap between current load carriage conditioning practices and load carriage requirements?

The results presented in this study suggest that a gap indeed exists between current load carriage conditioning practices and the load carriage requirements of ARA operational army units. Initial training institutions for both enlisted soldiers and officers, as well as a single corps training institution, were found to employ load carriage conditioning programs that aligned with the requirements of unit load carriage PT. Conversely, 75% (n=3 of 4) of corps training institutions were unlikely to meet the load carriage conditioning requirements of units for endurance marching, with two corps training institutions conducting no specific conditioning in the form of endurance marching load carriage as part of their PT program. On the basis of these findings it can be concluded that, in the majority of training institutions, a gap exists between load carriage conditioning and unit load carriage capability requirements.

The PT load carriage contexts of some training institutions align with the PT load carriage contexts of units. However, the PT load carriage contexts of units do not align with those of field training exercises or operational contexts. On this basis a potential disconnect in load carriage conditioning of unit PT programs may exist. Furthermore, with over half of respondents stating that the loads carried during unit PT met with unit load carriage policy (SOPs, load lists, etc.), it would appear that either unit policies are not well known and understood or that these policies contribute to the observed gap between training and operational load carriage characteristics by not accurately reflecting operational requirements. These results bring into question the role of unit policies in influencing the load carriage context, warranting further investigation.

6.5. LIMITATIONS AND FUTURE RESEARCH

Several limitations were identified in this study. Unfortunately, many of the PT programs provided by the units included only limited information, with the programs designed to be displayed in a single document on unit notice boards. In general, only the nature of the PT session (e.g. endurance march), the dress (e.g. patrol order), and the duration (e.g. 0730-0830) were detailed on the programs. Specific information, such as whether weapons were carried, overall loads, speed of march, type of terrain, etc., was lacking.

Although units were able to provide their PT program, there was no means available to determine whether any members missed a session or group of sessions due to other commitments (e.g. duty officer) or injury. Thus, although the programs were analysed and compared to best practice, the actual training dose for an individual might have been overestimated if the individual missed programmed PT sessions. Likewise, these programs did not capture whether personnel completed their own training; as such, the program could under-represent the amount of load carriage PT an individual actually conducted.

No open source data on mission specific training prior to deployment was available for use. On this basis, the gap identified in load carriage conditioning between PT and operations was based on unit PT programs and might underestimate the training dose and context of unit load carriage conditioning if additional training was conducted during mission specific training.

6.6. SUMMARY AND CONCLUSION

Viewed through the lens of the F.I.T.T. principle, the load carriage physical conditioning practices of ARA soldiers, training institutions and operational units were compared to standards derived from a review of the literature and considered to represent best practice. Overall, 42% of survey respondents, 25% (one in four) of corps training institutions and half of the operational units reported participating in load carriage PT sessions at a frequency that met with best practice – this being a minimum of one load carriage session every 14 days. Furthermore, while it is acknowledged that the type of training required to improve load carriage performance can vary, only half of the participating corps training institutions and operational units participated in specific load carriage marching PT activities.

In general, differences in PT loads and reported field training exercise and operational loads, and the context in which these loads were carried, suggested that a conditioning gap existed between the load carriage conditioning undertaken as part of PT and the load carriage requirements of field training exercises and on operations. Potential causes for this gap were differences in PT clothing requirements (fewer instances of soldiers wearing body armour or helmets or carrying weapons during PT, as an example), shorter durations of PT sessions, and differences in terrains traversed (both type and grade) during PT sessions compared to field training exercises and on operational deployments. Considering these differences in load weights and load carriage contexts, over half of respondents claimed that the loads carried during unit PT met with unit load carriage policies which govern loads to be carried during field training exercises and on operations. On this basis, a disconnect might lie in the appreciation (by both soldiers and training institutions) of the unit policies, or in unit policies relating to load carriage conditioning inadequately considering the load carriage requirements of field training exercises and military operations. These results bring into question the roles and influence of unit policies on load carriage practices. As such the role of these policies, as well as strategic level doctrine, in determining load carriage practices in the ARA warrants further investigation. That investigation is presented in Study D (Chapter 7).

7. STUDY D: SOLDIER LOAD CARRIAGE AND POLICY

7.1. INTRODUCTION

The literature review (Chapter 2), the historical review (Chapter 3) and Study B (Chapter 5) have identified load carriage as having the potential to cause soldier injuries and reduce soldier task performance. As physical conditioning may present as a means of reducing the injuries and negative impacts on task performance associated with load carriage (Knapik, et al., 2004), Study C (Chapter 6) assessed the physical conditioning experienced by, and prescribed to, Australian Regular Army (ARA) soldiers. That study also identified a potential disconnect in an appreciation of what the unit load carriage policies are or in whether unit load carriage policies under-represent the load carriage requirements of field training exercises and military operations.

In the military, guidelines are implemented in a variety of doctrinal manuals which in turn inform unit policies.[117] As an example, in the U.S. Army, the *Field Manual (FM) 21-18 Foot Marches* doctrine provides direction for commanders in procedures and techniques for managing load carriage marches on foot (Department of the Army, 1990). The document provides guidance on planning and conduct of these marches, and on the loads soldiers should carry. Specifically, FM 21-18, states that the ‘Fighting Load’, akin to the Australian Patrol Order, should not exceed 48 pounds (22 kg), that the ‘Approach March Load’, akin to Australian Marching Order, should be less than 72 pounds (33 kg), and for the ‘Emergency Approach March Load’, where soldiers are employed as porters, that loads of 120 to 150 pounds (54 to 68 kg) are feasible. On that basis, doctrinal guidelines specifically addressing load carriage tasks may provide a valuable means of reducing injuries and performance loss associated with load carriage by their guidance on load carriage practices and by limiting the maximum amount of load that a soldier is to carry to within determined, risk tolerable, safety limits.

Manual handling tasks are an acknowledged source of injury risk (Bewick & Gardner, 2000; Carrivick, Lee, Yau, & Stevenson, 2005; Straker, 1999). In Australia, national standards exist with the objective of preventing injuries resulting from manual handling tasks in the workplace (Australian National Occupational Health & Safety Commission, 1990, 2005). Although recently

---

[117] Military doctrine can be considered a concise expression of guidelines to meet conceivable military requirements.

superseded by a manual (Australian Safety and Compensation Council, 2007b) that avoids giving a specific load weight, previous national authority guidelines stated that, generally, no person should be required to lift, lower, or carry loads above 55 kg (Australian National Occupational Health & Safety Commission, 2005). Furthermore, the document acknowledged that as the load to be lifted and carried increased from 16 kg up to 55 kg, the percentage of healthy adults who can safely lift, lower or carry the weight decreases (Australian National Occupational Health & Safety Commission, 2005). In Study A (Chapter 4), 34% (n=74) of respondents reported carrying loads on military operations that would have breached the 55 kg guidelines. The average operational load for Australian soldiers over the last decade, when dressed in Marching Order, was 56.7 kg (SD=15.3), a load suggesting a trend of operational load carriage practices that contravened the previous national guidelines (Australian National Occupational Health & Safety Commission, 2005) when they were in place.

Although national guidelines exist, certain industries or professions have specific practice standards considered to be industry best practice. An example is the no-lift or safe-lift policy in a health care profession (Australian Nursing Federation, 2008), a policy implemented following the association of patient manual handling with a high incidence of injuries (Edlich, Hudson, Buschbacher, et al., 2005). The purpose of those guidelines is to prevent injuries associated with the specific manual tasks associated with the handling of patients. They provide clearly written guidelines for safe patient handling (Nelson, 2006). Following implementation of this policy in Australia, research has suggested that rates of injuries to nursing staff have decreased (Engkvist, 2006).

It is important to note that while doctrines may exist, they might not mitigate load carriage risks if adherence to the doctrine is lacking. A recent field study of U.S. soldier loads in Afghanistan found that the average Fighting Load was 31% heavier than doctrinal guidelines specified and that the average Approach March Load was just over 40% heavier (Task Force Devil Combined Arms Assessment Team, circa 2003). A potential reason for this departure from doctrine may be the commanders’ need to adjust loads to meet operational requirements. As an example, a military infantry doctrine might note that soldiers drop their heavy backpacks when in contact with the enemy in order to lighten their soldier fighting load and increase their mobility. During OPERATION ANACONDA in Afghanistan, U.S. infantry forces dropped their backpacks during a combat action with the enemy, in compliance with this doctrine. Due to the nature of the engagement, these soldiers were then required to retrieve their backpacks while under enemy fire (Kraft, 2002). This action led to the suggestion of a change in tactics, whereby one or two members per squad would keep their backpacks when in contact with the enemy. If these suggestions have since been implemented, they are yet to be reflected in doctrine.

There is an assumption that doctrine and policy can assist in minimising the negative impacts of load carriage, but it is not always known whether load carriage doctrine and policies exist and, if so, whether they are adhered to. Thus the aims of the current study were to determine whether load carriage doctrine and policies existed in the ARA, and whether commanders and soldiers adhered to these doctrines and policies. The cross-sectional study reported in this chapter addressed the following research questions:

1. What doctrines and policies detail the loads to be carried by Australian soldiers?
2. Do soldiers consider that the loads they carry meet with unit policies?

7.2. METHODS

7.2.1. Setting

The setting for this study was described in Study A (Chapter 4, Section 4.2.1).

7.2.2. Research Design

The RMF, discussed in Chapter 1, forms the framework for this program of research. This study, continuing the work commenced in Study B (Chapter 5) and Study C (Chapter 6), further informs the second step in the RMF, *Risk Identification* process (Standards Australia Working Group MB-002-01, 2004a, 2004b, 2004c). The study reported in this chapter aimed to explore the role of policy as a load carriage risk source and potential risk treatment.

The survey research design employed in the current study and Studies A through C was equivalent to that described for Study A (Chapter 4, Section 4.2.2). In addition to the survey data, the cross-sectional design employed in this study also involved collection of doctrines and policies, sourced through the Australian Defence Electronic Library and from units volunteering to participate in the survey (Study A: Chapter 4, Section 4.2.5).

7.2.3. Approvals

Command approvals and ethics approvals for this research were the same as those described in Study A (Chapter 4, Sections 4.2.3 and 4.2.4), which encompassed this and the other studies reported in this thesis.

7.2.4. Data Collection

Data for the findings reported in this chapter arose from two sources, survey data and textual data. Survey data were collected through the methods described in Study A (Chapter 4, Section 4.2.5). Textual data, being doctrine and policy, were sourced from the army units which volunteered to participate in the survey (Study A: Chapter 4, Section 4.2.5) and the Australian Defence Electronic Library (ADEL), an electronic storage site of all Australian Defence Force doctrine.

Participants

The ARA participants who agreed to participate in the survey used in this study were described in Study A (Chapter 4, Section 4.2.5).

Survey data

The Survey Design and Distribution

The survey design and distribution were described in Study A (Chapter 4, Section 4.2.5). This study reports the findings from Questions 9 and 17 (Appendix G) of the online survey questionnaire which addressed soldiers' perceptions of unit load carriage polices as they related to the demographic data (Questions 1 and 2: Appendix G) and self-reported loads (Question 8: Appendix G).

Textual data

At a strategic level, governing principles through which the Australian Army guides its training and operations are presented in a variety of military specific documents (Department of Defence, 1994). Depending on their purpose, these documents exist as 'doctrine', 'manuals', and 'publications'. Examples include *Land Warfare Doctrine* (LWD), *Manuals Of Land Warfare* (MLW) and *Land Warfare Publications* (LWP). For this study, the term 'doctrine' will encompass all of these documents.

Within a unit, an equipment load list for Patrol Order and Marching Order would normally be outlined in the unit's Standard Operating Procedures. Standard Operating Procedures are a set of orders that govern how a unit will carry out certain procedures (Department of Defence, 1994). Generic load lists for training exercises serve as examples. Amendments, variations or clarifications of Standard Operating Procedures may be presented in Standing Orders or Routine Orders (Department of Defence, 1994). Standing Orders are a set of orders issued by the unit that remain in place until specifically changed or withdrawn. These are longer-term orders and may describe procedures that are to remain in place for a given period (e.g. a year). Dress requirements for attending the shooting range are one example. Routine Orders are a set of short period instructions that apply for a short, defined period and assist in the day-to-day running of the unit (Department of Defence, 1994). Published regularly, these instructions are adaptable and capable of issue at short notice (Department of Defence, 1994). Authorisation to conduct a specific activity serves as an example. In this program of research these operating procedures and orders are collectively termed *unit policy*.

Procedure for collection of textual data

Textual data in the current study were sourced via three methods. First, strategic doctrines were sourced through the ADEL. Second, to ensure no doctrines were missed, the *Military Instructors* at the Royal Military College of Duntroon were contacted. These *Military Instructors*, who are selected as instructors due to their exemplary standards and general expertise in doctrinal knowledge, were able to refer the investigator to doctrines relevant to specific corps as well as those of an all-corps nature that might be applicable to the field of research. Third, unit policy documents were requested from units participating in the online surveys with the units requested to supply any and all unit policies that related to their unit's load carriage practices.

To capture relevant doctrine, the investigator accessed the ADEL website via the Defence Restricted Network. Using the mapping process available on the site, the investigator searched for doctrine that might be relevant to load carriage. Relevance was determined by reviewing the classification of each doctrine stream (e.g. 'Dismounted combat' versus 'Range safety') and the titles of the publications (e.g. 'Employment of Infantry' versus 'Geospacial support'. Once this process had been completed and relevant doctrine listed, the investigator repeated the process, this time through the use of 'drop down' menus on the website, that were corps-specific (that is, listing each corps and its doctrines) and concept-specific (e.g. 'operations'). The list of doctrines independently generated through the ADEL by both the investigator and the Military Instructors employing the above search strategy were combined to provide a single list of doctrines. Additional recommended texts from the Military Instructors were also included for review. All doctrines were then reviewed online through the ADEL site by the investigator. No source classified above ‘unrestricted’ was used without approval from the respective doctrine’s sponsor.

To obtain unit load carriage policies, unit POCs from the army units selected for the survey were contacted via email. Unit policies with a specific focus on load carriage were requested, along with other, less focused policies and documents that might be relevant to load carriage. Unit load lists were also requested. All documents were sent by the unit POCs to the investigator, electronically and securely over the Defence Restricted Network.

7.2.5. Data Extraction and Analysis

Survey Data

Data were extracted from the online survey by following the protocols described in Study A (Chapter 4, Section 4.2.6). Questions 1, 2, 8, 9 and 17 were downloaded as a Microsoft Office Excel (Microsoft, WA:USA, 2003) spreadsheet in order to address the research questions that underpinned this particular study.

Unit cooperation and survey response rate calculations were based on methods recommended by the ISER and AAPOR protocols as described in Study A (Chapter 4, Section 4.2.7) and Appendix H. Descriptive and inferential statistical analyses were employed to examine levels of self-reported compliance with unit load carriage policies across a range of tasks, and differences in compliance levels between corps. Frequency distributions and descriptive statistics were generated for all data variables, with means and standard deviations calculated for interval data and modal responses identified for categorical data. Before any comparative analyses were conducted, consideration was given to the assumption of normality by using the Kolmogorov-Smirnov test and the assumption of homogeneity of variances by using Levene’s test. An analysis of variance (ANOVA) was conducted to compare means between three or more groups (e.g. load weights and rating groups). As discussed in Study A (Chapter 4, Section 4.2.7), Bonferroni post-hoc tests for multiple comparisons were used to compare estimated marginal means.

Data were analysed using the IBM Statistical Package for the Social Sciences (SPSS) Statistics Version 19.0 for Macintosh and Windows (SPSS Inc., Delaware:USA, 2010), with the level of statistical significance set at 0.05.

Textual Data

Doctrine

A content analysis was conducted to analyse collected doctrinal text. Content analysis is a set of techniques used in qualitative and quantitative research to identify, measure, analyse, and describe written text (Elo & Kyngäs, 2007; Krippendorff, 2004; Waltz, Strickland, & Lenz, 2010). A distinctive feature of content analysis is its application to analysing documents, making it a useful approach for the current research (Elo & Kyngäs, 2007; Waltz, et al., 2010). Moreover, content analysis can cope with large volumes of data and can be adapted to cater for the unique requirements of the research question (Krippendorff, 2004; White & Marsh, 2006).

A content analysis can be conducted using an inductive or deductive approach (Elo & Kyngäs, 2007). An inductive approach is used when there is insufficient or fragmented knowledge about the phenomenon (Elo & Kyngäs, 2007). A deductive approach is utilised when the structure of analysis is employed on the basis of previous knowledge (Elo & Kyngäs, 2007), as was the case in the current body of research. On that basis, employing a deductive approach, the research questions were posed before the research was conducted (Neuendorf, 2002).

Elo and Kyngäs (2007) described three main phases for the conduct of a deductive content analysis: preparation, organising, and reporting. The preparation phase commences with selecting the 'unit of analysis'. As phrases and sentences are considered to be more difficult to use reliably (Waltz, et al., 2010), 'words' were selected as the unit of analysis. However, words often have multiple meanings and uses (Waltz, et al., 2010). To address this concern, a more sophisticated approach recommended by Robson (2002) was applied, involving differentiation between the sense of the words. On that basis, the phrases (or, if required, paragraphs) immediately surrounding the words were extracted to ensure that only relevant data were captured. 'Words' to be searched for in the text were derived from both the search terms of the literature review and terms known to the investigator to be specific to the ARA load carriage context. These terms were: 'carry', 'carriage', 'endurance', 'load', 'man-pack', 'march', 'marching order', 'pack', 'patrol order', 'porterage', 'rucksack', and 'webbing'.

Organisation of the captured data was achieved through the use of a structured categorisation matrix generated with the intention of extracting the data into a more usable form, an approach recommended by Sandelowski (1995). Categories for the matrix were derived from the foci of this program of research, namely load carriage context (Chapter 4), impact of load carriage (Chapter 5), and conditioning for load carriage (Chapter 6). As recommended by Elo and Kyngäs (2007) and Sandelowski (1995), the matrix was of a structured format where only content that fitted into it was chosen from the text. When terms matching those selected for the analysis were identified in the text, in each case the entire phrase in which the term appeared was captured within the matrix.[118] This matrix and its results are shown in Table 22 (later in this chapter).

Following establishment of the matrix, the next step, as described by Elo and Kyngas (2007) was to code the data according to categories. On this basis, Rourke and Anderson (2004) stated that the first step in developing a coding protocol is to identify the purpose for which it will be used. The purpose of the coding protocol in the current study was to answer the research question ‘What Australian Army processes and policies detail the loads to be carried by soldiers?’ With the information required to answer this question being already captured in the matrix, the investigator determined there was no need to further code the data. This decision is supported by the advice of Burnard (1996) and Sandelowski (1995), who stated that the key feature of content analysis is to classify texts into smaller content categories and that the framework chosen in the preliminary stage of a content analysis serves to put the data into a usable form for analysis. However, the investigator was open to any additional categories that might emerge during the conduct of the content analysis and the possible requirement to further categorise the data.

To enhance the internal validity of the results of the current research, multiple sources of data (doctrine, unit policies, and survey responses) were sourced and analysed to confirm or contradict emerging theories (Waltz, et al., 2010). Examples are provided in the results section of this chapter. External validity, reflecting in part the degree to which the research respondents were representative of the population to which the results are to be applied (Neuendorf, 2002), was achieved by identifying doctrines relevant to the study of load carriage through both specifically designed search engines within the doctrinal data base and input from subject matter experts from the Royal Military College of Duntroon. Links between the results and the data were demonstrated to ensure and enhance study reliability, as recommended by Polit and Beck (2004).

Unit documentation

The purpose of collecting and analysing unit policy data was to determine whether specific load carriage parameters were provided (i.e. maximum load, speed of march, load list, etc.) and whether readers were redirected to relevant doctrine from which to seek advice. The investigator extracted

---

[118] This matrix and its results are shown in Table 23.

data by typing annotations into an electronic journal when data relevant to load carriage or manual handling were found.[119] The designated ‘order’ number and section title of each section of interest within the policy document (e.g. 24. Manual handling within the unit), and subsequent text, were transcribed. As the unit policy data were only for use in a descriptive form as a means of triangulating and informing analysis of survey and doctrinal data, no additional coding or analysis of this unit policy data was required or conducted.

7.3. RESULTS

7.3.1. Survey Results

Unit Participation and Survey Response Rates

Unit participation and survey response rates were described in Study A (Chapter 4, Section 4.3.1). The demographic characteristics of survey respondents were also described in Study A (Chapter 4, Section 4.3.1, Table 3).

Self-Reported Responses Addressing Unit Policies

Respondents were requested to rate the operational loads they carried, against unit policies. As shown in Table 21, responses varied in range. However, over half of the respondents (54%) considered their loads to be heavier than those designated in their unit orders, with just under a third (28%) considering that their loads equated to those specified in unit orders.

Administration tasks, when compared to other tasks, were associated with the highest number of respondents (46%) rating their loads as *lighter* than those specified in unit policies. Mounted patrols (71%) and foot patrols (60%) were the tasks with the highest percentages of respondents claiming their loads were *heavier* than those specified in unit policies. Of all operational tasks, static patrols had the highest percentage of respondents (47%) who considered their loads to be commensurate with those specified in unit policies.

---

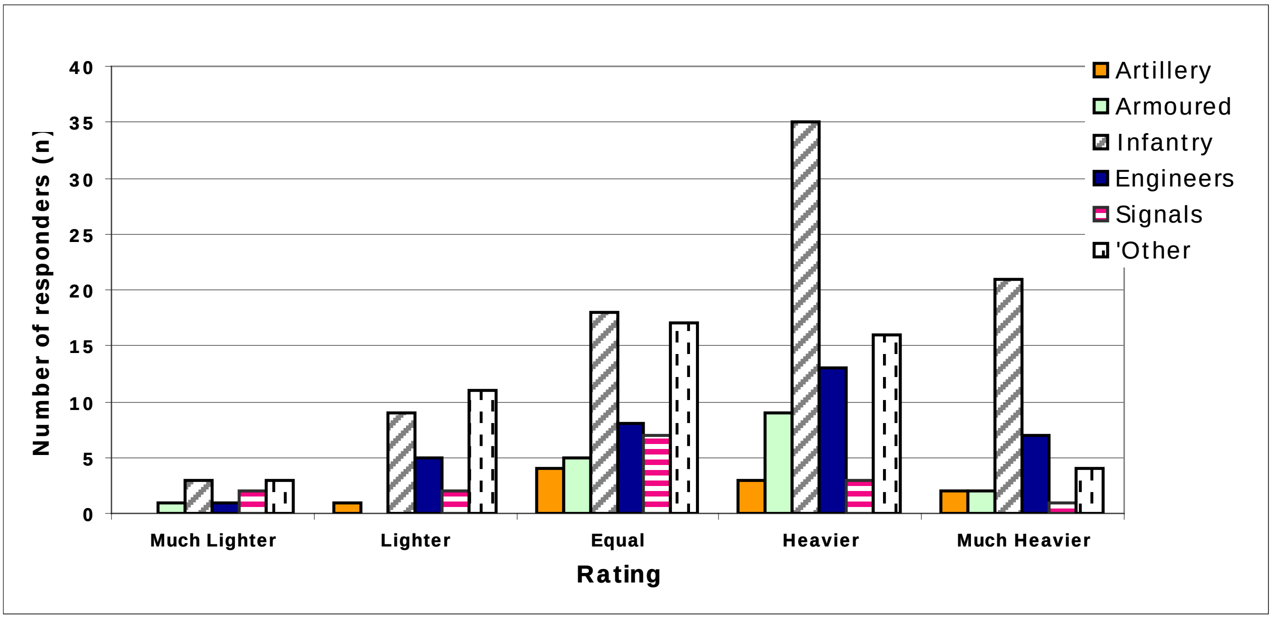
[119] This electronic journal was stored on the DRN with all identifying information replaced with alphanumeric pseudonyms for security.

Table 21: Distribution of responses comparing tasks performed against ratings of load carried in relation to loads specified in unit policies.

	Much Lighter ***n*** **(%)**	**Lighter** ***n*** **(%)**	**Equal** ***n*** **(%)**	**Heavier** ***n*** **(%)**	**Much Heavier** ***n*** **(%)**
Administration	4 (10%)	14 (36%)	13 (33%)	6 (15%)	2 (5%)
Static Patrols	0 (0%)	0 (0%)	7 (47%)	6 (40%)	2 (13%)
Foot Patrols	3 (3%)	13 (11%)	30 (26%)	43 (38%)	25 (22%)
Mounted Patrols	3 (7%)	1 (2%)	9 (20%)	24 (53%)	8 (18%)
TOTAL RESPONDENTS	10 (5%)	28 (13%)	59 (28%)	79 (37%)	37 (17%)

As different corps and units could have different load list policies, the responses were also reviewed in relation to specific corps. All corps had the majority of their responses (over 50%) lie in either the ‘equal’ or the ‘heavier’ classifications. Respondents from Infantry, Armoured, and Engineer corps had a greater tendency than personnel from other corps (graphically represented in Figure 17) to report carrying loads heavier than those specified in unit policies.

Figure 17: Distribution of corps rating responses for loads carried relative to unit policies.



A significant difference was found between corps in the self-reported ratings of how the loads being carried compared to the loads specified in unit policy, $F(4,208)=6.74, p=.001$. A post hoc Bonferroni comparison identified that respondents who considered their loads to be ‘much heavier’ (M=58.78 kg, SD=25.78 kg) than those specified in unit policy were indeed carrying heavier loads ($p<.01$) than those who considered their loads to be ‘equal’ to (M=39.42 kg, SD=17.45 kg) or ‘lighter’ than (M=39.11 kg, SD=21.61 kg) the loads specified in unit policies. Further, the loads carried by respondents who reported carrying ‘heavier’ loads (M=49.22, SD=18.47) than those specified in unit policy were heavier than loads carried by respondents who reported their loads to be ‘equal’ to those specified in unit policy (M=39.42 kg, SD=17.45 kg), but this difference did not reach statistical significance (p=0.053). The mean loads carried by respondents claiming their loads as ‘much lighter’ (*M*=53.04 kg, *SD*=24.94 kg) than those specified in unit policies were *heavier* than the mean loads carried by respondents who claimed their loads were ‘heavier’ (*M*=49.22 kg, *SD*=18.47 kg) than those specified in unit policies.

7.3.2. Textual Load Carriage Data

Doctrine and Policy

Relevant doctrine (*n*=22) identified during data sourcing, including key trade corps-specific publications, and general all-corps publications were reviewed. One additional text, recommended by the Military Instructors was excluded from review due to both its publication date (circa 1943) and difficulty in obtaining the fully published doctrine. Of the reviewed texts, eight publications referred to load carriage or porterage[120] activities. Of these eight doctrinal publications, five were infantry corps-specific and three were all-corps publications. Results of the content analysis are shown in Table 22.

Table 22: The content analysis of ARA doctrine - matrix and results.

What loads are to be carried by soldiers and what is the context of the load carriage?	REF: Australian Army. (2003). LWP-G 0-2-4. *All Corps Junior Commanders Aide-Memoir*. • Administration and Logistics …Lighten load to the essential for assault. REF: Australian Army. (2009a). LWP-G 7-7-1. *All Corps Soldier Skills*. • Combat Loadings. Commanders at all levels must be mindful of the soldier’s existing combat load. • Steeper slopes limit or deny access to vehicles and so access may be limited to dismounted soldiers or air insertion. For the dismounted soldier, movement is strenuous and the need to man-pack loads adds to the level of exertion required. • Unit SOP should include a load list of what goes where in a soldier’s pack and webbing, as well as any other special equipment to be carried by individuals. • The minimum equipment requirement for carriage on the soldier is specified in unit SOP, but can be modified by specific orders during force preparation. • Combat Loadings. Soldiers usually deploy into an AO[121] initially located in a secure base location from which other tasks are then launched. This means that the bulk of personal equipment not immediately needed for combat can be located there. REF: Australian Army. (1984). MLW 2-1-1. *The Infantry Battalion*. • Only items essential to the planned operation are carried and all loads are man packed. REF: Australian Army. (2009b). LWP-CA (DMTD CBT) 3-3-8. *Patrolling*. • The aim should be to keep the load of each soldier to the absolute minimum. REF: Australian Army. (2007). LWP-CA (DMTD CBT) 3-3-5. *Infantry Reconnaissance and Surveillance*. • In order to sustain themselves for the duration of particular tasks, R & S[122] assets may be required to carry heavy loads.

---

[120] Instances where soldiers act as porters to carry equipment and stores over terrain inaccessible by other means.
[121] Area of Operations.
[122] Reconnaissance and Surveillance.

What loads are to be carried by soldiers and what is the context of the load carriage?	REF: Australian Army. (2008). LWD 3-3-7. *Employment of Infantry*. • ...dismounted troops, often carrying heavy loads over distance for a prolonged period. • ...planners should aim for daily replenishment and the maintenance of forward troops as frequently as possible to minimise individual soldier loads. • The unit/BG SOP will dictate the lowest level of sustainment required to be carried in vehicles, by *sections* or patrols, and on the soldier. REF: Australian Army. (1986). MLW 2-1-2. *The Rifle Platoon*. • Platoons may be required to carry out porterage tasks… Porterage is normally an administrative requirement and much greater loads will be carried than for normal patrolling. • …A soldier should be able to carry about 1/3 of his body weight and still remain effective for extended operation periods. • Estimated weight[s] for individuals in a *section* dressed in Marching Order…varies from 43.755-50.947 kg or an average of 47.302 kg. • …Commanders must limit the load to be carried by soldiers to the minimum required for the operation or task. • Orders of dress not only list the items carried by the soldier, but imply the duration of the task. Platoon commanders should be aware of this relationship and select appropriate orders of dress. Orders of dress are given in Standing Operating Procedures (SOPs) and can be modified to suit the requirement. REF: Australian Army. (2005). LWP-G 7-7-4. *Combat Fitness Handbook*. • Typically, military tasks that consist of a large strength fitness component include manual material and ammunition handling, and carrying heavy loads over short distances. • On the battlefield, one has to be physically prepared to march with heavy loads exceeding 60 kg, to evacuate the injured, to dig weapon pits and to load heavy weapons systems.
What are the impacts of load carriage?	REF: Australian Army. (2009a). LWP-G 7-7-1. *All Corps Soldier Skills*. • If individual combat loads are excessive, there is an impact on team members' ability to carry any casualty's equipment to a safe area, then backload • There are limits as to what can be carried effectively and still enable the soldier to be combat effective. • Load carrying equipment always increases the profile of the individual soldier and should be reduced as much as possible. • The advantages of comfort and increased self-sufficiency must be weighed up against the disadvantage of reduced efficiency; as the load increases the efficiency of the soldier decreases. REF: Australian Army. (2008). LWD 3-3-7. *Employment of Infantry*. • Higher temperatures affect the performance of soldiers and reduce their capacity to carry combat loads. REF: Australian Army. (2005). LWP-G 7-7-4. *Combat Fitness Handbook*. • The energy cost of walking with backpack loads increases progressively with increases in the weight carried, body mass, and the walking speed or grade. The type of terrain also influences energy cost. • Common injuries associated with prolonged load carriage include foot blisters, stress fractures, back strains, metatarsalgia, rucksack palsy … and knee pain. Load carriage can be facilitated by lightening loads, improving load distribution, optimising load carriage equipment and taking preventive action to reduce the incidence of injury. • Locating the load centre of mass as close as possible to the body's centre of mass results in the lowest energy cost and tends to keep the body in an upright position, similar to unloaded walking. Loads carried on other parts of the body result in higher energy expenditures. Each kilogram added to the foot increases energy expenditure by 7 to 10 per cent; each kilogram added to the thigh increases energy expenditure 4 per cent. Hip belts on rucksacks should be used whenever possible as they reduce pressure on the shoulders and increase comfort. Low or mid-back load placement might be preferable on uneven terrain but high load placement may be best for even terrain. • The distribution of equipment around the body is one of a number of governing factors controlling how efficiently soldiers march. It not only affects the marching style, but energy consumption as well. Equipment should be spread evenly so that both legs are carrying the same weight and curvature of the spine is as near to normal as possible.

What physical conditioning is required for load carriage?	REF: Australian Army. (2005). LWP-G 7-7-4. *Combat Fitness Handbook*. • Physical training that includes aerobic exercise, resistance training targeted at specific muscle groups and regular road marching, can considerably improve road marching speeds and efficiency. • Typically, military tasks that consist of a large strength fitness component include manual material and ammunition handling, and carrying heavy loads over short distances. • On the battlefield, one has to be physically prepared to march with heavy loads exceeding 60 kg, to evacuate the injured, to dig weapon pits and to load heavy weapons systems.

As the remaining 16 documents, which held no load carriage information, were classified as 'Restricted' no details of these doctrines are provided, with security prudence dictating no value in requesting and obtaining document clearances for the policies that were not to be used further.

Of the eight Australian Army doctrines that were identified as providing information on soldier load carriage, none were specific load carriage doctrines. The doctrines investigated in this program of research were not of a hierarchical structure, meaning that no doctrine had precedence over another. Three doctrines were general to all corps and would typically be used by soldiers from any Australian Army corps (Australian Army, 2003, 2005, 2009a). One of these doctrines (Australian Army, 2005) was directed towards personnel qualified to conduct physical training.

Five doctrines were Infantry Corps specific and would typically be read by infantry personnel (Australian Army, 1984, 1986, 2007b, 2008b, 2009b). Of these five doctrines, one was written for commanders who might have infantry soldiers attached to their units (Australian Army, 2008b). That doctrine would therefore typically be read by commanders from all corps, although designed to specifically address the employment of infantry personnel.

The Australian Army (1986) *MLW 2-1-2, The Rifle Platoon* and the Australian Army (2009a) *LWP-G 7-7-1 All Corps Soldier Skills* doctrines provided the most guidance regarding load carriage weight and context. The focus of text in these two documents was on load carriage equipment and dress and limiting loads to being light as possible. Only the Infantry text, *The Rifle Platoon* (Australian Army, 1986), provided any numerical guidance as to the loads soldiers carry, stating that '*A soldier should be able to carry about 1/3 of his body weight and still remain effective for extended periods.*' The doctrine then redirected readers to the annex, which provided a load list with tabulated weights of soldier equipment. The annex reiterated the one-third body weight recommendation, stating that soldiers should not carry a load heavier than that into battle. The remaining six doctrines, consisting of up to 300 pages of text, provided considerably less guidance for load carriage: One doctrine provided three sentences (Australian Army, 2008b), one provided two sentences (Australian Army, 2005) and the remaining four doctrines provided only a single sentence on load carriage weight or context throughout their entire text (Australian Army, 1984, 2003, 2007b, 2009b). The focus of the information provided in these six doctrinal entries was on the planning of load carriage or the requirement to carry heavy loads (Australian Army, 2005). Among these latter texts, one doctrine, the Australian Army (2005) *LWP-G 7-7-4 Combat Fitness Handbook*, provided a numerical figure for the heavy loads soldiers are expected to carry, this being *'exceeding 60 kg'*. The purpose of this statement was to advise the requirement to condition soldiers to carry these loads.

In regards to the impacts of load carriage on the soldier, the Australian Army (2005) *LWP-G 7-7-4 Combat Fitness Handbook* provided the greatest volume of information. The doctrine discussed the impacts of soldier load weight, load placement, terrain and speed on soldier posture, marching and technique, and discussed common load carriage injuries. As the text focused on conditioning, the higher volume and nature of information on the impacts of load carriage impact were understandable. In addition to being one of the leading doctrine discussing load carriage load and context (when assessed in terms of volume of information), the text also provided four sentences on the impact of load carriage, the foci of which were on performance, logistics and tactics. The only other doctrine to mention the impacts of load carriage conditioning was the Australian Army (2008) *LWD 3-3-7 Employment of Infantry*. This text, rather than discussing the impacts of load or load carriage context on the soldier, discussed the impact of the load carriage context (environment) on load carriage and soldier performance stating that '*Higher temperatures affect the performance of soldiers and reduce their capacity to carry combat loads.'* Of note, none of the five *infantry* doctrines discussed the impacts of load carriage and the load carriage context on the soldier. As such, no guidance was provided to commanders describing the potential impacts of a load carriage task on soldier performance, such as impaired mobility and impaired lethality.

Only one doctrine (Australian Army, 2005) discussed conditioning for load carriage. While the focus of that doctrine was on physical conditioning, the text was generally restricted to discussing the need to conduct conditioning programs and the inclusion of load carriage as part of a conditioning program. No specific load carriage conditioning guidance (that is, training dose in relation to the F.I.T.T. principle of conditioning)[123] was provided.

Two discernible gaps were apparent in the doctrinal literature. First, none of the reviewed doctrine discussed load carriage weight and context, impacts of carrying loads, and conditioning for load carriage in a single doctrinal reference. Second, no linkages were identified between the guidance on load carriage provided in separate doctrines.

---

[123] See Section 6.2.4 and Section 6.2.

Unit Policies and Orders

Although two units failed to respond to the researcher's request for copies of unit policies in relation to load carriage, the other six of the eight units approached all explained that their loads were based on unit field equipment lists detailed in unit policies. Four of these six units provided their standard operating equipment loading lists. Of the remaining two units, one unit was in the process of reviewing its policy while the other stated that its load lists were vehicle based and would therefore be of limited value.

Although two unit policies included mention of auditing of equipment, all the unit policies were limited to providing detailed unit equipment load lists. Due to the nature of the load list details included in the unit policies, detailed load lists were withheld from publication in this thesis. However, based on assigned weight per piece of equipment, total anticipated load data suggested soldier loads of 34–44 kg. In all instances these loads excluded the additional loads detailed as 'section stores' or 'platoon stores'.[124] To maintain unit anonymity, the corps affiliated with the provided unit policies are not noted in this thesis.

7.4. DISCUSSION

7.4.1. What doctrines and policies detail the loads to be carried by Australian soldiers?

The U.S. Army has a distinct load carriage doctrinal publication, but this study failed to find an equivalent in the ARA. The eight doctrines identified to provide information on soldier load carriage were not specific load carriage doctrines. This lack of dedicated focus may explain why the load carriage guidance was limited to generic information. Generally, the guidance given by these documents was to minimise soldier loads where possible. For example, '*Commanders must limit the load to be carried by soldiers to the minimum required for the operation or task*'. The potential need for soldiers to carry heavy loads was also highlighted. For example, *'In order to sustain themselves for the duration of a task…assets may be required to carry heavy loads'*. In both instances no numerical figures to quantify what constituted 'minimum' or 'heavy' were provided. Indeed, what is considered 'minimal' or 'heavy' may vary between commanders. As an example of differences in perception, three research papers on load carriage which included the term 'heavy' in the title employed loads ranging from 36 kg up to 50 kg and over (Attwells, et al., 2006; Drain, Orr,

---

[124] A description of *section* and *platoon* can be found in Appendix A.

Billing, & Rudzki, 2010; Harper, et al., 1997).[125] While all of these loads can be considered 'heavy', the example demonstrates the range of load weight that can be construed by different researches as being a heavy load.

One Infantry doctrine did provided guidance in regard to load weight, namely that loads of one-third body weight should allow soldiers to remain combat effective for extended periods of operation. The validity of this recommendation was weakened by two factors, these being the load weights detailed in the doctrine and the age of the doctrine. First, following provision of the weight guidance of one-third body weight within the text and again within an annex, load lists provided in the annex estimated load weights for individual soldiers when dressed in Marching Order as varying '*from 43.755 to 50.947 kg, or an average of 47.302 kg'*. Should this be the case, the average Australian infantry soldier would have to weigh at least 142 kg to remain within the load range provided and still be effective for extended periods. Although it can be argued that soldiers would normally remove their backpacks during contact with the enemy to reduce their weight (that is, they would convert from Marching Order to Patrol Order), the load lists provided acknowledge that this weight excluded additional equipment that must be carried within the *section*.[126] Second, although the load weight figure may provide some guidance on what a 'normal' range of load should be for a soldier, the validity of this document is questionable as it was written in 1986, when Australia's last major conflict had been the Vietnam War. The outdated weapons systems and the failure to include key equipment used in current operational theatres (e.g. body armour) in the doctrine's annexed load lists limited the transferability of the load carriage guidance in this doctrine to the current operational context.

The impact of load carriage on soldiers is mentioned briefly in several doctrines. Again, the information provided is generic. '*There are limits as to what can be carried effectively and still enable the soldier to be combat effective*' and '*as the load increases the efficiency of the soldier decreases'* are two examples. As this information is quite generic, commanders may not appreciate the nature or extent of the impacts of load carriage on both on the soldier and the mission. As discussed in the literature review (Chapter 2), the Historical Review of Soldier Load Carriage (Chapter 3) and Study B (Chapter 5), excessive loads can impact on soldier mobility and lethality. No doctrine provided detail on the impacts of load carriage on task performance, but one doctrinal manual (Australian Army, 2005) provided comparatively comprehensive details on the impact of

---

[125] While all three references are from authors of different countries, the three countries represented (Australia, the U.K. and the U.S.) have been identified as carrying similar loads to Australian soldiers (Study A: Chapter 4, Section 4.4.1).
[126] A *section* is a group of eight to ten personnel (see Appendix A).

load on energy cost, with guidance as to how to minimise energy loss. As an example *'locating the load centre of mass as close as possible to the body's centre of mass, results in the lower energy cost...'* . This same document included a paragraph outlining the common injuries associated with load carriage. Guidance was given on how to minimise such injuries: reducing load weight, improving load distribution, optimising equipment and taking preventive action. Unfortunately this doctrine was targeted towards qualified physical training personnel and, with no other doctrine citing to this document, the information provided in this manual had a limited distribution.

The need to minimise loads was acknowledged in the doctrinal manuals, yet limited guidance was given as to achieving this recommendation. One doctrine (Australian Army, 2003) discussed the possibility of storing non-mission-essential stores in a secure base; another (Australian Army, 1984) explained that *'only items essential to the planned operation are carried'*. The effectiveness of this guidance would be influenced by readers' knowledge of what constituted 'mission-essential'. In this regard, three doctrinal texts directed readers to unit policies, explaining that, for example, '*the unit/BG SOP will dictate the lowest level of sustainment required to be carried'* (Australian Army, 1986, 2008b, 2009a). However, review of these unit policies found these documents to be generally limited to load and equipment lists only. These equipment lists were generic and designed to capture all unit personnel, rather than addressing specific, mission-essential, load carriage requirements. That is understandable given that the nature of missions varies. However, doctrine directed readers to unit policies for what constitutes mission essential stores when the unit policies provided only generic equipment lists. It is clear that no guidance was given for soldiers as to what determined mission-essential equipment, and as such no guidance was available as to which loads to remove in order to reduce loads to mission-essential items.

Overall, the findings of this study suggest that the doctrines and policies governing load carriage in the ARA were disjointed and irregular, in both dispersion through corps and level of detail. The advice given was limited and mostly generic, citing the need to minimise loads to mission-essential loads. Guidance was dispersed through several doctrines: the requirement for soldiers to carry load, the impacts of these loads, and the need to condition soldiers (and methods for conditioning them) serve as examples of this dispersion. None of these doctrines provided links to supporting information or guidance in other doctrines. Three doctrines indicated that unit policies were to determine the loads soldiers were to carry. However, the unit policies reviewed were limited to providing load and equipment lists, with no advice given on the impact of load weights or load carriage contexts, and no direction provided on load carriage conditioning. As such, the responsibility would rest with the commander and individual to use multiple sources (of which they may or may not be aware) to make decisions about the loads to be carried. Even then, the advice given from the doctrinal sources would be generic and might be of limited practical use: *'carry mission-essential stores only'* and '*lighten loads'* are examples.

7.4.2. Do soldiers consider the loads they carry to meet with unit policies?

Only one doctrinal document, an infantry manual, provided a numerical reference to load carriage weight (Australian Army, 1986). When infantry loads identified in Study A (Chapter 4) were compared to this doctrinal text, over two-thirds of respondents reported carrying loads heavier than the recommended one-third body weight in their Patrol Order, which is the minimum order of dress worn when in contact with the enemy. Furthermore, the mean infantry Marching Order load reported in Study A (Chapter 4) of 60.9 kg (*SD*=15.7) was notably heavier than the estimated Marching Order load in the doctrine, being *'an average of 47.3 kg'.* A potential reason for this difference might be infantry soldiers carrying loads in excess of their recommended unit policies. Infantry soldiers who rated their carried loads as equal to their unit's policies during military operations self-reported carrying a mean load of 55.5 kg, a load heavier than the loads noted in the doctrine. These results suggest a trend similar to that identified by the Task Force Devil Combined Arms Assessment team (Task Force Devil Combined Arms Assessment Team, circa 2003), that soldiers' loads were heavier than those recommended in doctrine.

The age of the doctrines described above provides a potential reason for this trend. The U.S. doctrine was released in 1990; the Australian doctrine was released in 1986. In the Australian context, in 1986 Australia's last major conflict had been the Vietnam War. On that basis, when the loads carried by Australian soldiers in Vietnam (as gathered in Chapter 3) were compared to doctrine, the loads carried (30 to 56 kg)[127] appear to be commensurate with the doctrinal range (43.8 to 51 kg). When this finding is considered against the findings of the historical review which identified a progressive increase in soldier loads since the World Wars, the failure of load carriage doctrine to remain current in light of current operational theatres might explain the discrepancies between doctrines and current load carriage practices.

More than half of the survey respondents rated the loads they carried during military operations as heavier than their unit SOP loads, with confirmatory findings suggesting that the reported loads carried by these respondents were heavier than those of respondents claiming their loads to be equal to or lighter than loads documented in unit policy. When respondents' results were compared

---

[127] This load includes Patrol Order (lowering the range of loads) and additional stores (increasing the range of loads).

against the weights of loads specified in unit policies, general alignment was found between respondents' perceptions of their loads and the loads specified in unit policy. Self-reported loads rated as 'much heavier' and 'heavier' than those specified in unit policies were indeed heavier than the corresponding range of loads specified in unit policies. Loads that were considered equal to unit loads were within the bracketed range of unit policies. These findings suggest that the majority of respondents were aware of their unit policy regarding loading requirements. Moreover, the results suggest that the majority of respondents were carrying loads above those specified in their unit policies. With unit policies providing a dedicated load list and load weights specified in policy, as determined in this study by summing the weights of individual items on the load list, one potential cause of the heavier load weights would be soldiers carrying additional equipment. The potential reasons for soldiers carrying additional equipment, whether by individual choice or superior direction, are not known.

One anomaly did present whereby respondents who rated their loads as 'much lighter' than those specified in unit policy (*M*=53.04 kg) were carrying a mean load heavier than respondents who claimed their loads as heavier than those specified in unit policy (*M*=49.22 kg).Three potential reasons for this unexpected result were considered. Firstly, the loads carried by these respondents were indeed 'much lighter' than those specified in unit policy. Secondly, a recall bias may have existed, whereby the recall of respondents, either concerning the loads they carried or the unit policies at the time, were inaccurate. Both the time period involved (Clarke, Fiebig, & Gerdtham, 2008; Coughlin, 1990) and the significance of the event to the respondent (Coughlin, 1990) are known to impact on recall accuracy. In this instance, with the event potentially being several (or more) years earlier and the significance of the loads carried by respondents, in relation to unit orders, potentially low, errors in recall are a noted possibility. Finally, a measurement error, which may be caused by a respondent unintentionally providing incorrect information due to the nature of a question, may have occurred (Biemer & Lyberg, 2003). In this instance, the measurement error may have led the respondents to grade their unit policies in relation to the loads they carried (policy load being lighter than carried load) rather than the loads they carried in relation to their unit policies (carried load being lighter than policy load). On this basis, the respondents may have been stating that the loads directed in their unit policies were 'much lighter' than the loads they carried.

Ultimately, the results of this study suggest that either doctrine and unit policies are not being adhered to, or that the guidance provided in doctrine and unit policies is not meeting the requirements of commanders and individuals on military operations. Furthermore, these concerns are not mutually exclusive. For example, a potential scenario arises where commanders and soldiers, realising that doctrine and unit policies are inadequate, modify load lists to suit requirements. Unfortunately, although this amendment may be necessary, no guidance exists as to what would constitute maximal loading or overloading. Ultimately, the results of this disconnect between doctrine, unit policies, and actual solder loads was evident in the high number of respondents carrying loads heavier than doctrine or unit policy dictated.

7.5. LIMITATIONS AND FUTURE RESEARCH

With the great number of doctrines in use in the Australian Defence Forces, the potential exists that some doctrines relevant to the subject of load carriage might not have been identified. While every effort was made to identify all defence doctrines relevant to the subject, it is acknowledged that other, less well publicised, doctrines may exist. Considering this limitation, use of subject matter experts in this area of doctrinal knowledge from the Royal Military College of Duntroon ensured that the doctrines most commonly in use by the wider ARA community were captured.

The potential impacts of these findings extend beyond the loading of military soldiers to current and future research. Norton, et al. (2003), for example, specifically stated that the 34 kg load they used in their research was based on the U.S. Foot Marches Field Manual (FM 21-18). Thus, although the researchers made an effort to align the load weights used in their research with current military load carriage practices, their loads were lighter than the loads actually being carried by U.S. soldiers (Task Force Devil Combined Arms Assessment Team, circa 2003). On this basis, the findings of the current study may help to inform future load carriage studies through improving alignment of load weights selected for load carriage research with the actual load weights soldiers claim to be carrying.

7.6. SUMMARY AND CONCLUSION

The findings of this study suggest that the doctrines and policies governing load carriage in the ARA are disjointed and irregular, in both dispersion through corps and level of detail. This study failed to find a single ARA doctrine dedicated specifically to soldier load carriage. However, eight separate defence doctrines focusing on various military topics (infantry tactics, general conditioning, etc.) were found to contain information on ARA load carriage practices. Overall, the advice given in these doctrines was limited and mostly generic. This generic guidance was dispersed through several doctrines, with no linkages between doctrines provided. One older infantry doctrine provided some guidance on the load weights to be carried by soldiers, being no more than one-third the carrier's body weight; that doctrine later suggested that soldier loads averaged 47 kg, implying that an average soldier needed to weigh 142 kg to meet the recommendation. A subsequent review of survey data revealed that over two-thirds of the respondents reported carrying loads heavier than this body weight recommendation. Of note, three doctrines redirected the reader to unit policies for further direction on equipment to be carried.

The guidance provided by unit policies was limited to outlining equipment load lists. A detailed review of two equipment load lists provided by units found that these equipment lists equated to loads ranging from 34 to 44 kg, a load noticeably lower than that reported to be carried by soldiers on operations. No advice was given in these unit policies to inform the commander on the impact of load weights carried or the impacts of the load carriage context, or to provide load carriage conditioning guidance. As such there is reliance on commanders and individuals to use multiple sources (of which they may or may not be aware) to make decisions about the loads to be carried. Even then, the advice given by these sources would be generic and could be of limited practical use.

More than half of the survey respondents rated the loads they carried during military operations as heavier than their unit policy loads. Respondents who reported carrying loads heavier than unit policy requirements were found to be carrying loads heavier than respondents who rated the loads they carried as equal to unit policy requirements. Furthermore, the respondents who reported carrying loads equal to loads directed in unit policies were indeed reporting load weights commensurate with these unit policies.[128]

In conclusion, the reviewed doctrines and polices governing ARA load carriage were disjointed and irregular in dispersion and level of detail provided. A potential disconnect also exists between either doctrine and the unit polices being followed, or the guidance provided in doctrine and unit policies not meeting the requirements of commanders and individuals on military operations. The impacts of these potential policy disconnects, together with the disconnects in load carriage conditioning (discussed in Chapter 6), injuries and reductions in soldier performance associated with load carriage (Chapter 5), and the risks posed by the ARA load carriage context (Chapter 4) are analysed and evaluated in the next chapter (Chapter 8).

---

[128] Load weights being determined from unit load lists.

8. ANALYSIS AND EVALUATION OF THE RISKS ASSOCIATED WITH SOLDIER LOAD CARRIAGE

8.1. INTRODUCTION

Guided by the Risk Management Framework (RMF),[129] preceding chapters in this thesis have *established the context* of contemporary military load carriage (Chapters 2 through 4) and *identified risks* associated with load carriage tasks (Chapters 5 through 7).

The established ARA context of contemporary load carriage presents as soldiers carrying heavier *absolute* loads than in previous conflicts, with mean self-reported Marching Order loads of 56.7 kg (*SD*=15.3 kg) on operations over the last decade (2001-2010). These operational loads differed between corps, with Infantry, Artillery and Engineer soldiers generally carrying heavier loads (*absolute* and *relative*) than other corps. Interestingly, female soldiers, regardless of load carriage dress type, were found to carry lighter *absolute* loads (*M*=26.4 kg, *SD*=13.3 kg) than their male counterparts (*M*=39.0 kg, *SD*=17.5 kg) but similar *relative* loads (female: *M*=43% BW, *SD*=21% BW; male: *M*=47% BW, *SD*=21% BW). Finally, lighter loads were carried during physical training (PT) (*M*=37.5 kg, *SD*=12.6 kg) and field training exercises (*M*=47.2 kg, *SD*=16.0 kg) compared to loads carried on operations. Based on these findings and the findings in the literature (Chapter 2), it was concluded that the loads carried by Australian soldiers constitute a source of risk, with injuries and deaths reported in previous historical conflicts (Chapter 3)[130] and injuries and loss of performance (such as in mobility and marksmanship) observed in the literature (Chapter 2)[131] and reported in the ARA population (Chapter 5).

The risks associated with carrying loads were found to be influenced by the contexts in which the loads were carried, with some researchers considering the context (like speed of march or terrain) as having a greater impact on the soldier than the loads carried (Soule, et al., 1978). Study A examined the broad context in which ARA loads were carried at the time of the study, and within this broad context are multiple sub-contexts. The context for load carriage was found to range from flat road terrain to steep hills through heavy bush, with load carriage durations ranging from under

---

[129] Described in Chapter 1, Section 1.3.

[130] Described though out Chapter 3, a historical review of soldier load carriage.

[131] Described in Chapter 2, Section 2.3.4.

60 minutes to over three days. Tasks conducted while carrying load were also varied and included administration tasks, mounted patrols and patrols on foot. Among these contexts, and as observed through history (Lothian, 1921: Marshall, 1980), carrying loads on foot remains the dominant load carriage task for soldiers (50% of tasks reported in Chapter 4: Study A).

Military load carriage, defined by both load weights and context, can generate risks for the Australian soldier, affecting both their chance of being injured and their military performance potential. These risks to individual soldiers can create downstream risks for Force generation and Force sustainment, and for individual mission success. Analysis and evaluation of these risks is necessary for efficient and effective risk treatment plans. This chapter details the application of the RMF steps of *risk analysis* and *risk evaluation* for this program of research, as a means of synthesising and extending the findings from the preceding chapters in order to:

- develop an overarching picture of key injury and performance risks associated with load carriage and their sources; and
- gauge the likelihoods, consequences and relative importance of each identified risk for ARA units and missions.

Risk analysis generates estimates of the *likelihoods* and *consequences* of particular risks, which can then be combined (often by multiplying likelihood by consequence or using a risk matrix) to provide an estimate of *risk level* (Standards Australia Working Group MB-002-01, 2004a). Risk criteria might include, for example, tolerable risk levels for particular risk types, as well as particular risk types which will never be tolerated or which are never of real concern. These risk criteria are established early in the RMF processes, by considering the context of operation and the objectives of the key stakeholders. The evaluation of identified risks then informs decisions regarding which risks need treatment and treatment priorities (Standards Australia Working Group MB-002-01, 2004a).

8.2. RISK ANALYSIS

The risk analysis technique for this program of research revolved around a *level of risk* matrix drawn from the Military Risk Management (MRM) framework. As described in Chapter 1, the MRM is closely aligned with the RMF, and guides the Military Appreciation Process (MAP), a process which guides military commanders and leaders to make well-reasoned and logical decisions (Australian Army, 2007a). Use of the MRM *level of threat* matrix provides for military commanders and leaders a framework with which they are familiar and which can integrate with the MAP when making decisions. On this basis, the MRM *level of risk* matrix was selected in place of a more general risk matrix (Standards Australia Working Group MB-002-01, 2004a, Table B3, p.56) to guide the risk analysis discussed in this chapter. The MRM *level of risk* matrix, modified for the current risk analysis[132] is shown in Table 23.

Table 23: The MRM level of risk matrix (Australian Army, 2007a, p. ANNEX J), modified for the current risk analysis.

			CONSEQUENCE		
LIKELIHOOD	**Catastrophic**	**Critical**	**Serious**	**Disruptive**	**Minor**
Almost Certain	Extreme	Extreme	High	Substantial	Medium
Likely	High	High	Substantial	Medium	Low
Occasional	Substantial	Substantial	Medium	Medium	Low
Rare	Medium	Medium	Medium	Low	Low
Highly Improbable	Low	Low	Low	Low	Low

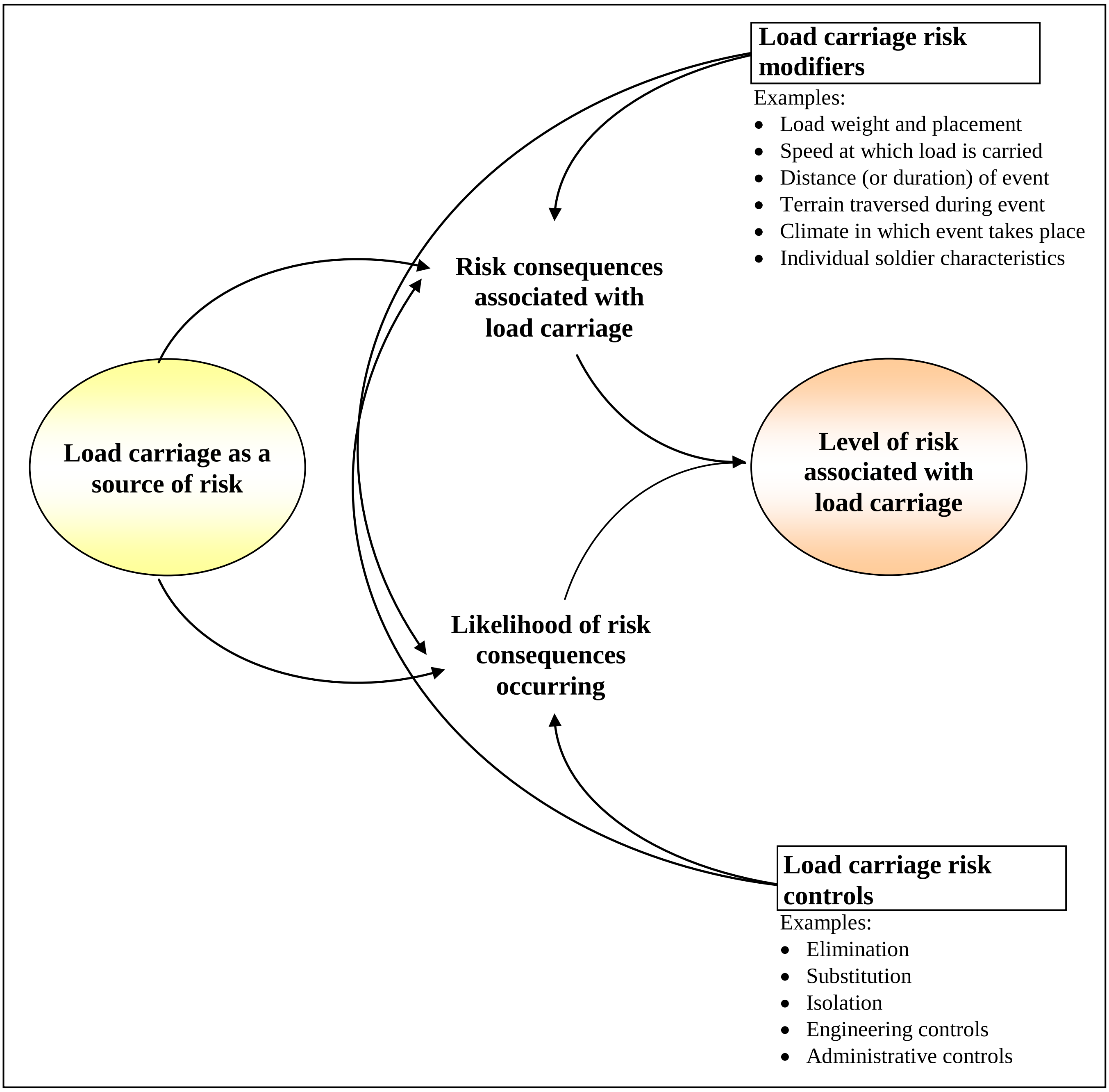
The *level of risk* for an event (in this instance a load carriage event) is determined by combining the severity of potential *consequences* associated with the event with the *likelihood* of these consequences occurring (International Electrotechnical Commission, 2009). As such, the *level of risk* associated with an event can be determined through the use of a *risk-ranking matrix* which combines scales of *consequence severity* and *likelihood* (Standards Australia Working Group MB-002-01, 2004a). Therefore, to align with the MRM framework's *level of risk* matrix, the *consequence* scale and *likelihood* scale selected for this current program of research were also drawn from the MRM framework and are discussed in detail later in this current chapter.

To further inform the risk analysis, factors that can influence the *level of risk* associated with a load carriage event by influencing the risk *consequences* associated with the event and the *likelihood* of the risk consequences occurring were considered. These factors include *risk modifiers*, which might alter the *level of risk* associated with a load carriage event (examples of risk modifiers are speed of march and terrain), and *risk controls,* which may be employed to mitigate risks associated with a load carriage event (examples of risk controls are physical training and load carriage policy). Figure 18 graphically represents the risk analysis process employed in the current program of research and the lines of discussion that follow in this chapter.

---

[132] For the purposes of this research the MRM level of risk matrix was modified by removing the associated numeric risk index references that guide endorsing authorities for non-operational activities.

Figure 18: A summary of the risk analysis approach for the current program of research.



8.2.1. Risk consequences associated with load carriage events

Physical injury and a reduction in military task performance are two potential consequences for soldiers participating in load carriage events (Knapik, et al., 2004). The review of the literature (Chapter 2) associated a variety of injuries with load carriage events. These injuries ranged from skin blistering to joint injuries and neurological trauma (like brachial plexus palsy and meralgia). Further, the review identified that load carriage can impact on soldier mobility, lethality, cognitive task performance, and general task performance. Study B (Chapter 5) confirmed the risk for the soldier of these consequences occurring during load carriage events within the ARA context.

Study B (Chapter 5) identified load carriage events as a cause of a variety of injuries suffered by ARA soldiers. Based on OHSCAR data, the majority of these injuries (91%) were classified as minor and 7% were classified as serious personal injuries. The lower limbs and back were the leading sites of load carriage injuries, with previous data from the ADF Health Status Report indicating that lower limb injuries incurred the highest number of working days when compared to other body sites of injury in the ADF context (Defence Health Services Branch, 2000).

In Study B (Chapter 5), survey respondents reported that during or immediately following load carriage they perceived reductions in military task performance capability in five key performance areas (mobility, marksmanship, grenade throwing, cognitive attention and general task performance). In particular, mobility was thought to be substantially reduced by current ARA load carriage practices. These findings from Study B regarding the effects of load carriage on military task performance supported objective findings from prior studies reported in the current literature review (Chapter 2), and confirmed that these performance effects of load carriage were perceived by Australian soldiers.

Evidence gathered in both the literature review and Study B showed that potential consequences for the soldier of participating in load carriage events included physical injury to the carrier and perceived impairment of their performance of military tasks. These potential consequences of load carriage for the soldier would in turn have downstream impacts for the military, most notably impacts on military force generation, force maintenance and mission accomplishment.

Injuries suffered by soldiers when participating in load carriage training or load carriage tasks have the potential to reduce the ability of a military force to generate trained soldiers. Injuries may delay soldiers' military training while they undergo rehabilitation or may lead to permanent loss of soldiers from the military due to their inability to continue training for a significant period (Pope, et al., 1999). Similarly, trained soldiers who suffer injuries may be less able to carry loads or to meet the physical requirements of operational deployments, thereby reducing the ability of the military to sustain a pool of trained, deployment-ready soldiers. Furthermore, as identified in Study B (Chapter 5), soldiers who have suffered an injury due to a load carriage event may be at increased risk of suffering a future load carriage injury; hence an ongoing pattern of injury, recovery and rehabilitation is created which again affects force maintenance. During military operations, reduced force numbers caused by load carriage injuries can increase the load carriage exposure of other soldiers due to requirements to increase their numbers of patrols to fill in for a missing capability.

The impairment of task performance associated with load carriage has a further potential to affect military force sustainment. Potential reductions in mobility, lethality and attention to tasks can increase the vulnerability of soldiers to combat wounds and even fatalities. Reductions in mobility while carrying loads may increase a soldier's exposure to enemy fire, with the soldier moving more slowly between areas of protective cover. The findings of Pandorf, et al. (2002) illustrate this point: the time taken to complete a section of an obstacle course with four step-overs increased from a mean of 5.4 seconds to a mean of 6.8 seconds as loads increased from 14 to 27 kg. If a soldier was exposed to enemy fire from an AK-47 assault rifle on full automatic fire,[133] this delay would expose the soldier to an additional 14 bullets per engaging enemy rifle when negotiating this single obstacle. A means of reducing the moving soldier's exposure to enemy fire is accurate application of lethal force onto the position of the enemy by fellow soldiers (Australian Army, 1986). However, with the reduction in lethality skills (like marksmanship and grenade throwing ability) associated with soldier load carriage, protective fire for the moving soldier, who in turn is more exposed due to reduced mobility, may be reduced and the enemy may be more able to apply effective weapon fire towards the exposed soldier. Finally, impairments in attention to task associated with load carriage may reduce the soldier's concentration and increase the risk of injury or mortality. On operational duties, for example, impaired concentration could reduce a soldier's ability to identify signs of improvised explosive devices (IEDs) when on patrol. The potential effect on military force sustainment of impaired attention to task (like scanning for IEDs) associated with load carriage tasks is made more poignant given the recent media release claiming that IEDs were associated with 36% of Australian soldier combat injuries (18 of 50 affected personnel) in 2011 and 40% of Australian soldier mortalities (13 of 32 deaths) during the Afghanistan conflict (Department of Defence, 2011a).[134]

Soldier injuries and impaired task performance, combined or in isolation, have the potential to affect mission objectives. Where possible, a soldier who sustains a serious injury or wound during a mission is evacuated within one hour of wounding (Department of Defence, 2011a). During this one hour period, fellow soldiers must secure the area from possible further enemy action, prepare for the arrival of evacuation assets (clearing and marking landing pads for helicopters) and provide immediate first aid treatment to the wounded soldier or soldiers (Department of Defence, 2011a). Consequently, mission objectives may be delayed, modified or abandoned entirely if a soldier is seriously injured.

---

[133] Based on a cyclic rate of ammunition fire of 600 rounds per second (Rottman & Shumate, 2011).

[134] Figures as of 21 November 2011 (Department of Defence, 2011a).

Impaired performance associated with soldier load carriage tasks can affect the ability of soldiers to complete tasks associated with mission success. For example, the role of the Australian Infantry is to '*seek out and close with the enemy, to kill or capture him, to seize and to hold ground, to repel attack, by day or by night, regardless of season, weather or terrain*' (Department of Defence, 2010b). Impaired performance associated with the loads carried by soldiers could limit their ability to close with the enemy, as was the case described by Breen (2000), where Australian soldiers in East Timor could not chase fleeing militia due to the heavy loads they were carrying. Reduced lethality could affect the ability to engage the enemy, to hold ground and to repel attack.

The previous paragraphs have presented the potential consequences of load carriage on military force generation, force maintenance and mission accomplishment. It is acknowledged that further potential consequences for the military associated with load carriage may exist. Examples of these other consequences are discussed throughout the next several paragraphs.

As mentioned previously in this chapter, the consequence scale for the risk analysis reported in this chapter is drawn from the MRM. The MRM arranges *consequences*[135] into five *threat impact* (*consequence*) categories of risk in order to provide standardisation (Australian Army, 2007a). These categories of risk are: *personnel, mission accomplishment, reputation, resources* and *environment* (Australian Army, 2007a). With physical injury and a reduction in military task performance being the two consequences of load carriage events identified in this program of research, and with the focus of this program of research being on the soldier, the threat impact categories *personnel* and *mission accomplishment* were considered the most relevant categories through which to describe the consequences of load carriage risk in the ARA context in this program of research. These two threat impact categories are defined as:

Personnel: Survivability (protection and preservation), health, wellbeing and human factors (e.g. load carriage systems) present as risks to the ARA workforce (Australian Army, 2007a). Failure to consider personnel in the planning and execution of an event can place them at risk. In addition, at the strategic and operational levels, lack of consideration for personnel factors can have a critical impact on an individual's workload, morale, preparedness and retention (Australian Army, 2007a).

Mission accomplishment: In the ARA, every training event (unit training and PT, field exercises) or operational event will have mission aims, objectives or effects to be achieved (Australian Army,

---

[135] In the MRM framework the term 'impact' is synonymous with the RMF term 'consequence' (Australian Army, 2007a; Standards Australia Working Group MB-002-01, 2004b).

2007a). In addition, the unit undertaking the event must be capable of future tasking at mission conclusion (Australian Army, 2007a).

Although the impact categories of risk *personnel* and *mission accomplishment* can be used to describe the *consequences* of load carriage in this program of work, it is important to note that these consequences of load carriage risk are not isolated to these two impact categories. Furthermore, these two categories of risk themselves influence other threat impact categories. As an example: high injury rates to soldiers in training and reduced mission accomplishment through poor load carriage practices have the potential to impact on the MRM threat impact categories of *reputation* and *resources*.

Damage to the Australian Army's *reputation* can have serious consequences at a strategic, operational and tactical level (Australian Army, 2007a). Unsafe load carriage practices that have the potential to cause soldier injuries (*personnel*) and failure to achieve stated missions (*mission accomplishment*) can create conditions that may undermine legitimacy and support for operations, hence negatively impacting on Army's *reputation* (Australian Army, 2007a). The results of these consequences may lead to a loss of *reputation,* undermining support from the Australian public and the international community (Australian Army, 2007a).

Resources, which include finances, equipment and facilities, are considered essential to all military operations (Australian Army, 2007a). Injuries to *personnel* caused by poor load carriage practices bring with them financial costs, be they for medical evacuation or rehabilitation. Likewise, poor load carriage practices that negatively impact on *mission accomplishment* can lead to loss of equipment and facilities. These consequences will impact on the resources available to the ARA and hence overall capability (Australian Army, 2007a).

Although the consequences of *reputation* and *resources* are noteworthy, they are excluded from further consideration in this work, as the focus of the current program of research is on the consequences of load carriage risk on the soldier (like injury and impairment of performance of military tasks) and possible downstream effects associated with these consequences.

Following selection of the impact categories of risk *personnel* and *mission accomplishment* through which to describe the *consequences* of load carriage, the scale against which to rate the level of *consequence* requires selection. For the current risk analysis, the standardised MRM *consequence* scale was selected. This scale was specifically selected for two key reasons: first, the scale provided a means of integrating the RMF into the ARA context. Second, it provided descriptors specifically aligned to the consequence impact categories of *personnel* and *mission accomplishment*. The MRM consequence scale, modified to improve clarity by removal of additional categories and simplification of descriptors, is presented in Table 24.

Table 24: The MRM consequence scale and descriptors (Australian Army, 2007a, p. Annex I), as modified for the current risk analysis.

Consequence	Descriptors Personnel	Mission accomplishment
Minor	First aid treatment on site.	Mission achievement not at risk.
Disruptive	Temporary injury requiring non-emergency treatment at a medical facility.	Ability to achieve mission reliant on reallocation of resources or adjustment of timings.
Serious	Temporary disability <30 days; emergency treatment required; admission to hospital.	Failure to achieve non-critical aspects of mission.
Critical	Temporary disability > 30 days; injury or illness is compensable.	Failure to achieve some decisive events of the mission.
Catastrophic	Death or permanent disability.	Failure to achieve mission.

8.2.2. Likelihood of occurrence for risk consequence associated with load carriage events

In a risk management context, the term '*likelihood*' is used to refer to the chance of something occurring (like an injury or impairment of task performance) and is described using terms like *probability* and *frequency* (Australian Army, 2007a; International Electrotechnical Commission, 2009). As discussed in Chapter 2, for this program of research *likelihood* was assessed as the probability of the *causes* of risk during load carriage events (load weight as an example) leading to a *consequence* or *impact* (in this instance an injury or impaired task performance). As discussed earlier in this chapter, to maintain alignment with the ARA context and the MRM consequence scale described in Table 24, the *likelihood* scale selected for this body of research was drawn from the MRM framework. Again, descriptors were modified slightly through the removal of examples that were irrelevant for the current program of research (e.g. '*damage to vehicles through wear and tear'*), to improve clarity and relevance (Table 25).

Table 25: The MRM likelihood scale and descriptors (Australian Army, 2007a, p. Annex H), modified for the current risk analysis.

Likelihood	Descriptor
Highly improbable	Not likely to occur but not impossible.
Rare	Could occur at some time. Usually requires combination of circumstances for it to occur.
Occasional	Is sporadic but not uncommon. It might happen in training or operations. Specific controls are needed
Likely	Has occurred several times before during sub-unit or unit training. It will occur without adequate and specific controls and good supervision.
Almost certain	Occurs regularly during sub-unit or unit training. Standard and specific controls are always applied.

8.2.3. Load weight as a primary risk factor in determining the level of risk for load carriage events

The sheer volume of factors that impact on the broader load carriage context (e.g. load position, speed of march, terrain, morphology, physical conditioning, etc.), which are described in the literature (Chapter 2), combined with the complexity of the broader load carriage contexts in the ARA (e.g. load weight, nature and type of load carriage event), identified in Study A (Chapter 4), make it difficult to attribute a single cause to the risk consequences associated with load carriage. However, load weight presents as a recurrent and relatively stable and consistent theme throughout all the evidence gathered in the current program of research, with mean loads ranging between 37.5 and 62.5 kg. On this basis, and considering the nature of the activity of interest, namely ‘load carriage’, load weight presents in this program of research as the primary and most consistent factor in determining the risk consequences of contemporary soldier load carriage.

Study A identified mean self-reported loads of 37.5 kg, 47.2 kg and 62.5 kg being carried for PT, field training exercises and on operations, respectively. The literature review (Chapter 2) provided strong evidence to suggest that load weight increases the energy cost of performing given tasks, like standing and walking, and alters the biomechanics of the body when performing these tasks[136] in such a way as to increase the stress on the musculoskeletal systems of the carrier (Harman, et al., 2000; Polcyn, et al., 2000). These increases in stress have the potential to induce musculoskeletal injury (Wright, 2009). Studies by Knapik (1992) and Reynolds, et al. (1999), with loads of 46 kg and 47 kg respectively, observed a 24% to 36% injury incident rate for given load carriage events. Furthermore, the literature review (Chapter 2) identified significant decreases in mobility, lethality and cognitive measures (like attention to stimuli) with loads ranging from 14 kg up to 61 kg.

Study B (Chapter 5) provided further supporting evidence to suggest that the weight of the loads carried by ARA soldiers could lead to soldier injury and impairment of soldiers’ ability to perform certain military tasks. Within the ARA context, specifically, 34% of respondents reported suffering an injury during a load carriage event, a load carriage injury frequency[137] of 104.1 injuries per 1000 years. The mean self-reported load weight carried by soldiers who reported sustaining an injury during load carriage tasks was 29.5 kg. Furthermore, the injury surveillance database identified that 8% of all body-stressing injuries in the ARA over the years 2009 to 2010 were attributed to load

---

[136] The volume of evidence is provided in Appendix D.

[137] Load Carriage Injury Frequency = Total number of injuries reported by all survey respondents / sum of the number of years of military service of survey respondents x 1000.

carriage. In regard to task performance, soldiers self-reported declines in their performance of five military tasks (movement, marksmanship, grenade throw, attention to task and administration) while carrying the above listed loads. It is important to note that, while load carriage was considered the causal factor in the incidence of injury and self-reported decreases in performance in Study B (Chapter 5), no specific component of the load carriage task (e.g. load weight, speed of march, etc.) was identified in the data. However, when the findings of Study A (Chapter 4), in relation to load weight carried, and Study B (Chapter 5), in relation to injury frequency and decreases in performance, are combined with the evidence presented in the literature review (Chapter 2) regarding the impacts of specific load weights and their associated impacts on the load carrier, sufficient evidence supports the claim that load weight is a causal factor for soldier injuries and for impairment of military task performance during load carriage events.[138]

On this basis, given that load weight presents as a recurrent and relatively stable and consistent theme throughout all the evidence gathered in the current program of research and that specific loads weights have been associated with specific impacts on the load carrier, load weight can be considered as a primary factor in determining the *level of risk* associated with a load carriage event.

8.2.4. The impact of risk modifiers in determining the level of risk for load carriage events

As identified in the literature (Chapter 2), the broader context in which the load is carried has an impact on soldier load carriage (Knapik, et al., 2004; van Dijk, 2009). Broader contextual variables that include variations in load weights and position of the load, speed of march, terrain traversed, climate, range of soldier morphology and levels of physical conditioning were all identified as impacting on load carriage tasks (Knapik, et al., 2004; van Dijk, 2009). When considered in regard to the Australian load carriage context (Chapter 4) the broader contexts associated with load carriage were found to be varied and complex. For example, not only were Australian soldiers required to carry heavy loads up steep inclines, but they had to move through thick bush. Adding to these contextual variables, Study B (Chapter 5) found that 34% of respondents reported sustaining an injury during a load carriage task within their army career, with 42% of these soldiers also reportedly sustaining an additional load carriage injury. On this basis, a previous injury sustained during a load carriage task can present as a risk modifier. When previous injury is added to the

---

[138] The influence of varying load weights and other load carriage contextual factors (like load placement, speed of march, terrain etc.), is discussed later in the chapter under the sub-heading ‘risk modifiers’.

above example of the Australian soldiers who reported carrying heavy loads up steep inclines through heavy bush, the complexity of the load carriage context is further highlighted.

Unfortunately, these contextual variables have no clear hierarchy of importance and thus assigning a specific level of risk to each variable based on the hierarchy of controls[139] is not possible within this program of work. Considering this, however, these variables, through having the potential to alter the impact of load weight on the body, could influence the *consequences* associated with carrying load as well as the *likelihood* of these consequences occurring. In essence, broader contextual variables can modify the level of risk associated with load carriage tasks. Considering this influence, broader load carriage contextual variables, identified in the literature (Chapter 2) and as they appear in the Australian Army (Chapter 4), are presented here as risk modifiers to a load carriage event and are discussed in greater detail below.

Modification to load carriage risk associated with variations in load weight and load position

While load weight is considered the primary factor in determining type and severity of risk *consequences* in military load carriage and the *likelihood* of these consequences occurring, variations in the weight of the load being carried and the position in which it is carried may modify the *level of risk* presented by a load carriage event.

A historical review of soldier load carriage (Chapter 3), supporting and extending the earlier works of Knapik, et al. (1989, 2000; 2004), confirmed that the load weight carried by soldiers is increasing. Study A (Chapter 4) identified that operational loads carried by ARA soldiers were heavier than field training exercise loads which in turn were heavier than loads carried during PT. No specific research evidence was found during the current program of research to directly support an association between progressive increases (or decreases) in load weights carried by a soldier and injuries sustained. However, heavier loads have been associated with increasing the energy costs of load carriage and affecting the biomechanics of movement (Attwells, et al., 2006; Knapik, et al., 2004: LaFiandra, Lynch, et al., 2003; van Dijk, 2009)[140] in such a way as to increase the carrier's risk of injury (Attwells, et al., 2006; Knapik, et al., 1992: 2004). As the load weight to be carried by the soldier increases, so too does the energy cost of carrying the load (Knapik, et al., 2004). These increases in energy costs have the potential to increase soldier fatigue (Epstein, et al., 1988) which in turn can increase the soldier's risk of sustaining an injury (Murphy, 2002). Increases in load

---

[139] Discussed in the next section, Section 8.2.4

[140] The volume of evidence is provided in Appendix D.

weights carried have also been found to affect the biomechanics of the load carrier (Fowler, et al., 2006; Majumdar & Pal, 2010). These biomechanical changes associated with increasing loads during a load carriage task have the potential to injure the soldier (Attwells, et al., 2006; Pope, 1999). The potential increase in the risk of sustaining a lower back injury due to the impacts of fatigue and biomechanical changes associated with increases in the load weight carried serves as an example. Bonato, et al. (2000) suggest that increases in lower back muscle activation observed in participants during a hand load carriage task were a means of compensating for increasing carrier fatigue (Bonato, et al., 2000). Increases in load weight have also been observed to affect the biomechanics of the load carrier through increasing the forward lean of the trunk, increasing spinal compression, increasing spinal shearing forces and potentially altering spinal shape (Attwells, et al., 2006; LaFiandra, Lynch, et al., 2003). On this basis, clear evidence exists to suggest that increasing the loads carried by soldiers will have the potential to increase the risk of spinal injuries due to the stresses these heavier loads impose on muscles and other body structures.

Apart from modifying the soldier’s risk of injury, variations in load weight can impair soldier task performance. Regarding the impact of increasing loads on soldier performance, evidence has been reported in the literature (Chapter 2) to suggest that as loads carried increase, soldier performance can often decrease (Knapik, et al., 2004). One example is the impairment of soldier mobility associated with increases in the load weight soldiers must carry. When load weights increased from 14 kg to 41 kg, the time taken by soldiers to cover a distance of 3.2 km was found to increase by 44% (Pandorf, et al., 2002). As discussed earlier in this chapter, decreases in mobility, like in the example presented above, have the potential to increase soldiers’ exposure to enemy weapon fire and therefore increase risks of wounding and overall mission failure. Another issue is that of alertness. Johnson, et al. (1995), in a study of 15 male U.S. Army soldiers, found that self-reported alertness was reduced as the load weight carried by the soldiers increased from 34 kg to 48 kg to 61 kg. Again, as discussed above, reduced alertness (or even perceived alertness) can impair soldiers’ ability to detect an IED, leading to potential injury, mortality and mission failure.

On the basis of the examples in the last two paragraphs and the findings in the literature (Chapter 2), increases in the weight carried by soldiers may have the potential to increase their risk of injury and to impair military task performance. Conversely, reducing the weight carried by soldiers may have the opposite effect and reduce their risk of injury and of performance impairment.

In the current program of research, the impacts of carrying loads on different parts of the body (e.g. the head, the back, the hands, etc.) were considered on the basis of evidence provided by previous studies. However, Study A (Chapter 4) confirmed that Australian soldiers did carry loads across various parts of the body, most notably helmets on the head, packs on the back, webbing on the back and chest or hips, boots on the feet, and weights in the hands (See Table 10). Therefore ARA soldiers are subjected to the effects of their load positions. The available research evidence (Chapter 2) suggests that the position of the load around the body influences the energy costs of carrying the load (Abe, et al., 2004; Datta & Ramanathan, 1971; Holewijn, et al., 1992; Knapik, et al., 2004) and potentially even the risks of injury to the carrier and mission failure. Loads carried on the feet (boot weight) and in the hands (weapon systems and attachments, and additional equipment) entail higher energy costs than loads carried on the back (Abe, et al., 2004; Datta & Ramanathan, 1971; Holewijn, et al., 1992). Within a backpack, loads carried lower on the back may elicit a higher energy cost than loads carried higher up the back (Abe, et al., 2008a; Knapik, et al., 2004; Stuempfle, et al., 2004). Conversely, loads placed higher up the back in a backpack, while potentially more energy cost-efficient, can reduce the carrier's stability (Johnson, et al., 2000; Knapik, et al., 2004; Qu & Nussbaum, 2009; Schiffman, et al., 2004). This is worthy of note, as among the reported load carriage injuries reported in Study C (Chapter 5), 77% of ankle injuries were due to mis-step and tripping. Loads carried on the head (helmet and night vision devices) present another potential source of injury risk, with Jumah and Nyame (1994) reporting a high frequency of spondylosis of the cervical spine in Ghanaians who were habitually involved in head load carriage (porters, heavy construction labour). Apart from potential injury, loads carried on the head can also increase the size of the soldier's body signature (Knapik, et al., 2004), making the soldier more susceptible to detection by the enemy. Likewise loads on the chest can increase the soldier's body signature in a prone position and may also reduce a soldier's field of vision, impairing their potential to spot trip hazards or IEDs in close proximity. As such, through influencing soldier energy costs, thereby potentially increasing levels of fatigue and so increasing the risk of injury to the carrier and impairing soldier performance, the position of the load on the body of the soldier can modify the risks associated with soldier load carriage.

Modification to load carriage risk associated with variations in the speed, duration, and terrain in which the load is carried

Just as variations in the position of the load around the body have the potential to modify the risks associated with load carriage, so too does the speed at which the load carriage task takes place, the duration of the load carriage task, and the terrain over which the load must be carried. Strong evidence, presented in the literature review (Chapter 2) and in Appendix D, has associated increases in walking speed during a load carriage task with increases in the energy costs of carrying the load (Knapik, et al., 2004). The importance of considering the impact of walking speed on load carriage was highlighted by Soule, et al. (1978) who considered walking speed to have a greater impact on the energy costs of load carriage than the load weight itself. Furthermore, the speed of walking while carrying load can also increase the risk of injury to shorter carriers. Shorter load carriers may be required to increase their stride length to keep in step or maintain pace with taller carriers (Kelly, et al., 2000). These increases in stride length have the potential to increase shearing forces through the pelvis and lead to stress reactions and injury (Kelly, et al., 2000). On this basis, increases in the speed of march required during a load carriage task (with a given load) have the potential to both modify both the energy cost of carrying the load (increasing fatigue and decreasing performance) and the risk of injury to the soldier (particularly shorter female soldiers (Pope, 1999:2001)) carrying the load.

The duration (or distance) over which a load carriage event takes place has the potential to modify the risks associated with load carriage through altering the exposure of the load carrier to these risks. A study of the broader load carriage contexts of the ARA (Chapter 5) identified load carriage tasks of varying duration. For example, the majority of PT load carriage events lasted for less than 3 hours. Conversely, the majority of foot patrols (carrying load) lasted between 3 and 6 hours or for longer than 3 days. Review of the literature (Chapter 2) found that the impact on the energy costs of the carrier of given loads for increasing durations or over increasing distances was unclear. The majority of evidence supported findings that increases in the duration of a load carriage event were associated with progressive increases in energy costs over time (Blacker, et al., 2009; Epstein, et al., 1988; Patton, et al., 1991; Schiffman, et al., 2009) but not all research supported these findings (Holewijn & Meeuwsen, 2000; Sagiv, et al., 2002; Scott & Ramabhai, 2000a). However, research focusing on the musculoskeletal system observed increases in a chemical marker for muscle overload and possible injury following a long load carriage event (Vaananen, et al., 1997). Research has also observed that the hydration status of the body can be negatively influenced during longer load carriage events (Blacker, et al., 2009). Blacker, et al. (2009) observed that sweat loss during a 2-hour load carriage event was not matched by voluntary fluid replacement, and they suggested that a progressive increase in dehydration and increased risk of heat illness would result. The importance of these findings is highlighted by the fact that 7% of all injuries and 31% of the body stressing serious personal injuries reported in Study B (Chapter 5) as occurring during load carriage events were heat-related. On this basis, given the durations of load carriage tasks reported by ARA soldiers (Chapter 4) and the findings of the literature review (Chapter 2) and Study B (Chapter 5), the duration of a load carriage task has the potential to modify the associated risks to the carrier through potentially increasing both energy costs (leading to fatigue and potential injury) *and* muscular and systemic (heat-related) injuries.

The nature of the terrains crossed, in terms of terrain grade and type, has varied throughout the history of soldier load carriage (Chapter 3) and in the broader soldier load carriage context of the ARA (Chapter 5). Consideration of the influences of terrain type and grade on the risks associated with soldier load carriage is therefore important. Changes in the grade of terrain traversed have been associated with changes in the energy costs of carrying a given load (Knapik, et al., 2004).[141] The review of the literature (Chapter 2) provided strong evidence demonstrating that inclines in the gradient of the terrain led to increases in the energy cost of carrying a given load when compared to carrying the same load over flat terrains (Knapik, et al., 2004). Considering these findings, it is notable that Study A (Chapter 4) provided evidence that Australian soldiers were required to carry loads over terrains ranging from flat gradients to steep hills. Likewise, changes in the nature of the terrain traversed have been associated with varying the energy costs of carrying a given load (Soule & Goldman, 1972; Strydom, et al., 1966). As an example, traversing swamp and loose sand when carrying load is associated with higher energy costs compared to traversing heavy bush when marching at a given speed. Heavy bush in turn is associated with higher energy costs of carrying a load when compared to sealed roads (Soule & Goldman, 1972). Thus the terrain covered by ARA soldiers participating in a load carriage task will affect the amount of energy required to complete the task. This in turn can affect each soldier’s risk of injury and performance impairment (Murphy, 2002).

Although no specific research was found that examine the effect of terrain type on load carriage injury, Study B (Chapter 5), examining injuries attributed to load carriage in the ARA, found some differences in injury rates over different terrains. Study B, incorporating data from Study A (Chapter 4), drew associations between the more challenging terrain traversed during field training exercises (light bush over mild or steep hills) when compared to PT (roads or on dirt or grass over flat terrain or mild hills) and a higher frequency of injury. In particular, Study B (Chapter 5) suggested that differences in terrain traversed while carrying loads might account for the higher rates of ankle injury sustained during field craft (40%) as opposed to PT (10%).

Finally, while the impact of grade and nature of terrain on load carriage are presented separately above, these variables should be considered concurrently. As an example, self-reported evidence presented in Study A (Chapter 4) suggests that, over the last decade, 24% of ARA operational foot patrols (carrying load) were conducted by soldiers who traversed steep hills through heavy bush – indicating that a difficult incline and difficult type of terrain were traversed concurrently.

---

[141] The volume of evidence is provided in Appendix D.

Based on the above discussion, the speed at which the load carriage task takes place, the duration of the load carriage task, and the terrain over which the load must be carried have the potential to modify risks to the soldier associated with soldier load carriage. Moreover, as the loads may be carried over varying grades of terrain and through varying terrain types concurrently, the potential modifications to load carriage risk posed by the terrain can be compounded.

Modification to load carriage risk associated with variations in the climate in which the load is carried

Through altering the environment in which the soldier must carry load, climate has the potential to modify the risks associated with soldier load carriage. The impacts of climatic conditions like rain and temperature (cold and hot) were discussed in the literature review (Chapter 2) and the historical review of soldier load carriage (Chapter 3). In both World Wars, rain was found to increase the load weight carried by soldiers through rainwater absorption into equipment and clothing In the First World War, the coats worn by British soldiers were thought to absorb up to 9 kg of water (Ellis, 1989; Lothian, 1921), and in the Second World War the overcoats worn by American soldiers were thought to increase in weight by around 3.6 kg following rainwater absorption (Neill, 2000). Besides increasing load weight, rainwater can influence the nature of the terrain traversed. Conversion of dirt paths to muddy tracks, for example, would increase the energy cost of carrying a given load through altering the terrain surface (Soule & Goldman, 1972; Strydom, et al., 1966). These rainfall-induced changes to the terrain surface can likewise increase the load weight the soldier must carry – by mud adhering to boots, for an example. With rainwater potentially being absorbed into clothing and equipment and concurrently altering terrain surface, rain presents a compounding influence as a load carriage risk modifier. In the First World War, for example, British soldiers could start a march with a 27.5 kg load and finish it with loads in excess of 43.5 kg when both water saturation and mud were taken into account (Ellis, 1989; Lothian, 1921).

Variations in temperature can also modify load carriage risk. In the cold, additional clothing worn by the soldier can increase the load weight to be carried. This additional clothing worn by soldiers to keep warm can also restrict their movements, increasing the energy cost of carrying a given load (Haisman, 1988). In hotter temperatures, carrying loads has been associated with reduced physical performance, potentially increasing the thermal stress of the carrier (Cadarette, et al., 2001; Cheuvront, et al., 2008; Johnson, et al., 2000; Johnson, et al., 1995; Snook & Ciriello, 1974) and increasing the load weight through the need to carry additional water (Cheuvront, et al., 2008) in order to reduce the potential for heat injury. The latter impact, heat injury, is a vital consideration in light of the findings of Study B (Chapter 5) which attributed 31% of body stressing serious personal injuries over the period 2009–2010 to heat injury during load carriage events.

Following the above discussions, climatic conditions like rain and temperature have the potential to increase the soldier’s load (rainwater absorption, mud, increased clothing weight and increased water carried), alter the terrain over which the load is carried, restrict soldiers’ movement and potentially increase their thermal stress. The results of these impacts are an increased risk of injury to soldiers and a reduction in their ability to perform military tasks. On this basis, the climate in which the load carriage event takes place has the potential to modify risks for the soldier associated with military load carriage.

Modification to load carriage risk associated with individual soldier characteristics

Characteristics of the individual load carrier can act as risk modifiers. Two such characteristics identified in this body of work are the soldier’s level of fitness and the soldier’s history of injuries suffered during load carriage events.

Low levels of physical fitness have been associated with an increased risk of physical injury to the soldier (Pope, et al., 1999; Pope, Herbert, Kirwan, & Graham, 2000). Gemmell (2002) goes so far as to suggest that lower levels of aerobic fitness, rather than their gender, are the primary cause of the greater incidence of injury among female recruits during initial training. Of greater relevance to the current research program, previous research suggests that low levels of fitness are associated with an increased risk of injury during load carriage tasks (Jones, 1983; Knapik, 2000). A viable means of minimising the risks of injury associated with load carriage tasks and potentially improving load carriage task performance is physically conditioning soldiers to carry loads (Buckalew, 1990; Genaidy, et al., 1989; Harman, Gutekunst, Frykman, Sharp, et al., 2008; Knapik, et al., 2004; Maurya, et al., 2009; Soule & Goldman, 1969; Williams & Rayson, 2006). Conditioning soldiers to carry loads is not new and can be traced as far back in time as the Roman legionnaires (Renatus, 1996). Supporting this approach, research suggests that a lack of load carriage physical conditioning is associated with an increased risk of physical injury during a load carriage event (Knapik, et al., 1992). On this basis, whereas soldiers’ level of fitness may modify their risk of suffering a physical injury during a load carriage task, physical conditioning may provide a means of mitigating this risk (physical conditioning as a risk control is discussed later in this chapter).

A soldier’s previous history of suffering a load carriage injury can modify the risks associated with load carriage to the soldier. Study B (Chapter 5) identified that soldiers who had previously suffered a load carriage injury were at a heightened risk of sustaining a new injury or aggravating a previous injury while carrying load. Over 40% of the respondents in Study B (Chapter 5) who reported sustaining an injury during a load carriage event reported sustaining an additional injury either to the same bodily site or an alternative site. Of most importance, over half of the respondents who reported suffering an injury during initial training had since suffered additional injuries while conducting load carriage tasks.

Concluding comments

Although load weight is considered a primary factor in determining types and severities of risk *consequences* in military load carriage and the *likelihood* of these consequences occurring, several *risk modifiers* have been identified that can affect the *level of risk* posed by load weight. These *risk modifiers* include variations in the load weight carried and the load position, the speed of movement while carrying load, the duration of the load carriage task, the terrain over which the load carriage takes place, the climatic conditions faced by the soldier carrying loads and the individual characteristics of the soldier carrying the load. These risk modifiers have been found to influence the potential for soldier injury and a soldier’s performance of military tasks, which in turn affect the *level of risk* associated with a load carriage event.

8.2.5. The impact of risk controls on determining the level of risk for load carriage events

A means of avoiding or reducing the impact of an identified risk is the use of *risk controls* (Standards Australia Working Group MB-002-01, 2004a). In an occupational health and safety setting, *risk controls* refer to *risk avoidance* and *risk reduction* measures (Standards Australia Working Group MB-002-01, 2004a). *Risk avoidance* involves measures to eliminate a risk through elimination of exposure to that risk and *risk reduction* involves measures to reduce the *likelihood* and *consequences* of a risk. These risk controls can be applied across a variety of load carriage factors, from personnel to equipment and environment. With a variety of risk controls potentially available, the *hierarchy of controls* can be used to rank the risk control methods from most to least preferred.

The *hierarchy of controls* employed in the international RMF (Standards Australia Working Group MB-002-01, 2004a) and the Australian MRM framework (Australian Army, 2007a), provides six levels of risk control:

1. Elimination.
2. Substitution.
3. Isolation.
4. Engineering controls.
5. Administrative controls.
6. Personal protective devices.

The *hierarchy of controls* is listed from most preferred to least preferred treatment options, while being cognisant that these controls should, where possible, be applied in combination (Australian Army, 2007a; Standards Australia Working Group MB-002-01, 2004a). Each level in the *hierarchy of control,* and its applicability and suitability as a *risk control* for the risks to ARA soldiers associated with the weights of the loads carried and the broader context in which these loads are carried (*risk modifiers*), is discussed below.

Elimination

Elimination is the removal of the cause of risk from the workplace and is the most preferred *risk control* measure (Australian Army, 2007a; Standards Australia Working Group MB-002-01, 2004a). Unfortunately, as demonstrated in the current program of research, soldiers have been required to carry loads for over three millennia (Chapter 2), are currently carrying loads on military operations (Chapter 4) and, based on the *soldier modernisation* programs being undertaken by numerous defence forces across the globe (Chapter 1: (Baddeley, 2007; Basan, 2007; Bossi & Tack, 2000; Curlier, 2004; Jackson, 2004; Reid, et al., 2000; Reid & Whiteside, 2000; Siebrand, 2002)), will be required to carry loads in the future. On this basis, while possibly a risk control in the distant future, elimination is not considered a viable risk control in the current military ARA load carriage context.

Substitution

Substitution involves the replacement of a risk cause with a solution presenting a lower *level of risk* (e.g. replacing a stronger chemical with a weaker chemical that provides the same outcomes) (Australian Army, 2007a; Standards Australia Working Group MB-002-01, 2004a). Due to the nature of load carriage, there is no known substitution for load weight, and thus substitution does not present a workable risk control in the current military ARA load carriage context at this time. It should be noted that in this body of work, the replacement of heavier equipment with lighter alternatives is not considered substitution of the risk, as technological or engineering interventions form the basis of the control. On this basis, the potential of replacing heavier equipment with lighter variations is considered under 'engineering controls.'

Isolation

Isolation as a risk control involves the enclosure of the risk to minimise exposure to it. For the load carrying soldier, isolating the load being carried from the soldier would require separation of soldiers from their key tools of trade – tools responsible for lethality, protection and sustainment. Therefore, the use of isolation as a risk control is of limited value for controlling soldier load carriage weights. As a point of note, the potential for risk isolation might exist if soldiers transfer a portion of their load to another soldier, a vehicle or a mechanical aid (like the Multifunction Utility/Logistics Equipment (MULE) designed to carry the soldier's pack (Bachkosky, et al., 2007)). This potential to transfer load (as opposed to strictly isolating load) is discussed in detail in Chapter 9.

Engineering controls

Engineering as a risk control includes the use of mechanical aids to perform given tasks. Hand guards on cutting machinery and trolley carts to pull loads are examples. As discussed in Chapter 1, technology is often called upon to address concerns over the weight of the load soldiers are required to carry. To address these concerns, defence forces from around the world invest heavily in force modernisation programs which include load reduction strategies (Baddeley, 2007; Basan, 2007; Bossi & Tack, 2000; Curlier, 2004; Jackson, 2004; Reid, et al., 2000; Reid & Whiteside, 2000; Siebrand, 2002). Unfortunately, these modernisation programs often have countervailing effects, with loads reduced in one area only to be returned in another (Brown, et al., 2010; Mayville, 1987; Owen, 2008). For example, the beneficial effects of engineering controls that led to the load weight reduction of combat body armour (Bernton, 2011a) were counterbalanced by the potential inclusion of batteries into body armour to power other systems (Kuchment, 2010).

History indicates the limitations of technological and engineering solutions as viable *risk controls* for risks associated with soldier load carriage. The historical review of soldier load carriage

(Chapter 3), supporting the work of Knapik, et al. (1989, 2000; 2004), confirmed increases in the absolute loads carried by soldiers throughout history and, in conjunction with Study A (Chapter 4), confirmed load weight increases within the ARA load carriage context. The historical review (Chapter 3) found that Australian soldier loads during the First (1914-1918) and Second (1935-1945) World Wars ranged from 27 kg to 33.5 kg (Landers, 1998; Stanley, 2005) and 20.5 to 41 kg (Brune, 2003; Johnston, 1996; Kuring, 2002; Millett & Murray, 1988), respectively. Conversely, examination of the current ARA load carriage context (Chapter 4) found that Australian soldiers reported carrying loads for which the means ranged from 40.7 kg to 50.9 kg[142] during the most recent load carriage decade (2001-2010). This example, together with Figure 4 (Chapter 3, p. 98) which depicts three millennia of soldier loads, demonstrates the lack of load weight reduction in light of changes in battle field technology and feats of military engineering over the historical periods discussed. Based on these findings, engineering controls do not present as effective risk control strategies for load reduction at this stage. However, this does not suggest that technological advances do not have a role in minimising the impact of load weight on the carrier. Hip belts designed to shift load from the shoulders to the hips, a process already found to reduce loading on the shoulder and potentially physiological cost (LaFiandra et al., 2004, Knapik et al., 2004), may reduce the physiological and biomechanical impacts of soldier load carriage. So too may devices designed to shift a portion of the soldier's load from the back to the front of the body (Knapik et. al., 2004).

Administrative controls

Administrative controls are oriented towards reducing and controlling exposure to identified risk (Standards Australia Working Group MB-002-01, 2004a). The no-lift or safe-lift policy in health care professions introduced to reduce the risk of injuries associated with manual handling tasks is an example (Australian Nursing Federation, 2008). In the military, doctrine and policy serve as a means of providing administrative guidance and controls to meet conceivable military requirements. Study D (Chapter 7) investigated the doctrines and policies available in the ARA that potentially serve as administrative controls for load carriage. The study identified a lack of clear guidance for commanders and soldiers in regard to controlling the potential consequences of weights carried during load carriage tasks and to limiting the likelihood of their occurrence. The doctrine and policies provided appeared disjointed and irregular in both dispersion through corps and level of detail. No links between doctrines dealing with load carriage were found, and

---

[142] Mean loads calculated as the mean of mean annual loads in the decade 2001 to 2010.

segmented advice given was either generic or based on outdated doctrine. Furthermore, in Study D (Chapter 7) more than half of the survey respondents reported carrying loads in excess of unit administrative guidance. Similar breaches of load carriage policies were identified in a recent field study of American soldiers deployed on operations in Afghanistan (Task Force Devil Combined Arms Assessment Team, circa 2003). The research noted that the average Fighting Load carried by soldiers was 31% heavier than U.S. Army doctrinal guidelines and the average Approach March Load just over 40% heavier (Task Force Devil Combined Arms Assessment Team, circa 2003). Considering the above findings, the effectiveness of ARA policy and doctrine as administrative risk controls for soldier load weight carriage is considered to be limited.

Personal protective **devices**

Personal protective devices are typically described as protective equipment, clothing or substances used to protect the wearer from exposure to the risk (Standards Australia Working Group MB-002-01, 2004a). However, in the current context, these additional sources of protection may serve as the primary source of risk by increasing the carrier’s load. Consider for example, that body armour is an acknowledged personal protective device found to decrease injuries among police officers (Spellman & Bieber, 2011). In the context of load carriage risk, the weight of the body armour, through its negative impacts on soldier task performance (Ricciardi, et al., 2008) becomes a source of risk. Conversely, if the load carrier is physically conditioned to carry the load, physical fitness may provide a means through which personal protection against load carriage risk can be facilitated. This bears merit as physical fitness is seen as a consideration for the control of risks associated with manual handling tasks (Australian Safety and Compensation Council, 2007; SafeWork South Australia, 2006) and ultimately, the soldier is the physical weapon system (Gourley, 2003)

Considering this, it is acknowledged that training is typically described as an administrative control in the risk management process (Manuele, 2011: United States Congress Office of Technology Assessment, 1985). This stands to reason as administrative controls in essence are oriented towards reducing and controlling exposure to identified risk (Standards Australia Working Group MB-002-01, 2004a) through changing the way people work (Manuele, 2011). On this basis, training in relation to technical ability or procedure would be considered an administrative control. In contrast, the intent of the physical conditioning discussed in this context is not to change a work process but rather to develop the physical resilience of the carrier and as such, use the development of the physical body as the device through which to minimise the physical risks to the carrier associated with load carriage.

The historical review (Chapter 3) noted that physically conditioning soldiers to carry loads was not a new concept and could be traced back to armies of antiquity (Campbell, 2004; Renatus, 1996). Through review of the literature (Chapter 2) and the establishment of industry 'best practice' for load carriage conditioning (Chapter 6), the conditioning practices used in the ARA and their alignment with the Australian load carriage context (established in Study A) were examined. Study C (Chapter 6) examined the conditioning practices of ARA personnel from initial training through to trade training and within operational units. The study determined that, when viewed through the lens of the F.I.T.T. (frequency, intensity, time and type) framework for physical conditioning prescription, load carriage conditioning programs across the ARA had limited success in meeting with the best practice guidelines established within this thesis, for load carriage conditioning. Deficiencies existed to some extent across all four F.I.T.T. framework components. Of most concern, half of the trade training institutions and half of the operational units investigated in this study did not include specific load carriage conditioning within their PT programs. Furthermore, the two trade training institutions which failed to include such conditioning within their programs of training were from trade corps which had heavy load carriage requirements (Chapter 4).

8.2.6. Assigning a Level of Risk to the ARA Load Carriage Context

The variability and diversity of load carriage events in the ARA was highlighted in Study A (Chapter 4). Soldiers reported carrying loads of various weights, constituting various pieces of equipment, for various durations, across various terrain types and grades while performing various tasks. Considering these findings, application of the risk analysis process described in this chapter to determine a *level of risk* that could be validly applied to all ARA load carriage events is not considered viable as, even with the key risks associated with load carriage events identified (load weight and potential risk modifiers like speed of march and terrain traversed), each load carriage event will vary in load weight and context. Thus, to determine a valid *level of risk* for a given activity, an individual and specific risk analysis must be undertaken for each load carriage event.

To this end, determination of a valid *level of risk* measure for a given ARA load carriage event would require each identified *consequence* associated with the risks posed by carrying a given load weight in its unique context to be considered individually (soft tissue injury, reduction in shooting performance as examples) (Standards Australia Working Group MB-002-01, 2004a). These *consequences* would then be considered against their *likelihood* of occurrence (again considering the influence of load weight and the risk modifications posed by the context) to determine their respective *levels of risk* (Australian Army, 2007a; Standards Australia Working Group MB-002-01, 2004a). Finally, risk control measures specific to an event would be considered and the final *levels of risk* applicable to each consequence determined. The findings of the risk analysis process would then be used to inform the next stage in the RMF process, that of *risk evaluation*.

8.3. THE RISK EVALUATION

The purpose of the risk evaluation is firstly to make decisions, based on the outcomes of the risk analysis, on which risks need treatment, and secondly to assign treatment priorities (Standards Australia Working Group MB-002-01, 2004a). To determine whether a risk requires treatment, the *level of risk* established in the risk analysis (above) is compared to risk tolerance thresholds (Australian Army, 2007a). Risk tolerance thresholds are in essence the overall level of risk that an organisation is willing to tolerate for a given event (Great Britain Office of Government Commerce, 2007). The ARA risk tolerance threshold descriptors for non-operational activities, in relation to the MRM's *level of risk*, are detailed in Table 26.

Table 26: The MRM levels of risk and associated risk tolerance thresholds (Australian Army, 2007a, ANNEX G) modified[143] for this risk analysis.

Level of risk	Risk tolerance threshold
Extreme	Intolerable. Discontinue except in extreme circumstances.
High	Intolerable without treatment. Exposure to the threat should be discontinued as soon as reasonably practical.
Substantial	Tolerable with continual review. Unnecessary exposure to the threat must be discontinued as soon as is reasonably practicable and continued exposure would be considered only in exceptional circumstances.
Medium	Tolerable with periodic review. Exposure may continue provided it has been appropriately assessed.
Low	Acceptable with periodic review. Exposure may continue but is subject to periodic review.

It is important to note that the risk tolerance thresholds described in the MRM (Table 26) are for non-operational activities and that the Military Appreciation Process (MAP) is used to determine operational risks and thresholds on the battle field (Australian Army, 2007a). This does not mean that the risk evaluation is limited to non-operational activities. The MRM provides clear guidance on how to integrate the MRM into the various MAPs (Australian Army, 2007a).[144]

---

[143] In this instance the MRM tolerance table was modified through the removal of endorsing authorities and associated risk indices used to guide endorsement of events in relation to the level of risk associated with the event.

[144] The MAPs include the Staff MAP, Individual MAP and Combat MAP.

8.3.1. Risks associated with ARA load carriage tasks requiring treatment and treatment priorities

As the *level of risk* associated with ARA load carriage activities is expected to vary among individual load carriage events,[145] so too is the resultant *risk tolerance threshold* for the event. However, with the fundamental principle of the MRM process being to lower the *level of risk* to '*as low as reasonably possible'* (Australian Army, 2007a), risks associated with load carriage that have the potential to increase the *level of risk* to the soldier carrying the load must be treated.

As an increase in load weight is anticipated to increase the *level of risk* to the soldier carrying the load, load weight presents as a primary risk requiring treatment.[146] However, *risk modifiers*, like speed of march and the terrain traversed, have the potential to increase the *level of risk* associated with a specific load weight even further. For example, a requirement for soldiers to carry a load of 57 kg would entail a higher level of risk than a requirement to carry a load of 37 kg. Considering this, the *level of risk* to soldiers would be expected to increase further if they were required to carry the 57 kg load up a steep incline as quickly as possible. On this basis, the identified load carriage *risk modifiers* (in this example, terrain grade and speed of march) would present as a higher priority for risk treatment than load weight, as these *risk modifiers* could impart a higher *level of risk*, and therefore a lower tolerance threshold, than the load weight. On the other hand, these *risk modifiers* are enabled by load weight. Furthermore, although not previously discussed in detail, these *risk modifiers* have the potential to reduce the *level of risk* for a given load carriage activity. If, in the example above, soldiers were allowed to carry the load over flat ground, at their own pace, and they had been well trained for the task, the *risk modifiers* of terrain grade, speed and individual fitness characteristics would be expected to reduce the *level of risk* associated with a load carriage task.

Given the findings of this program of research and subsequent discussions, it is concluded that load weight presents as the primary risk associated with load carriage and as such is considered the leading treatment priority. Moreover, acknowledging the complexities of soldier load carriage and the potential impacts of the identified *risk modifiers*, *risk modifiers* are likewise considered to require treatment.

---

[145] See Section 8.2.5.
[146] See Section 8.2.3.

8.4. SUMMARY

This chapter has provided a synthesis of the available research, including the current research findings, to provide commanders with relevant information to inform their application of risk management processes unique to their own military load carriage contexts and scenarios. Load weight was identified as the usual primary cause of load carriage risk for ARA *personnel* and *mission accomplishment*. Key consequences of load carriage risk were determined to be soldier injuries and impairment of soldier task performance.[147] Moreover, several risk modifiers were identified as having the potential to influence the risk consequences of a weight load carriage task as well as the likelihood of these consequences occurring. These risk modifiers included load weight and placement, the speed and duration of the load carriage event, the terrain traversed, the climate in which the task was conducted and individual soldier characteristics.[148] Risk controls which have the potential to control the risks associated with load carriage were viewed through the lens of the hierarchy of controls. Key controls identified included *administrative controls* (in this context, ARA doctrine and policy) and *personal protective devices* (in this context, physical conditioning). A third risk control, *engineering control* (in this context, technologically lighter equipment and logistics), was discussed in view of current international defence forces efforts (Chapter 1) and the historical review of soldier load carriage (Chapter 3). However, none of these indentified risk controls in their current state was considered to be effective as a risk control for either the load weights carried by soldiers or the associated risk-modifying contexts in which the loads were carried.

Having identified the usual primary cause of load carriage risk and potential load carriage risk modifiers and discussed the current status of known ARA load carriage risk controls, treatment options to reduce these risks to a *level of risk* that is *as low as reasonably possible* are required. These treatment options form the basis of discussions in Chapter 9.

---

[147] See Chapter 8, Section 8.2.1 for greater detail.
[148] See Chapter 8, Section 8.2.3 for greater detail.

9. RISK TREATMENTS AND RECOMMENDATIONS FOR SOLDIER LOAD CARRIAGE

9.1. INTRODUCTION

The risk analysis and evaluation of the Australian Regular Army (ARA) soldier load carriage context (Chapter 8) identified risks associated with contemporary load carriage tasks that require treatment. Load weight was identified as the usual primary cause of load carriage risk for ARA *personnel* and *mission accomplishment*, with the load carriage context (e.g. speed of march, terrain) contributing *risk modifiers* that could increase or decrease the *level of risk* associated with a given load carriage task. To treat these identified load carriage risks and to reduce the *level of risk* for a given load carriage event to *as low as reasonably possible*, a range of risk treatments need to be identified and assessed, and treatment options prepared and implemented (Standards Australia Working Group MB-002-01, 2004b). These treatment options should have regard for the hierarchy of controls and should involve implementation of risk controls to reduce the consequences of the identified risks and the likelihood of these risks occurring (Australian Army, 2007a).

In this chapter, risk treatments to address identified load carriage risks requiring treatment are identified and assessed and risk treatment options proposed. ARA commanders can use this information when deciding which risk treatment options should be implemented in their unique load carriage contexts and scenarios.

9.2. RISK TREATMENTS FOR THE ARA LOAD CARRIAGE CONTEXT

Selecting the most appropriate risk treatment requires the risk manager to balance the costs associated with a treatment against the benefits to be derived from the treatment (Standards Australia Working Group MB-002-01, 2004b). Although detailed fiscal review was beyond the scope of this program of research, the realignment of the defence budget directed by the Minister for Defence, Mr. Stephen Smith, was a consideration (Smith, 2011). A key aim of this budget realignment was to reduce operating expenditure through increased efficiencies, thereby reducing defence's call on the Australian government budget by $2.7 billion over the next 4 years (2011-12 to 2014-15). Thus, cost-effective risk treatments which could be sourced from within the existing defence structure (that is, use of available personnel, departments and programs) are primarily considered within this chapter. Seeking risk treatments that already exist within the defence structure aligns with the need of the Risk Management Framework (RMF) to review existing guidelines or strategies as a starting point for treating risks (Standards Australia Working Group MB-002-01, 2004b). Three risk treatments currently within the sphere of the ARA arise from the risk controls reviewed in the analysis and evaluation of contemporary ARA load carriage risks (Chapter 8). These three risk treatments are (a) load carriage doctrine and policy implementation or revision, (b) load carriage physical conditioning, and (c) load weight reduction.[149] In this chapter, the potential effectiveness of each of these identified risk treatments is assessed against findings from both the literature review (Chapter 2) and Studies A to D (Chapters 4-7).

Before further discussion of these three selected risk treatments, it is important to note that other risk treatments may exist. An example of another potential risk treatment is the use of nutritional supplementation to enhance the capability of the load carrier (Bennett, Bathalon, Armstrong, et al., 2001). This and other potential risk treatments may form the impetus for future research, but they fall outside the scope of the current program of research. Although the current program of research has challenged and further informed approaches to risk management in the ARA load carriage context, the risk treatments considered in this chapter are limited to those that fall within the bounds of contemporary ARA practice, in order to ensure that the resulting recommendations regarding risk treatment can be readily adopted by commanders, at their discretion.

9.2.1. Risk Treatment: Improved Load Carriage Doctrine and Policy Controls

ADF doctrines provide governing principles through which the ARA guides its training and operations. Unit policies are issued by individual units to govern how they will carry out certain procedures. Together, tailored doctrines and policies can provide a form of *administrative control* by reducing and controlling soldiers’ exposure to risk by means of prescribing work procedures (Standards Australia Working Group MB-002-01, 2004a). However, a review of current ARA load carriage doctrines and policies (Chapter 7) identified two flaws. First, limited guidance was provided to inform commanders of load carriage practices. Information was dispersed across several doctrines and was often vague. Moreover, doctrinal manuals often redirected the reader to unit policies, yet a review of these policies identified only generic load lists for load carriage activities, with no other guidance regarding loading or load carriage practices. Second, in some

---

[149] See Chapter 8, Section 8.2.4.

cases doctrine and unit polices were not followed or the guidance provided in doctrine and unit policies did not meet the requirements of commanders and individuals on military operations. One of the possible consequences of these issues was that soldiers reported carrying load weights greater than those dictated by their unit policies (see Chapter 7). For these reasons, the reviewed ARA doctrines and policies are not considered to be a viable method of risk control in their current state.

In fact, research evidence supporting the use of doctrine and policy as a load carriage risk treatment and risk control is difficult to find. A recent field study of U.S. soldier loads in Afghanistan observed the average Fighting Load[150] carried by U.S. soldiers to be 31% heavier than the *Field Manual (FM) 21-18 Foot Marches* doctrinal guideline (Department of the Army, 1990; Task Force Devil Combined Arms Assessment Team, circa 2003). The average Approach March Load[151] was over 40% heavier than recommended doctrinal guidelines. In the current program of research, Study D (Chapter 7) showed that 54% of survey respondents reported carrying loads in excess of those espoused by their unit's policies. These two examples highlight the difficulties in translating doctrinal load weight guidelines into practice.

This difficulty in providing an enforceable load weight guideline is not surprising given the inability of researchers to agree on a maximal load weight figure. Load carriage researchers have provided several guidelines for optimal load weight during load carriage. In a consensus of previous research, Kinoshita (1985) recommended that load weight should not exceed 40% body weight for continuous activity and 50% body weight for intermittent activity (periods of work interspersed with periods of rest). Furthermore, the author recommended loads of no more than 20% body weight for participants unfamiliar with load carriage tasks. For the lightest Australian soldier represented in the current program of research, who weighed 52 kg (Chapter 4, Table 3), this would equate to a load of 10 kg at the commencement of training and 26 kg on operations. This load is noticeably lower than the mean load reportedly carried by Australian soldiers on current operations, which was 47.7 kg (*SD*=21.0 kg; Chapter 4). Epstein (1988), adopting nearly identical guidelines to those of Hughes and Goldman (1970), considered maximum load carriage efficiency to be achieved by carrying loads of up to 40 to 50% body weight at speeds of 4.5 to 5.0 km/h. Subsequently, Harman, et al. (2000) recommended that soldiers carrying an absolute load of around 45 kg should avoid walking more quickly than 4.8 km/h. Although the marching speed was similar in the studies of Hughes and Goldman (1970) and Harman, et al. (2000), the loading recommendations varied

---

[150] Fighting Load is akin to Australian Patrol Order (described in the Glossary and Annex A: ARA Load Carriage Systems Orders-of-Dress).

[151] Approach March Load is akin to Australian Marching Order (described in the Glossary and Annex A: ARA Load Carriage Systems Orders-of-Dress).

substantially. Based on the range of body weights of Australian soldiers presented in Study A (Chapter 4, Table 3), the recommendation of Harman, et al. (2000) would equate to a loading range of 87% body weight for the lightest soldier to 36% body weight for the heaviest soldier – a notably broader range than that recommended by Hughes and Goldman (40 to 50% body weight). The disparities in body weight between lighter and heavier soldiers highlight a potential flaw in the use of an absolute load weight guideline. Conversely, as the fitness of the load carrier (Chapter 6) and previous load carriage injury history (Chapter 5) can impact upon soldiers' ability to carry load, the use of an absolute load weight to determine fitness requirements of soldiers can provide a standard measure for a given military task where, regardless of body weight, fitness or previous injury, it is understood that a soldier is required to carry a given load to achieve a set task. This concept of basing soldiers' physical fitness requirements on the tasks they are required to perform rather than on their level of fitness is the rationale behind the ARA Physical Employments Standards study (Defence Science and Technology Organisation, 2009).

An alternative to providing a set load weight is to provide set work intensities for load carriage tasks. A load weight that allows the carrier to work at below 50% aerobic capacity may seem appropriate to the military environment, with its generally long continuous work requirements (Murphy, 2002). This consideration comes from findings of increased energy cost, which can lead to fatigue, when load carriage work efforts were over 50% aerobic capacity (Epstein, et al., 1988). However, there is contention over the 50% aerobic capacity value for load carriage tasks. In the study by Epstein, et al. (1998) the aerobic capacity of the load carriers was measured using a running test. Yet Rayson, et al. (1995) found that aerobic capacity measures differed between running and loaded walking. Based on their findings, these authors suggested that a loaded march at 50% of a soldier's maximal aerobic capacity, as assessed by a running test, would have subjects working at a peak of 63% aerobic capacity for loaded walking. That finding suggests that load carriage workloads are underestimated when based on running aerobic capacity measures. On this basis, a load carriage workload of 50% of aerobic capacity, determined via a running test, might not accurately reflect the aerobic capacity demands of the load carrier.

Despite the lack of agreement on a defined work intensity based on aerobic capacity, implementation of such an approach may present challenges, both in the use of predictive formulae and the ease of application of this formula prior to load carriage tasking and events. Givoni and Goldman (1971) devised a mathematical equation to predict the aerobic cost of load carriage. This equation was later updated by Soule and Goldman (1972), who improved the terrain coefficients, and then by Pandolf, et al. (1977) who improved the range of speeds and included the static standing aspect of the formula. While the formula developed by Pandolf, et al. (1977) may have its uses in a generic application where load weight, speed of march and terrain type and grade are known, follow-up research has found that the equation might still not accurately predict the energy cost of load carriage when walking downhill (Pimental & Pandolf, 1979; Pimental, Shapiro, & Pandolf, 1982), walking up moderate to steep hills (Santee, Blachard, et al., 2001), when workloads exceed 730 watts (Cymerman, Pandolf, Young, & Maher, 1981), when static standing (Pimental & Pandolf, 1979), or over time (Knapik, et al., 2004; Patton, et al., 1991). Pandolf, et al. (1977) themselves acknowledged that the energy expenditure of loaded walking varies *'within wide individual limits'*. Apart from individual variations, there is potential for the load carriage contexts (speed of movement and terrain types and grades as examples) to vary during the load carriage event (Brown, et al., 2010). Given these variations in both individual limits and load carriage contexts, the value of load weight planning calculated through a formula is limited. Furthermore, application of a formula, en masse, for each soldier prior to every load carriage event (including daily operational missions) would be time-consuming and onerous, especially on operations where the commander must consider numerous broader mission-planning details (such as the environment and effects of the battlespace) (Australian Army, 2007a).

A final consideration in the attempt to determine a maximal load weight figure for load carriage events is that the system contains inherent limitations. For some members of an ARA unit, like section machine gunners and signallers,[152] the limitations of their systems (i.e. machine gun or signal equipment weights) cannot be overcome using current equipment, causing their loads to increase above recommendations (Mayville, 1987).

From the evidence provided above, it is apparent that load carriage decisions (with regard to both weight and context) ultimately depend upon the military situation (O'Connor & Bahrke, 1990). On that basis, there are recommendations in previous published research that commanders develop an appreciation for the load carriage problem and make realistic risk assessments of loads to be carried (Knapik, et al., 2004; Mayville, 1987). Furthermore, the locus of control with regard to load carriage decision making may need to shift down from strategic doctrine to operational and tactical levels, where battalion[153] commanders, who control the logistical resources of their units, are responsible for directing their soldiers' loads (Mayville, 1987). It has also been recommended that battalion commanders should allow sub-unit (company)[154] commanders, who will be responsible

---

[152] Combat communications specialists.
[153] A battalion is a military unit typically consisting of a headquarters and three to four companies.
[154] A company is a unit of soldiers, usually consisting of three platoons and a small command element.

for carrying out the missions, to decide on the load carriage requirements of soldiers for each operation (Porter, 1992). A potential concern about this approach would lie in commanders overloading soldiers in an attempt to anticipate every potential outcome of a mission (Porter, 1992). This concern about excessive loading might be mitigated through the provision of broader generic load carriage guidelines within which the sub-unit commander must act, as well as through formal education in load carriage decision making. It is interesting to note that these recommendations to shift and adapt the decision-making process of load carriage down the chain-of-command to unit and sub-unit commanders who carry out given missions is not new, and has previously been presented in military trade journals (Porter, 1992). Yet no evidence of application of this concept has been found in this program of research.

In summary, doctrines and policies for load carriage could be an effective risk control if two elements are addressed. First, load carriage doctrine and unit policies should be established and enforced. Second, consideration should be given to shifting the locus of control for load carriage event decision-making down the chain-of-command to unit and sub-unit commanders, who are at the impact point for these decisions.

On the basis of the evidence presented above it is recommended that:

- The ARA develop a dedicated load carriage doctrinal manual, akin to the ‘Commanders Guide to Fatigue Management’ (Murphy, 2002), that focuses on providing guidance to unit and sub-unit commanders on load carriage practices, as opposed to providing specific maximum load weights. In essence, this is a ‘how to’ as opposed to a ‘what to’ approach. The doctrine should include (a) an academic section that lays out the scientific appreciation of load carriage, and (b) an easy-to-read commander’s guide that provides a concise overview of key load carriage guidelines and considerations. The doctrinal manual must provide for the means to make rapid changes in light of new research evidence and changes in military and load carriage contexts. This risk treatment will guide treatment not only for the direct cause of load carriage risk examined in this research (load weight and the load carriage context) but also for the associated risk modifiers.[155]

---

[155] See Chapter 8, Section 8.2.5.

- Unit policies, capturing the intent of the overarching load carriage doctrine (outlined above), be developed by all ARA units to direct and inform sub-unit commanders regarding load carriage practices. This direction should include:
  - An outline of risk causes and consequences during load carriage events, risk modifiers, risk controls, and means of minimising the impact of load carriage on soldiers.
  - The load carriage physical training (PT) requirements for unit members.
  - Instructions and guidance that can be provided to sub-unit commanders and enforced down to section level.[156]

As well, to provide a means of implementing direct control over soldiers' exposure to load carriage risk, the administrative risk control afforded by doctrines and policies can support other risk treatment initiatives. For example, doctrines can provide guidance on optimal load carriage conditioning to be conducted within a unit. Unit policies can then direct soldiers within their units to participate in the nominated load carriage conditioning program and can appoint a staff member to ensure attendance at the conditioning sessions and compliance with further guidance in regard to load weight or unit load lists.

9.2.2. Risk Treatment: Improved Load Carriage Conditioning Practices

Physical conditioning was used by armies of antiquity to prepare their soldiers for marching with loads (Renatus, 1996). The marching ability of some of these armies suggests that this conditioning was effective. The Roman legionnaires, for example, were thought to carry loads of around 37 to 38 kg and march up to 32 km per day before fortifying their night camp (Addington, 1990; Jordan, 2001; Montross, 1960).

Within the current ARA context, PT is performed to physically condition soldiers for load carriage tasks (Australian Army, 2005). A review of current ARA PT programs (Chapter 6) identified two flaws in the conditioning processes for load carriage within the ARA. First, the PT programs of initial and trade training institutions and operational units were found to have deficiencies, to some degree, across all four components of the F.I.T.T. (frequency, intensity, time and type) principle (Ehrman, et al., 2008; Wilmore, et al., 2008). Second, in the majority of training institutions and in half of the operational units reviewed, a gap was identified between load carriage conditioning and unit load carriage field training and operational requirements. For example, there were differences

---

[156] The military *section* is described in Appendix A.

in load weights, equipment carried and terrains traversed during PT compared to those covered in field exercises and operations. Overall, the findings on current ARA physical conditioning practices detailed in Study C (Chapter 6) and discussed in Chapter 8 indicate that the current PT regimes, through not meeting industry best practice guidelines (as suggested by a review of the relevant literature) and failing to prepare soldiers to carry the loads required in the field and on operations, are not an effective risk control for load carriage tasks.

Evidence supports the use of physical conditioning as a means of potentially reducing load carriage injuries and improving load carriage performance (Harman, Gutekunst, Frykman, Nindl, et al., 2008; Knapik, et al., 2004). In a study of load carriage injuries, Knapik, et al. (1992) suggested that a high number of injuries will occur during load carriage tasks if soldiers have limited recent load carriage exposure. Noting the findings of Knapik et al. (1992) no studies have been identified which specifically investigated load carriage injuries presenting in soldiers who did, or did not, receive a dedicated load carriage conditioning program. However, several studies have reported improvements in load carriage task performance following implementation of a suitable load carriage PT program (Harman, Gutekunst, Frykman, Nindl, et al., 2008; Knapik, et al., 1990; Kraemer, et al., 2001; Kraemer, et al., 2004; Williams, et al., 1999). It is important to note that these studies measured outcomes in terms of time to complete a given distance, and mobility has been found in this program of research (Chapter 5; soldier self-report) and in other studies (Harper, et al., 1997; Johnson, et al., 1995; Knapik, et al., 1997; Pandorf, et al., 2002) to be impaired by load weight increases.

In Study C (Chapter 6), the F.I.T.T. principle was applied to develop industry best practice guidelines. ARA data captured during Study C were then compared to these guidelines. Specifics of the differences between these industry best practice guidelines for load carriage conditioning and observed ARA load carriage practices were discussed in Chapters 6 and 8, and the industry best practice guidelines developed as part of Study C have been used to inform recommendations in the current chapter. For example, recommendations regarding the frequency with which specific load carriage PT sessions should be conducted, being two to four times per month, were derived from the industry best practice guidelines developed in Study C (Chapter 6).

Not only evidence-based academic research but also professional trade journal articles written by military personnel have emphasised the importance of specific load carriage conditioning as a means of preventing load carriage injuries and improving load carriage task performance (Henning & Khamoui, 2010; Leslie, 2007; O'Connor & Bahrke, 1990; Porter, 1992; Stringer, 2000). The latter articles, although providing limited academic evidence, provide insights from military personnel who were required to carry these loads and to command soldiers carrying these loads. Apart from specific load carriage conditioning, the literature suggests that strength training (notably upper body strength) and aerobic training may improve a soldier's load carriage performance. While neither of these two training methods in isolation have been found to improve load carriage task performance, in combination, these training methods have been observed to improve load carriage task performance (Kraemer, et al., 2001; Kraemer, et al., 2004).

On the basis of the findings of the current body of research and the industry best practice guidelines developed in Study C (Chapter 6), it is recommended that:

- ARA training institutions and operational units be advised to conduct load carriage physical conditioning using PT programs structured to meet industry best practice for load carriage conditioning, which involves:
    - Specific load carriage PT sessions conducted between two and four times per month (Knapik, et al., 1990; Visser, et al., 2005),
    - The intensity of the PT sessions (load weight, speed, terrain) being sufficient to elicit the desired training response and progressing to carrying loads in similar contexts to those required for field training exercises and operational tasks (Henning & Khamoui, 2010; Leslie, 2007; Rudzki, 1989). The load weights selected must be considered in terms of both *relative* and *absolute* loads, with the former based on eliciting a given training response and the latter replicating the loads required for field training exercises or operational tasks.
    - The durations of the PT sessions progressing in length to ultimately meet the lengths of load carriage tasks undertaken during field training exercises and operational deployments.
    - The types of load carriage conditioning undertaken as part of a PT program representing the natures of planned field training exercises and operations tasks, including terrains covered and equipment carried or worn.
    - Conditioning exercises which stimulate upper body strength and increase aerobic fitness, in particular, may be of benefit for load carriage conditioning, provided they do not become the focal point of the training and reduce time allocated to load carriage specific training.
    - PT sessions including technical instruction and practice of lifting and lowering techniques for load carriage systems during every load carriage session, to decrease the

number of injuries sustained during the donning and doffing of load carriage systems identified in Study B (Chapter 5),

Apart from improving load carriage performance through structured physical conditioning, it is recommended that other measures be taken to better prepare soldiers for load carriage tasks within a unit. Such measures may, for example, include ensuring that field training loads and load carriage contexts are commensurate with those required of unit soldiers during operations and when conducting joint lethality and load carriage training.

Additional measures that may assist in better preparing soldier for load carriage tasks within a unit include the following:

- Load carriage activities conducted during field training exercises need to simulate those required on military operations, with regard to load weight, equipment worn and carried, and the context (terrain, duration, etc.) in which loads are carried, to minimise disconnects between the load carriage practices of field training exercises and operational deployments (Chapter 4).

- Lethality training, including shooting and grenade-throwing from a variety of positions in a variety of conditions (both fresh and when fatigued) while wearing load carriage equipment, should be conducted regularly. With shooting accuracy expected to decrease, either objectively (Chapter 2) or subjectively (Chapter 4) following load carriage tasks, marksmanship skills need to be given greater attention (Mayville, 1987). The same would apply for grenade-throwing practice and training.

Finally, it is recommended that formal education be provided to physical training instructors (PTIs) with regard to industry best practice for load carriage conditioning, as follows:

- Formal education and training of PTIs at the Australian Defence Force Physical Training School is required to ensure that PTIs are aware of load carriage conditioning best practice when designing unit conditioning programs. This education should be included in both the initial PTI training program (Basic PT Course) and continuing education programs (Advanced PT Course).

The implementation of load carriage physical conditioning as a risk treatment should be guided by the hierarchy of controls. Evidence arising from this research (the literature review and Studies C and D), shows that load carriage physical conditioning appears to be considered as a control at the level of personnel protective devices (PPD) only.[157] However, load carriage conditioning can also be employed as a risk control through other levels of the hierarchy of controls, such as elimination, substitution, and administrative controls. Elimination of the risk can be achieved through ceasing load carriage PT events that fall outside the scope of an established PT program. The random conduct of a load carriage PT event (or unit training event) without consideration of the soldier's current level of load carriage conditioning is an example of an event that might be eliminated. Even when insufficient load carriage conditioning is conducted within a unit, a random load carriage conditioning session that does not take into account a soldier's level of conditioning must be avoided if load carriage conditioning is to become a risk control rather than a source of risk. Likewise, substitution can serve as a load carriage risk control in situations where soldiers, although currently undergoing load carriage conditioning, are not yet sufficiently conditioned to withstand a given load. For example, when a soldier returns to unit load carriage PT following injury, certain equipment might be substituted by lighter alternatives (such as carrying a rifle rather than a heavy machine gun) until the soldier is sufficiently conditioned to carry a heavier load.

If load carriage conditioning is to serve as an effective risk control it must align with administrative controls which, as mentioned earlier in this chapter, can support other risk treatment initiatives. Administrative controls provided by doctrines and policies could guide and enforce the load carriage physical conditioning process. Doctrines could provide guidance to ARA PTIs on industry best practice for load carriage physical conditioning. They could also direct training establishments and operational units to undertake formal load carriage conditioning PT. Individual unit policies would subsequently direct personnel within their units to undertake the load carriage PT and to ensure that all load carriage physical conditioning is conducted in accordance with the industry best practice guidelines for load carriage PT programs.

Although the PPD level is considered the least effective level of risk control under the hierarchy of controls (Australian Army, 2007a; Standards Australia Working Group MB-002-01, 2004a), the findings of this research suggest that, at this level, load carriage conditioning has the highest volume of evidence supporting its potential effectiveness as a risk treatment for soldier load carriage (Knapik, et al., 2004; van Dijk, 2009).(Harman, Gutekunst, Frykman, Nindl, et al., 2008;

---

[157] In this program of research it has become apparent that physically conditioning the load carrier to carry weight serves as a form of personal protection. See Section 8.2.5.

Kraemer, et al., 2001; Kraemer, et al., 2004; Visser, et al., 2005). Moreover, effective employment of load carriage conditioning as a risk control at the PPD level is required if elimination and substitution are to be viable risk controls. Without a structured PT program to guide load carriage physical conditioning, there is no platform upon which to determine whether a load carriage PT event needs to be eliminated or the load weight substituted. Unfortunately, in its current state, the effectiveness of load carriage conditioning in the ARA as a risk control at the PPD level is limited. To establish and fully optimise the use of load carriage physical conditioning as a risk control, it should be represented at each of the identified four levels of the hierarchy of controls. To achieve this representation, implementation of this risk control would need to be progressive. Progressive implementation strategies are discussed later in this chapter.[158]

9.2.3. Risk Treatment: Continued Investment in Soldier Load Reduction Measures and Practices

Soldier load weights can be reduced through two approaches, these being a permanent reduction in load weight and the temporary transfer of a portion of load weight to another load carriage system. A permanent reduction in load weight can be achieved through reductions in the need for soldiers to carry equipment[159] or, more likely, the reduction in load weight of a given item.[160] A temporary transfer of load can be achieved through the use of other systems capable of carrying load or the use of an augmented load carriage system to transfer load away from the structure of the soldier. A prime example is the transfer of a portion of the soldier’s load to vehicles that accompany soldiers on mounted patrols.[161] Other examples include the multifunction utility/logistics equipment (M.U.L.E.) (Bachkosky, et al., 2007; Lockheed Martin, 2006) designed to carry a portion of the soldiers load, and the use of a lower body exoskeleton (Eby, 2005), like the human universal load carrier (H.U.L.C.). These devices enhance soldiers’ physical ability to carry a given load through mechanical transfer of the load to the ground (Lockheed Martin, 2009).

Key mechanisms behind these approaches to load weight reduction include both technological advancements (e.g. production of lighter body armour) and changes to logistic practices (e.g. the

---

[158] See Section 9.3.

[159] An example is the current use of the F88 Steyr assault rifle with a M203 40 mm Grenade Launching Attachment (5.1 kg) as opposed to carrying both an F88 Steyr (3.6 kg) plus a separate M79 40 mm grenade launcher (2.7 kg) (Australian Army, 2004).

[160] The decrease in Australian body armour weight from 11 kg to 5.3 kg is an example (Australian Associated Press, 2010).

[161] Tactical situations (like impassable terrain for a vehicle, use of vehicles in an overwatch position, vehicle damage) may require soldiers to separate from their vehicles and carry their complete load weight. Thus this transfer of load is considered temporary rather than permanent.

use of vehicles to carry soldier stores). Neither of these mechanisms has yet proven effective as a long-term solution to the loads carried by soldiers, with soldier loads found to be increasing (see Chapter 3) even though warfare over the last three millennia has seen extensive changes in the technology available to military forces and in logistic practices.[162] As well, technological advances have been shown to have countervailing effects, reducing load in one area only to return it in another (Task Force Devil Combined Arms Assessment Team, circa 2003). This results in soldiers becoming *'overburdened with the weight of …[their] technologies'* (Task Force Devil Combined Arms Assessment Team, circa 2003). Indeed, through providing more equipment to the soldier (Brown, et al., 2010; Mayville, 1987; Owen, 2008), technology can relegate the soldier to being a *'Christmas tree on which we hang ornaments'* (Kreisher, 2009), a concern graphically represented in a recent DSTO risk analysis of the ground-based air defence trade (see Figure 1 in Attwells, et al., 2007).

Interestingly, one older professional trade journal predicted that technology might provide a 6% reduction in the soldiers load (O'Connor & Bahrke, 1990). For the average Australian soldier in the current program of research, a reduction in load weight of 6% would change the average Australian operational Marching Order load from 57 kg to 53.5 kg. This gain would be minimal considering the total loads carried and in light of the research which observed decrements in soldier task performance with carried loads lighter than 50 kg (Harper, et al., 1997; Johnson, et al., 1995; Knapik, et al., 1997; May, et al., 2009; Pandorf, et al., 2002; Park, et al., 2010). Overall, it is important that any limited gains made by technological and logistic advancements are not compromised by commanders supplying their soldiers with more equipment.

Finally, although previous research has not established the effect of reducing loads carried by soldiers, heavier loads have been found to impose greater physiological costs on the human body (Beekley, et al., 2007; Holewijn & Meeuwsen, 2000; Lyons, et al., 2005), to affect the biomechanics of the carrier (Attwells, et al., 2006; Ling, et al., 2000; Majumdar & Pal, 2010) and to reduce carrier performance (Harper, et al., 1997; Johnson, et al., 1995; Knapik, et al., 1997; Pandorf, et al., 2002). Reducing load weight can be considered a viable load carriage risk treatment by decreasing these effects.

---

[162] Discussed in The Historical Review of Soldier Load Carriage (Chapter 3) and Study A (Chapter 4).

On that basis, it is recommended that:

- A review of current logistical support mechanisms and procedures be undertaken for the ARA, with the intent of transferring load weight from the soldier to other systems capable of carrying load (e.g. an accompanying vehicle).

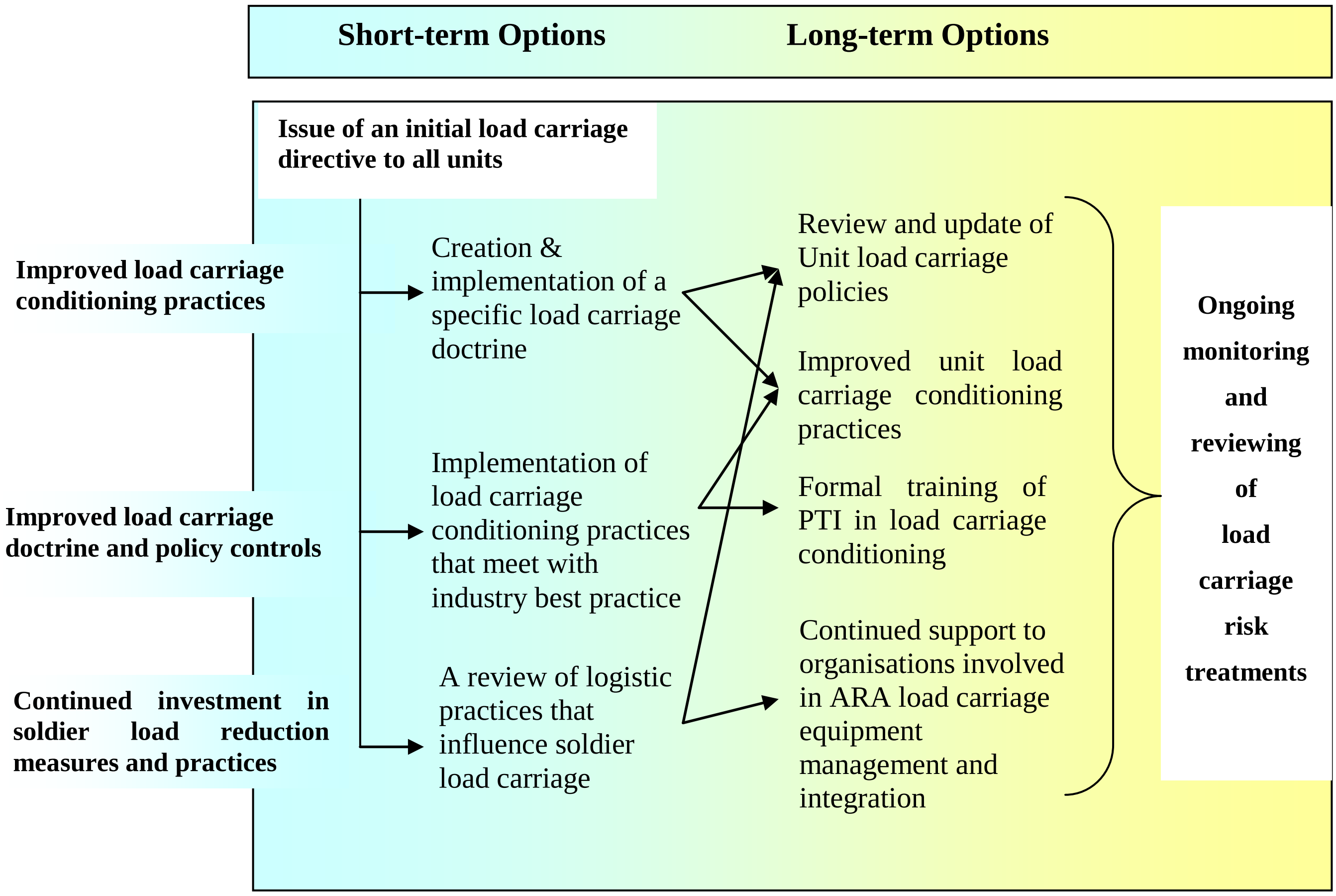
- Organisations created to address equipment integration concerns and prevent ad hoc additions to the soldier’s load, such as *Diggerworks* in Australia (Army, 2011) or Gruntworks in the United States (Kreisher, 2009), be provided with ongoing support (command support, staffing and financial support). This support should extend to ensure that the organisation is involved in collaborative research with foreign services and in the investigation of, and investment in, future logistical support mechanisms and load weight transfer systems. Policy should dictate that these organisations created to address equipment integration concerns and prevent ad hoc additions to the soldier’s load be consulted prior to all personnel equipment acquisitions.

9.3. RISK TREATMENT OPTIONS FOR THE ARA LOAD CARRIAGE CONTEXT

Risk treatments can be applied either individually or in combination (Standards Australia Working Group MB-002-01, 2004b), with an organisation often benefiting from adoption of a combination of risk treatments (Standards Australia, 2009). The load carriage risk treatment options derived from the current research can feed into development of a risk treatment plan for a particular military context. This risk treatment plan could utilise a combined approach to risk treatments where risk treatment options lend support to each other. The use of load carriage doctrine to enforce soldier load carriage conditioning is an example of this support afforded by one risk treatment to another.

The risk treatment options derived from the current research can be divided into short-term and long-term strategies. The short-term risk treatment options arising from this research are those that can be effectively implemented within a short time period or which are required to provide the platform for long-term risk treatment options. The period of time allocated for each risk treatment depends on the nature of the specific risk treatment and its subsequent alignment with prerequisite treatments. For example, the risk treatment *‘improve unit load carriage conditioning practices’*, a long-term option, can commence once the short-term risk treatments ‘*the creation and implementation of a specific load carriage doctrine*’ and ‘*implementation of load carriage* *conditioning practices that meet industry best practice'* have been implemented. Conversely, the long-term risk treatment option, *'review and update unit load carriage policies'* may be delayed for several months or more until the short-term option *'a review of logistic practices that influence soldier load carriage'* has been completed. If not all recommended risk treatment options are selected for implementation, progression from short-term options to long term options could occur more rapidly. The task of assigning responsibility for the implementation and auditing of risk treatments within short and long terms lies beyond the scope of this program of research and rests with the ARA chain-of-command. An overview of the recommended short- and long-term risk treatment options derived from the current program of research is shown in Figure 19.

Figure 19: An overview of the recommended short- and long-term risk treatment options derived from the current program of research.



9.3.1. Short-term risk treatment options

The use of short-term risk treatment options allows rapid implementation of risk treatments to initiate reduction of the risks associated with load carriage as quickly as possible. Recommendations regarding short-term risk treatment options were derived from the current program of research and based on ease of implementation (in terms of personnel and fiscal factors) as well as the capacity of the proposed short terms risk treatment options to subsequently support long-term risk treatment options. For example, the generation and release of a doctrinal directive is a short-term risk treatment option that will support achievement of the long-term option of load carriage conditioning in the field and when performing lethality tasks. The short-term options recommended on these bases are presented below.

Issue of an initial load carriage directive to all units

Formal directives from higher elements of the Army command chain would be required to initiate implementation of recommended load carriage risk treatments within units under their command. These directives would ensure implementation across the respective commands and provide authority for the implementation of risk treatments. Direction from higher authorities within the military chain-of-command is important as it facilitates implementation of risk controls at a higher level of the *hierarchy of control*[163] when compared to the implementation of risk treatments in isolation. For example, a Brigade directive to operational units requiring that they conduct load carriage conditioning will impart a greater breadth of influence than a directive at unit level.

The directives should, collectively, include direction in regard to:

- Ensuring that all training institutions and units demonstrate that they are conducting load carriage conditioning that conforms to industry best practice. Programs failing to meet with best practice are to be modified to ensure compliance. Only suitably trained Army PTIs[164] are to audit and, if required, modify the conditioning programs. Ongoing review and monitoring will be required to ensure risk treatment longevity.[165]

- The requirement and delegation of responsibility for the establishment of a working group to develop an Army load carriage doctrine.

- The requirement and delegation of responsibility for the establishment of a working group to review current ARA load carriage practices in relation to current and future logistic practice. This working group should be required to provide input into current and future load carriage doctrines and policies.

---

[163] Hierarchy of controls is discussed in Chapter 8, Section 8.2.6.
[164] See Section 9.2.2 regarding PTI education in industry best practice for load carriage conditioning.
[165] See Section 9.3.3, ongoing monitoring and reviewing of load carriage risk treatments.

The creation and implementation of a specific load carriage doctrine

To establish enduring change, formal guidance via doctrine is required. Creation of a load carriage doctrine working group consisting of academic personnel (e.g. from the Defence Science and Technology Organisation) and professional personnel (e.g. military commanders and soldiers), as well as personnel from organisations responsible for load carriage system purchase and integration (e.g. the Defence Material Organisation, 'Diggerworks'), would allow the collaboration of stakeholders who are capable of influencing current and future load carriage practices within the ARA.

Roles of the doctrine working group would include, but not be limited to, generation of a load carriage doctrinal text,[166] promotion and dissemination of the doctrinal text to the ARA community, and frequent doctrine review. Generation of a single load carriage doctrine would centralise load carriage guidance and information. It is recommended that the doctrine be subdivided into two sections: a scientific section, for scientific review and validation of load carriage practices, and a quick reference section, providing information and guidance for commanders which can be quickly reviewed. Promotion of the new doctrine to all levels of command will be needed to generate awareness of its existence. In conjunction with the doctrine's promotion, dissemination plans for the doctrine need to ensure that the text is easily locatable and available to commanders. The dissemination plan should also include the provision of links to and from other relevant doctrinal texts. Finally, the doctrine needs to be reviewed regularly following changes to the theatres of war, scientific knowledge on associated topics, and logistic practices, to ensure that it remains relevant to the current ARA load carriage context.

The primary outcome of this working group would be the generation of a dedicated load carriage doctrine that can inform military personnel on load carriage practices (strategic through to tactical advice promulgated in unit policies) and guide load carriage practices (e.g. conditioning practices). Additional outcomes such as the establishment of a regular framework for auditing unit policies may also be required.

---

[166] Content considerations are provided in Section 9.2.1.

Implementation of load carriage conditioning practices that are consistent with industry best practice

PTIs are responsible for the conduct of the majority of load carriage conditioning in training institutions and operational units (Australian Army, 2005). These PTIs are specifically trained to facilitate soldier conditioning. On this basis, direction to PTIs (via the aforementioned directive) to ensure the units for which they hold responsibility are participating in load carriage conditioning that meets with recommended best practice will facilitate improved load carriage conditioning. As these military members are well versed in conditioning protocols, they have the ability to implement improved load carriage practices in a short period of time.

PTIs need to be provided with guidance on what optimal load carriage conditioning entails. This guidance can be developed by the Australian Defence Force Physical Training Instructor School in consultation with the Defence Science and Technology Organisation and peer review by an external subject mater expert. Initially, in the short term this may be facilitated by the aforementioned issue of an initial load carriage directive to all units, directing implementation and providing guidance for the conduct of load carriage conditioning. In the long term, formal education on best practice for load carriage conditioning will need to be incorporated into PTI initial qualification courses and training (see the long-term risk treatment option, *'formal training of PTI in load carriage conditioning'*, later in this chapter).

The outcome of this risk treatment option would be conditioning programs within training institutions and operational units consistent with best practice for load carriage conditioning when audited. This auditing could be accomplished through use of Warrant Officer PTIs who report back to senior commanders or through the proposed load carriage doctrine working group already discussed.

A review of logistic practices that influence soldier load carriage

A working group to review logistical practices as they relate to load carriage is also recommended, The group would conceivably include, at a minimum, experienced military logistic personnel, personnel from the Centre for Army Lessons (CAL) and representatives from the Defence Material Organisation ('Diggerworks') responsible for purchase and integration of all forms of logistical equipment (from load carriage systems to mobility aids and vehicles). Academic load carriage experts from within the military science community and relevant military personnel would be further useful inclusions. Inclusion of personnel from the load carriage doctrine working group, recommended earlier in this chapter, would allow the relevant findings regarding logistics to be properly considered and potentially included in load carriage doctrine. For example, the logistical practice of caching equipment and the off-loading of stores to accompanying vehicles may be considered in doctrine.

The outcomes of implementing a load carriage logistics working group, as recommended here, would be the generation of considered logistical guidance to facilitate decision-making regarding load carriage practices in the field and on operational deployments, and representation of this guidance in load carriage doctrine.

9.3.2. Long-term risk treatment options

Long-term risk treatment options derived from the findings of the current program of research would require longer-term personnel and fiscal budgeting and planning investments. Some rely on the implementation of short-term risk treatment options. As an example, implementation of evidence-based general load carriage conditioning physical training practices within units (a short-term risk treatment option) is needed before implementation of unit-specific load carriage preparation, which might include field exercise loads and lethality training while carrying loads (long-term risk treatment option). The long-term risk treatment options that can be recommended on the basis of findings from the current program of research are now discussed in further detail.

Review and update of unit load carriage policies

Subsequent to guidance provided earlier in this chapter in relation to short-term risk treatment options (specifically, '*creation and implementation of a specific load carriage doctrine*' and '*review of logistic practices that influence soldier load carriage*'), it is recommended that all training establishments and operational units must update, or where necessary generate, a formal unit load carriage policy.[167] These unit policies could be specific to meet unit needs rather than providing redirection to other doctrine and policies or being copied from load carriage doctrine. Failure to adapt the guidance to unit capabilities and requirements would foster continued practices where soldiers fail to comply with unit policies, as these policies would not meet the specific requirements of their unit. To ensure that units continually review and update their load carriage

---

[167] Content considerations are provided in Section 9.2.1.

policies, the policies should identify unit positions with the responsibility of updating the document on an ongoing basis (e.g. the unit adjutant).

The outcome of this long-term risk treatment option would be the successful implementation and audit of unit load carriage policies. The audit should be able to identify unit-specific representation of the load carriage doctrine within the unit policy and a scheduled tasking for review of the policy.

Improved unit load carriage conditioning practices

In some instances, improved unit load carriage preparation initiatives (e.g. field training exercises) could be implemented rapidly and serve as short-term risk treatment options, but it would be neglectful to implement these strategies without a well-established unit load carriage conditioning program. The current research identified that, during PT, loads carried are lighter and the contexts different from to those experienced during field training exercises and on operations. However, increasing the load weight and changing the context to more closely resemble field training exercises and operational load carriage requirements without sufficient physical preparation might increase the likelihood of risks associated with load carriage. With this in mind, it is recommended that implementation of unit-specific load carriage conditioning, such as field exercise loads and lethality training while carrying loads, be built upon and informed by the short-term risk treatment options of load carriage conditioning (*Implementation of load carriage conditioning practices that meet industry best practice*) and formal load carriage guidance (*The creation and implementation of a specific load carriage doctrine*), both discussed earlier in this chapter.

The outcomes for this long-term risk treatment option would be that loads carried by units, and the context in which these loads are carried during field training exercises, are commensurate with the unit’s load carriage practices during operations. Unit lethality training would progress to a series of lethality tasks conducted either during or immediately following a load carriage task at a minimum frequency of twice per year in operational units.[168] These outcomes would be confirmed by regular auditing of unit load carriage preparation. The load carriage doctrine working group established as part of the risk treatment ‘*creation and implementation of a specific load carriage doctrine*’ could be tasked to provide and formalise the framework through which units are audited.

---

[168] A minimum frequency of twice per year is recommended to align this practice with ARA weapons qualification requirements.

Formal training of PTIs in load carriage conditioning

To optimise load carriage conditioning within the ARA, it is recommended that the personnel responsible for developing and conducting all physical conditioning within the ARA receive formal training in principles governing load carriage conditioning. Currently, educational training provided to PTIs is focused on marching techniques, the PTI's instructional techniques, and safety for load carriage training (e.g. ways to safely move troops in large groups). The conditioning principles taught are based on general endurance training principles for all populations, with a small focus on military specific populations (Australian Army, 2005).[169] The formal training for PTIs should arguably include instruction on best practice for load carriage conditioning programming through use of the F.I.T.T.[170] principle. The F.I.T.T. principle is selected as the programming platform for load carriage conditioning as PTIs are familiar with it as the platform for planning other forms of physical conditioning. Although a PTI doctrinal reference (Australian Army, 2005) discussed in Study D (Chapter 4) provides some information on the impacts of load carriage on the soldier, PTIs require formal instruction on the physiological and biomechanical impacts of load carriage (both load weight and context) as part of their initial training. Apart from providing formal education for PTIs undergoing qualification training, it is also recommended that a means of up-skilling currently qualified PTIs be investigated and that a program for 'gap' training be developed by the Australian Defence Force Physical Training Instructor School in consultation with the Defence Science and Technology Organisation and peer review by an external subject mater expert.

The outcomes for this long-term risk treatment option would be the formal inclusion of training in load carriage conditioning in the PTI qualification framework and all currently qualified PTIs receiving specific education on programming for load carriage conditioning.

Continued support to organisations invested in ARA load carriage equipment management and integration

The current Department of Defence strategic plan of support for organisations like 'Diggerworks', whose key roles include assessment of new technologies as they emerge and integration of soldier combat systems (Australian Defence Magazine, 2011), is beyond the scope of this program of research.

---

[169] These findings are based the current ARA Combat Fitness Handbook (Australian Army, 2005) and the author's role as an instructor and program developer for the PTI training school (1997-2011).

[170] The Frequency, Intensity, Time and Type of Training (F.I.T.T.) principle is discussed in Chapter 6, Section 6.4.

However, based on findings discussed earlier in this chapter (Section 9.2.3), it is recommended that organisations like ‘Diggerworks’ be involved in the purchase process for all forms of equipment that have an impact on the soldier’s load, either directly (e.g. new body armour) or indirectly (e.g. purchase of portable signal jamming equipment). An example is the successful procurement and distribution of the Australian Army Tiered Body Armour System by Diggerworks as part of the Soldier Combat Ensemble program with soldiers claiming a reduction in movement restrictions which in turn allows them to move faster and maintain a lower physical profile (Army, 2011). It is important to note that the intent of this organisation’s involvement would conceivably be to guide rather than to block purchases, and to inform units of potential integration issues. Flexibility to allow the organisation to adjust rapidly to battle-field requirements and technological changes is an important feature in this support. Examples include the ability to fund and rapidly acquire required technology and to temporarily increase organisational size in order to facilitate the required integration and suitability testing of newly acquired technology prior to large-scale purchase and distribution.

The outcomes for this long-term risk treatment option would have command direction for organisations invested in ARA load carriage equipment management and integration (e.g. *Diggerworks*) to be involved, in some capacity, in the purchase of equipment that has the potential to impact on the soldier load carriage context.

9.3.3. Ongoing monitoring and reviewing of load carriage risk treatments

One of two additional parallel and ongoing elements of the RMF is *monitoring and reviewing* (discussed in Chapter 1)(Standards Australia, 2009; Standards Australia Working Group MB-002-01, 2004a). Monitoring and reviewing of the RMF process and inputs throughout this program of research was required because of the potential for the context, risks and causal factors associated with load carriage to change during the course of the research. This element of the RMF needs to be continued during the implementation of risk treatments, to serve three key purposes. First, risk treatments can themselves introduce risk. Potential new risks will in turn require assessment, treatment and monitoring (Standards Australia, 2009; Standards Australia Working Group MB-002-01, 2004b). Second, the soldier load carriage context is likely to change through time, be it through changes in technology or operational theatres. Monitoring and reviewing of the risks and risk treatments would ensure that the risk treatments remain valid. Finally, research evidence supporting the effectiveness of the recommended load carriage risk treatment options is currently limited. These risk treatments and their impacts on load carriage risk require ongoing monitoring and evaluation so that any concerns arising from their implementation can be quickly identified and mitigated.

The best means of establishing this ongoing process of monitoring and reviewing ARA load carriage practices, risks and risk treatments lies within Army planning processes, and may include both the scheduled review of practice by a working group and ongoing review of the load carriage doctrine by the doctrine sponsors.

9.4. SUMMARY

Based on the findings of the current research, the risk treatment options recommended in this chapter provide a starting point for addressing the identified risks associated with soldier load carriage in the ARA context. In summary, these recommendations are:

- Short-term risk treatment options:
  - The issue of an initial load carriage directive to all units from higher elements of the Army command chain to initiate implementation of recommended load carriage risk treatments within units under their command.
  - The creation and implementation of a specific load carriage doctrine that can inform and guide military personnel on load carriage practices.
  - The implementation of load carriage conditioning practices that are consistent with industry best practice through a directive to PTIs detailing the conditioning standards required and the need for PTIs to ensure that the units for which they are responsible are participating in load carriage conditioning that meets these standards.
  - A review of logistic practices that influence soldier load carriage in order to generate considered logistic guidance through which to facilitate decision-making for load carriage practices in the field and on operational deployment.

- Long-term risk treatment options:
  - The review and update of unit load carriage policies that are specific to unit needs, with designation of responsibility for ongoing review of the policies.
  - The improvement of unit load carriage conditioning practices to align with the unit's field training exercises and operational load carriage contexts, and the inclusion of lethality training while carrying load.

  - Implementation of formal training of PTIs in load carriage conditioning through inclusion of load carriage conditioning education in the PTI qualification framework; all currently qualified PTIs to receive specific education on programming for load carriage conditioning.
  - The provision of continued command support to organisations invested in ARA load carriage equipment management, and integration through supporting these organisations' involvement in the purchase of any equipment that has the potential to impact on the soldier load carriage context.

- Ongoing monitoring and reviewing of load carriage risk treatments to ensure that implemented risk treatment options do not themselves introduce load carriage risks and to ensure that the risk treatment options remain valid.

Finally, where possible, additional risk controls should be sought to further reduce the *level of risk* associated with load carriage (Australian Army, 2007a). The nature of these additional risk controls will be influenced by various factors, including the availability of technology, funding and personnel availability. Possible areas for consideration and further research are discussed in Chapter 10: Conclusions, Transferability of Findings and future Research.

9.4.1. ADDENDUM: Brief summary of developments associated with this program of research and the recommended risk treatment options

Since the commencement of this program of research and following the progressive dissemination of its findings, the author has been involved in the planning or implementation of several load carriage risk treatments initiated by the ARA to improve soldier load carriage practices. These involvements include assisting in the development of a load carriage guide for commanders, consideration of potential changes to load carriage conditioning practices for trainees and soldiers on field training exercises, and consideration of potential changes to the program of education for PTIs regarding load carriage conditioning.

In late 2010, the author was approached by the Defence Science and Technology Organisation (DSTO), which had been tasked to develop a guide to load carriage conditioning for commanders. The author has subsequently been working closely with members from the Human Performance and Protection Division of DSTO to develop this document. This guide, which is currently undergoing higher level review before dissemination, has the potential to form the framework for ARA load carriage doctrine.

Following publication of an article derived from this program of research, titled *Load Carriage: Minimising Soldier Injuries Through Physical Conditioning – A Narrative Review* (Orr, Pope, Johnston, & Coyle, 2010), the author was requested to present research findings from this program of research to the Force Generation Lessons Board, an ARA board (with international representation) of military personnel involved in soldier training and key field exercises within the ARA. The focus of the presentation was on improving load carriage conditioning for soldiers in training and for field exercises. The impact of this presentation on the ARA is not yet known by the author.

Following discussions with the training development staff and course implementation officer at the Australian Defence Force Physical Training School, means of implementing education for PTIs on programming specific to load carriage are being investigated. Further discussions are scheduled for April 2012.

10. CONCLUSION, TRANSFERABILITY OF FINDINGS AND FUTURE RESEARCH

10.1. CONCLUSION

The aims of the current program of research were to investigate the full context of contemporary load carriage, identify risks arising from contemporary military load carriage for the soldier, and identify and evaluate specific risk management strategies through which to reduce identified risks. As a novel approach to researching load carriage, the Risk Management Framework (RMF) (Standards Australia, 2009; Standards Australia Working Group MB-002-01, 2004b) was chosen to guide this research program. Reasons for selecting the RMF, discussed in detail in Chapter 1, include the RMF being an internationally acknowledged framework (Standards Australia, 2009; Standards Australia Working Group MB-002-01, 2004a) and the close alignment and ready interface of this framework with the Military Risk Management (MRM) framework (Australian Army, 2007a). Employing a 5-step process of *establishing the context, identifying risk, analysing risk, evaluating risk* and *treating risk*, the RMF allowed for the collection and analysis of a vast amount of varying and meaningful information in a systematic way within the current research program.

The historical review (Chapter 3) and Study A (Chapter 4), supported by the literature review (Chapter 2), informed the first step in the RMF of '*establishing the context*'. The historical review, confirming previous research findings that the loads carried by soldiers were increasing, extended current knowledge by quantifying that these increases in load were more notably of an absolute rather than relative nature. The historical review also examined the Australian Army context and so drew Australian load carriage into the broader historical account of load carriage. Study A provided new insights into the loads carried by Australian Regular Army (ARA) soldiers and the contexts in which the loads were carried. The weights and key contextual factors of load carriage (most notably terrain, dress and equipment) were found to differ between load carriage scenarios occurring in physical training, field training exercises and operational deployments. Interestingly, the loads carried by the ARA were found to be commensurate with those carried by allied military forces (Chapter 4: Task Force Devil Combined Arms Assessment Team, circa 2003). Finally, differences between Corps were identified in loads carried, as were the tendencies for female soldiers to carry lighter absolute but similar relative loads compared to male soldiers, and for lighter male soldiers to carry similar absolute loads but heavier relative loads compared to heavier male soldiers. These differences in load weight distributions between gender and body-weight groups suggested the need for new avenues of load carriage research, studies of differences between lighter and heavier soldiers in patterns and rates of injuries sustained during load carriage tasks being one example.

Study B (Chapter 5), Study C (Chapter 6), and Study D (Chapter 7), informed the second step in the RMF, '*risk identification*', and sought to identify risks arising from contemporary military load carriage for the soldier. Study B (Chapter 5) investigated the impacts of load carriage on soldier injuries and self-reported performance. The investigation into documented and self-reported soldier injuries revealed load carriage as a cause of injury to Australian soldiers, with the most common sites of injury being the lower limbs, followed by the back. Unlike previous investigations into soldier load carriage and injury, this study included self-reported retrospective injury data. Through such data it was identified that, among survey respondents who self-reported having experienced load carriage injuries, more than 50% reported suffering additional injuries during subsequent load carriage events. Also unique to this study was the discovery of environmental injuries reported as occurring during load carriage tasks. Among the environmental injuries, heat-related injuries accounted for over a third of all reported serious personal injuries associated with load carriage. This finding is of importance considering that this mechanism of injury has in the past caused the deaths of ARA personnel undertaking physical activity (Rudzki, 2009).

Whereas previous research has measured the impacts of load carriage on task performance including mobility, lethality and cognitive tasks, Study B was limited to assessing performance impacts from self-reported data. However, the self-reported data provided new insights into soldiers' perceptions of the impacts of the loads they carried on their abilities to perform tasks. With the majority of soldiers in the study reporting that mobility, lethality (marksmanship and grenade throwing), cognitive task performance and general task performance deteriorated with load carriage, new insights into the perceptions of soldiers as to the impacts of load were gained. Further, new avenues for research are indicated. Examination of the correlations between soldier perceptions of load weight impacts on performance and quantitative measures of load weight impacts on performance constitute one example of such research.

Study C (Chapter 6) continued to inform the RMF step of '*risk identification*', identifying risks arising from contemporary military load carriage for the soldier. This study was the first known study of its kind to investigate the load carriage physical conditioning of soldiers from selected trades, from initial training through trade training and into operational units. Furthermore, the study adopted a unique approach by developing evidence-based guidelines framed by the established industry best-practice F.I.T.T. (frequency, intensity, time and type of training) principle, against which to measure the selected load carriage conditioning programs. The study identified deficiencies, to some degree, across all four components of the F.I.T.T. principle in the selected load carriage conditioning programs. At least half of the physical training (PT) programs of both trade training and operational units failed to include any form of load carriage conditioning. Most notably, even in units that included load carriage conditioning as part of their PT program, the loads carried during PT tasks and the contexts in which the loads were carried did not match (or were inconsistent with) the requirements of field exercise training and operations, with the latter two being much more demanding. This study highlighted that although physical conditioning may be considered a means of preparing soldiers to carry loads, the conditioning itself must be adequate to meet the load carriage requirements and simulate the contexts in which these loads will be carried.

The first known study of its kind in the field of load carriage, Study D (Chapter 7) investigated the role of military doctrine and unit policy on soldier load carriage. The study found that limited load carriage guidance was provided to commanders and soldiers in current ARA load carriage doctrine. Available doctrinal load carriage guidance was limited in detail, spread across several doctrinal documents and, in some instances, was notably outdated. Likewise, unit policies provided limited guidance and were generally restricted to being load carriage equipment lists. The consequence of this limited governance for load carriage led to a reported tendency for soldiers to carry loads above those detailed in their unit’s policies. In the current program of research it was not possible to determine whether these breaches of policy were attributable to doctrine and unit polices not being followed or to the guidance provided in doctrine and unit SOPs not meeting the requirements of commanders and individuals on military operations, and these questions warrant future investigation.

Analysis and evaluation of the identified load carriage risks were guided by the RMF steps of *‘risk analysis’* and ‘*risk evaluation’* described in Chapter 8. From a RMF perspective, physical injury and self-reported reductions in the performance of military tasks were two important consequences associated with load carriage tasks. Load weight was considered the lead cause of these consequences, with load weight *risk modifiers,* like speed of march, terrain traversed and personal characteristics (fitness, previous injury) having the potential to increase or decrease the *level of risk*. Unfortunately the key risk controls identified, which were physical conditioning and doctrine and unit policy, were inadequate in their current state to control the risk imposed by load weight or to minimise the negative impacts of risk modifiers.

To treat the key identified risks, three treatment options have been recommended: (a) improved load carriage conditioning practices, (b) improved load carriage doctrine and policy controls, and (c) continued investment in soldier load reduction measures and practices. These treatment options have varying degrees of research support. The use of load carriage conditioning as a risk treatment option had sufficient evidence to support its use as a risk treatment. Conversely, the lack of research into the use of doctrine and unit policies, and load weight reduction through logistic and research methods, meant that there was insufficient evidence from which to draw conclusions regarding their potential effectiveness (or ineffectiveness).

10.2. LIMITATIONS OF THE CURRENT PROGRAM OF RESEARCH

The findings of this program of research were restricted by several limitations impacting on specific elements within it or on the research program as a whole. The limitations observed during the specific research elements (Chapters 3-6) included (a) the lack of objective load weight and load context data, (b) the lack of available exposure data to enable calculation of injury rates from injury data recorded on organisational databases, (c) the non-availability of open-source data on load carriage conditioning as part of mission-specific training prior to operational deployment, and (d) the restriction of citable doctrine and policy to unclassified documents.[171] To minimise the impacts of these limitations on the research findings the investigator sought corroboration of facts from several sources and, where possible, compared captured data with other information and data derived from similar contexts.[172]

Limitations that affected this program of research as a whole included (a) an inability to obtain data from commanders on their decision-making processes for the load carriage practices of their units, (b) limitations imposed by the use of a cross-sectional methodology, (c) the specific ethnic and nationality-specific military nature of the ARA load carriage context, and (d) a lack of intervention studies to support evaluation of risk treatment options. To gain further insight into the command decision-making processes behind unit load carriage practices, semi-structured interviews with unit commanders were originally proposed. Although use of the associated data collection tool was approved by both ARA command elements and relevant ethics committees, participation in the interviews was markedly low, with only one of the six volunteering commanders available to

---

[171] In this instance, ‘unclassified documents’ includes texts that may have been classified as ‘restricted’ but were approved for ‘unclassified’ release by the doctrine sponsors.

[172] Limitations specific to the historical review (Chapter 3) and Studies A-D (Chapters 4-7) and approaches to mitigate these limitations were discussed in greater detail in their specific chapters.

participate in the interviews. Often commanders were obliged repeatedly to cancel scheduled interviews in order to attend to higher priority tasks, or were simply unavailable during the data capture period. Insights from commanders into their decision-making processes regarding their unit's load carriage requirements and subsequent conditioning practices and policies would have permitted greater insights into the identified discrepancies between the actual loads claimed to have been carried by soldiers and loads dictated in unit policies. Moreover, this knowledge might have better informed the risk treatment option to improve load carriage polices and doctrine within the ARA and hence potential effectiveness.

The cross-sectional research design employed in Studies A through D (Chapters 4-7) restricted the data collected to a single time period. The data collected to inform the load carriage context for Australian soldiers (Chapter 4) was restricted to currently serving ARA soldiers. Thus the majority of data was based on events that had transpired in the last two decades. This time period, while contemporising the research, is relatively limited when considered in the broader time frame explored in the historical review (Chapter 3) – that being three millennia. Quantitative injury data was drawn from a 2-year period. Although such data was supported by self-reported injury data spanning the respondents' careers, this limitation could mean that specific events within the time period (e.g. potential increases in soldier deployments and deployment durations, and specific international field training exercises) might have influenced the research findings. For load carriage conditioning, the unit PT programs examined were restricted to those in use during the survey data collection period. Thus only a snapshot of each participating unit's yearly training and conditioning cycle was captured. This limitation can be tempered by the fact that the data capture period occurred during a key period of field training exercises and operational deployments, but still it is possible that different load carriage conditioning practices were conducted outside the data capture periods. While the cross-sectional approach for the studies undertaken in this program of research can limit findings to being representative of a snapshot of a specific contextual period, this snapshot was a key requirement for the program of research which was designed to provide knowledge of the current ARA load carriage context, knowledge that could inform identification of effective load carriage risk treatment options. The immediacy with which these results can be translated into practice contributes to the uniqueness of this research. Evidence of the relevance of these research findings was presented in Section 9.4.1).

The restriction of data collection to the ARA context could also limit the transferability of the current research findings to wider international defence and other non-military communities. The specific ethnicity of the Australian and ARA communities could have affected the findings of the current program of research. Injuries resulting from load carriage activities serve as an example, since ethnicity is known to be associated with the risk of foot blistering during load carriage marching due to reported differences in the mechanical and physiological properties in white, Hispanic and black skin types (Knapik, et al., 1999). Moreover, the Australian climate may present challenges that differ from those of other countries. For example, soldiers in countries with colder climates may present with more cold-related injuries compared to the heat-related environmental injuries identified in the current program of research (Lehmuskallio, Lindholm, Koskenvuo, et al., 1995; Rudzki, 2009). Finally, one can expect that ARA-specific load carriage systems and equipment influenced the findings of the current program of research, considering that differences in load placement have the potential to influence the energy costs of carrying a given load (Knapik, et al., 2004).[173] However, despite the limitations posed by the conduct of the research within the ARA context, there remains potential for the findings of this current program of research to be transferred to the wider community. This potential is explored in the next section of this chapter.

A key limitation in the current program of research was the lack of any intervention studies investigating the effectiveness of the recommended treatment options. Intervention studies of selected short- and long-term treatment options would have provided an opportunity to assess the impact of proposed treatment options. The creation and implementation of load carriage doctrine and implementation of load carriage conditioning practices that meet with industry best practice are examples of short-term risk treatment options that would benefit from intervention studies, while the review and update of unit load carriage policies and conditioning practices are examples of long-term options. Intervention studies would have provided a better understanding of the potential effectiveness of the proposed risk treatment options on risk measures (increased risk of injuries and loss of performance), identified potential opportunities for treatment option improvement, and possibly identified additional risk treatment options. However, a preliminary step in interventional research is to develop understanding of the problems and the various options available to address them. The research conducted in this thesis comprised an essential step in the development of intervention research by detailing the current ARA load carriage context – a prerequisite for the development or testing of any risk treatment recommendations and associated interventions. With the ARA context now established and risk treatment options devised, opportunities exist for post-doctoral intervention studies to examine the impacts of accepted and implemented risk treatment options. These intervention studies can continue the work commenced in this program of research as part of the RMF process of *monitoring* and *review*.

---

[173] See Section 2.3.9. for greater detail.

Specific limitations pertaining to the survey data captured for this program of research include those of response bias and recall bias. With a response rate of 21% there is the potential for error to result from characteristic differences between responders and non-responders (Creswell, 2003; Killewo, Heggenhougen, & Quah, 2010). The degree of error may lead to mis-representation of certain characteristics (Kotaniemi, Hassi, Kataja, et al., 2001) or alternatively may not bias results substantially (Littman, Boyko, Jacobson, et al., 2010). One means of addressing response bias is to contact non-responders and compare their characteristics against those of responders (Bruce, Pope, & Stanistreet, 2008; Creswell, 2003). As responses were anonymous this option was not viable. Considering this, another approach to treat response bias is to compare the survey findings against findings from other independent sources (Bruce, et al., 2008). Where possible this approach has been taken (comparing survey injury response data and OHSCAR data as an example). The potential for recall bias, whereby the recall of respondents to survey questions may be inaccurate, has been alluded to throughout the thesis. Both the period involved (Clarke, et al., 2008; Coughlin, 1990) (recalling operational loads over the most recent deployments or load carriage injuries sustained during their military careers as examples) and the significance of the event to the respondent (Coughlin, 1990) (foot blisters versus a fracture for example) are known to impact on recall accuracy. A means of combating recall bias is to limit the recall period to a very short period (two weeks for example) (Clarke, et al., 2008). Such a short recall period may reduce recall error but at a notable cost in terms of information loss (Clarke, et al., 2008) most notably in time relevant data (injury profiles over a soldier’s career as an example). As data from alternate sources can be employed to limit the impact of any potential recall bias (Clarke, et al., 2008) survey data were triangulated against other data sources where possible (OHSCAR injury data base, and Unit physical training programs as examples).

While the author is cognisant of the limitations of the current program of research, the program was nevertheless successful in achieving its aims, these being to investigate the full context of contemporary load carriage, identify risks arising from contemporary military load carriage for the soldier, and identify and evaluate risk management strategies. Furthermore, the current body of research will inform similar fields of research. It also identifies opportunities for future research, two of which are discussed in detail below.

10.2.1. Transferability of Findings

The focus of the current program of research has been contemporary military load carriage within the ARA, as it relates to the soldier. While this field is very specific, there is potential for the approach (RMF) and findings within this body of research to be transferred to other vocational and recreational practices to varying degrees. Immediately apparent is the potential to apply the research findings to other services within the Australian Defence Force (ADF), such as the Royal Australian Air Force (RAAF) and the Royal Australian Navy (RAN), and to the defence forces of other nations.

In the RAAF, Airfield Defence Guards are required to secure allied airfields (Department of Defence, n.d.). This task requires personnel to conduct patrols, evacuate casualties, conduct building entries and searches, and seize and secure prisoners while carrying loads similar in nature to those carried by ARA soldiers (Stackpole, 2011). In the RAN, boarding parties are required to wear ballistic vests and carry weapons, water, radios and spare batteries and other pieces of equipment vital for search and detain tasks (Navy News, 2004). Furthermore, if part of a fire fighting team, naval personnel are required to don heavy clothing (fearnought suit) and equipment (back-mounted self contained breathing apparatus) weighing up to 22.3 kg and move throughout the ship, running, climbing ladders and carrying hoses (Bilzon, Scarpello, Smith, Ravenhill, & Rayson, 2001).

As discussed in the literature review (Chapter 3) and the historical review (Chapter 4), defence forces from many nations have been and currently are required to carry loads. Study A (Chapter 4) confirmed that the loads carried by Australian soldiers in recent combat operations were similar to those of allied forces (Bachkosky, et al., 2007; Brown, et al., 2010; Task Force Devil Combined Arms Assessment Team, circa 2003). On this basis, the RMF which guided the current program of research, together with program findings and risk treatment options, will resonate with other ADF services and foreign defence forces facing similar load carriage concerns.

Apart from military services, other vocations that require loads to be physically carried may benefit from the insights gained through employing the RMF to guide the current program of research and the subsequent risk treatment options identified and assessed. Examples of these vocations are protective services like fire and police departments. Firefighters can carry loads of up to 37 kg made up of various forms of breathing apparatus, protective clothing, and firefighting equipment while performing tasks that include stair climbing and dragging or carrying other people (Louhevaara, et al., 1985; Park, et al., 2008; Richmond, et al., 2008; von Heimburg, et al., 2006). The consequences of carrying these loads can range from increased trip risk when fighting fires in urban environments (Park, et al., 2008) to increasing the time required to negotiate escape routes in wilderness fires (Ruby, Leadbetter III, Armstrong, & Gaskill, 2003).

Police officers carry loads that include their firearm, ammunition, police baton, handcuffs, torch, mobile phone and other pieces of equipment related to their duties (Jacobsen, 2009). These loads can range in weight from 5 kg to 10 kg (Jacobsen, 2009; Pritchard, 2010) and are worn daily while moving in and out of vehicles, walking, and even chasing criminals over obstacles at a maximum pace (Jacobsen, 2009; Pritchard, 2010). The stress placed on the lower back from carrying this load on a hip belt has been reported as an occupational health concern (Pritchard, 2010) and led to the trial of vest webbing (Calligeros, 2011) similar in concept to the load-bearing webbing of soldiers. Specialist arms of the police may take on paramilitary roles and wear and carry corresponding equipment including ballistics vests, Kevlar helmets, gas masks, non-lethal grenades, and additional weapons (Paul, 2008). Given the loads carried (which may range up to those carried by military personnel), the mechanisms of load carriage (on the back, chest webbing, or hip belt) and the circumstances in which the load is carried (walking, running, negotiating obstacles, engaging hostiles), the RMF and the research findings which underpin the risk treatment options recommended based on the current program of research may be of benefit to these protective services.

While the vocations identified above (other military service arms and forces and protective services) may benefit from this program of work, it is acknowledged that the findings of this program of research may be of limited value to those in other load carriage vocations. Porter services constitute one such example. Even though hired porters perform load carriage tasks, carrying very heavy loads for example along the Inca trails of Peru or in the Nepalese mountains (Bastien, et al., 2005; Bauer, 2003; Malville, et al., 2001), the occupational environment (poor working conditions and health problems (Bauer, 2003)) in which these load carriers may be employed is likely to limit application of the RMF approach and the risk treatment options considered in this thesis.

For recreational load carrying events, the RMF and subsequent risk treatment options may be of value. Recreational load carriers such as hikers carry loads on their backs and walk over various distances, terrains, and elevations for enjoyment or personal challenge (Lobb, 2004). As such, recreational hikers may benefit from strategies to improve load carriage conditioning and load carriage weight reduction.

The employment of a risk management approach to load carriage may also be of benefit to companies providing recreation activities that require loads to be carried. Companies that support people navigating the Kokoda trail serve as one example. The Kokoda trail, in Papua New Guinea, saw fierce fighting in World War II, with Australian forces holding off a numerically superior Japanese force in very rugged, isolated and mountainous terrain, accessible only by foot (Brune, 2006). Today, thousands of Australians trek the 96 km trail through mud and mountains each year (Thompson, 2002). Although porters do carry some of the food stores and may be hired to carry personal equipment, hikers can carry packs weighing up to 15 kg (Kokoda Trekking, n.d.). The physical strain of completing the trek led to four Australian deaths in 2009 alone (Australian Associated Press, 2009). For companies conducting these Kokoda treks, the current body of research may be of use as they generate, augment, or review their load carriage risk management plans, participant load carriage standards and requirements for the event, and as they provide load carriage conditioning advice to participants. Trekking service providers for other famous trails or adventures may also benefit from this research.

As a final point on transferability of findings from the current program of research, it is acknowledged that the way in which the RMF was applied and the processes leading to and influencing the risk treatment options discussed in this thesis will differ from those in other vocational and recreational applications. Risk assessments and risk treatments will need to be reviewed and assessed within the context specific to each vocation or recreational activity.

10.2.2. Future research

While Study A (Chapter 4) involved the first known collection of load carriage data across several contexts simultaneously within the ARA (and possibly any regular military service), the research was limited to capturing subjective reports of loads carried and the nature in which they were carried in order to gather a broad cross-section of information from across the service. Further investigation of loads carried during physical training (PT), on field training exercises and on operations, and the context in which they are carried, is needed to support the findings of this thesis. Where possible, objective measures should be sought of the loads carried and the contexts in which they are carried by soldiers during field training exercises and on operations, while performing generic tasks (headquarters duties) and active combat-oriented tasks (vehicle check-points, patrolling). Given the findings from the current research of differences in loads carried by different corps, female soldiers (lighter absolute loads), and lighter soldiers (heavier relative loads), the collection of load carriage data in the future should, where possible, include soldiers from these demographics. This information can be used not only to better inform load carriage practices within the military (for example, doctrine and physical conditioning program outcomes), but also to inform future load carriage research protocols (for example, load weights, marching speeds).

Study B (Chapter 5) is distinctive in its capture of data indicating self-reported impacts of load carriage on task performance. Although the perceived negative impacts of load carriage on task performance were similar to those indicated by previous research findings (Chapter 2: Knapik, et al., 2004), the correlation between objectively measured impacts on load carriage performance and subjectively measured impacts warrants further investigation. The importance of this proposed further investigation lies in the determination of whether soldiers under-appreciate, over-appreciate or accurately appreciate the impact of the loads they carry on task performance. The findings of such research can be used to inform future load carriage practices and policies. For example, if objective research suggests that cognitive processing task performance declines with load carriage (discussed in Chapter 2), yet soldiers do not consider the loads they carry to affect their cognitive ability, what impacts might this disconnect have on the soldiers' decisions regarding actions to take when patrolling along a road littered with improved explosive devices, when staffing a vehicle check-point, or when directing subordinate soldiers engaged in combat? Conversely, if soldiers consider the impacts of the loads they carry to have a greater impact on their marksmanship skills than objective measures suggest, might this lead them to carry additional ammunition (and hence load) or precipitate higher rates of less accurate weapon fire?

Guidelines for optimising load carriage conditioning, guided by best practice protocols of the fitness and conditioning industry (the F.I.T.T. principle),[174] were developed for the current program of research through use of previous research findings on load carriage physical conditioning (Chapter 2). In addition, on the basis of findings of the current program of research, physical conditioning is recommended as a risk treatment option and risk control for load carriage risk management. Currently, limited research has been conducted on the impacts of load carriage on load carriage task performance and injury potential, and, to my knowledge, no research has examined the effects of a comprehensive physical training program, explicitly guided by the F.I.T.T. principle on these outcomes of implementation[175]. On this basis, further research is needed that examines the impacts of physical conditioning on load carriage risk consequences such as injury and reduced task performance. Furthermore, validation of the use of the F.I.T.T. principle as a determinant of training dose for load carriage conditioning would benefit from further research.

The effectiveness of military doctrine and policy in controlling the loads carried by soldiers is yet to be determined. Study D (Chapter 7) examined the doctrine and policies employed by the ARA in

---

[174] Discussed in Chapter 6, Section 6.2.4.

[175] It is however acknowledged that, while not employing the F.I.T.T. principle explicitly, several investigations were probably guided by these concepts.

relation to the loads carried by Australian soldiers. In that study, the guidance on load carriage provided to commanders and soldiers through ARA doctrines and policies was very limited. Moreover, instances were reported where ARA soldiers were considered to be carrying loads heavier than those detailed in their unit policies. The current results suggest that either the guidance provided in doctrine and unit policies does not meet the requirements of commanders and individuals on military operations, or doctrine and unit polices are not being enforced and adhered to. Further research into these two areas is needed to guide future doctrine and policy development. With limited research available into the effectiveness of doctrine and policy, research investigating the impact of any load carriage doctrine and unit policies developed in the future as risk treatment options is needed in both the short and long term.

Current continued investment in soldier load reduction measures and practices presents ongoing and future research opportunities. Examples of areas where research is still required to identify and trial long-term solutions include research into means of permanently reducing the soldier’s load through the production of lighter multifunctional equipment, enhancing the soldier’s physical load carriage ability (e.g. physical conditioning and biomechanical aides) and transferring the soldier’s load to a load carriage aid.

The endeavour to reduce the loads carried by soldiers is an age-old battle that has yet to be won. If victory is to be gained, dedicated research must be continued exploring many fields. Those fields include a better understanding of contemporary military load carriage contexts, non-technological solutions (for example, load carriage conditioning and policy), and future technological solutions. Failure to continue such research may mean more than just the loss of this complex battle. It may mean the loss of soldier lives.

11. REFERENCES

Abe, D., Muraki, S., & Yasukouchi, A. (2008a). Ergonomic effects of load carriage on energy cost of gradient walking. *Appl Ergon, 39*(2), 144-149.

Abe, D., Muraki, S., & Yasukouchi, A. (2008b). Ergonomic effects of load carriage on the upper and lower back on metabolic energy costs of walking. *Appl Ergon, 39*(3), 392-398.

Abe, D., Yanagawa, K., & Niihata, S. (2004). Effects of load carriage, load position, and walking speed on energy cost of walking. *Appl Ergon, 35*(4), 329-335.

Addington, L. H. (1990). *The Patterns of War Through the Eighteenth Century*. Bloomington: Indiana University Press.

Akers, W. A., & Sulzberger, Z. B. (1972). The Friction Blister. *Mil Med, 137*, 1-7.

Almeida, S., Williams, K., Shaffer, R., & Brodine, S. (1999). Epidemiological patterns of musculoskeletal injuries and physical training. *Medicine & Science in Sports and Exercise, 31*(8), 1176-1182.

Anderson, A. M., Meador, K. A., McClure, L. R., Makrozahopoulos, D., Brooks, D. J., & Mirka, G. A. (2007). A biomechanical analysis of anterior load carriage. *Ergonomics, 50*(12), 2104-2117.

Anonymous. (2004). Field Studies in Afghanistan finds needs for a lighter combat load. *Army Logistician, 36*(3), 47-48.

Archer, C. I., Ferris, J. R., Herwig, H. H., & Travers, T. H. E. (2002). *World History of Warfare*. Lincoln: University of Nebraska Press.

Arellano, C. J., Layne, C. S., O'Connor, D. P., Scott-Pandorf, M., & Kurz, M. (2009). Does load carrying influence sagittal plane locomotive stability? *Medicine & Science in Sports and Exercise, 41*(3), 620-627.

Army. (2011, 28 Apr). First of new combat ensembles delivered, *Army. The Soldiers Newspaper*.

Ashley, J. R. (1998). *The Macedonian Empire: The era of warfare under Philip II and Alexander the Great, 359-323 B.C.* North Carolina: McFarland and Company Incorporated Publishers.

Attard, G. J. (1985). Pack palsy. *J R Army Med Corps, 131*(1), 50-51.

Attwells, R., Birrell, S. A., Hooper, R. H., & Mansfield, N. J. (2006). Influence of carrying heavy loads on soldier's posture, movements and gait. *Ergonomics, 49*(14), 1527-1537.

Attwells, R., & Hooper, R. H. (2005). Gender differences in military load carriage. *Contemporary ergonomics 2005*, 151.

Attwells, R., Pope, R., Billing, D., Patterson, M. J., Ham, D., Moorby, G. M., et al. (2007). *Trade-Task Risk Analysis of the Ground Based Air Defence Trade*: Defence Science and Technology Organisation.

Australia-Japan Research project. (2008). The Human Face of War: Equipment. Retrieved from http://ajrp.awm.gov.au/ajrp/ajrp2.nsf/pages/NT0000DA5A?openDocument

Australian Army. (1984). The Infantry Battalion. *Manual of Land Warfare 2-1-1*. Commonwealth of Australia.

Australian Army. (1986). The Rifle Platoon. *Manual of Land Warfare 2-1-2*. Commonwealth of Australia.

Australian Army. (2002). The Fundamentals of Land Warfare. *Land Warfare Doctrine 1*. Commonwealth of Australia.

Australian Army. (2003). All Corps Junior Commanders Aide-Memoir. *Land Warfare Publication - General 0-2-4*. Commonwealth of Australia.

Australian Army. (2004). *LWP-G 7-4-12 5: 56MM Austeyr Individual Weapon Family F88, F88C, F88SA1. F88T and 40MM Grenade Launcher Attachment, Vol 1*. Puckapunyal, VIC: Commonwealth of Australia.

Australian Army. (2005). Combat Fitness Handbook. *Land Warfare Publication - General 7-7-4*. Commonwealth of Australia.

Australian Army. (2007a). *Army Technical Instruction 01/2007: Military Risk Management*: Army Headquarters. Commonwealth of Australia.

Australian Army. (2007b). Infantry Reconnaissance and Surveillance. *Land Warfare Publication - Combat Arms (Dismounted Combat) 3-3-5*. Commonwealth of Australia.

Australian Army. (2008a). *DI(A) OPS 80-1 AMDT4: Army Individual Readiness Notice*: Commonwealth of Australia.

Australian Army. (2008b). Employment of Infantry. *Land Warfare Doctrine 3-3-7*. Commonwealth of Australia.

Australian Army. (2009a). All Corps Soldier Skills. *Land Warfare Publication - General 7-7-1* Commonwealth of Australia..

Australian Army. (2009b). Patrolling. *Land Warfare Publication - Combat Arms (Dismounted Combat) 3-3-8*. Commonwealth of Australia.

Australian Army Staff. (2008). *The Australian Army at War: An Official Record of Service in Two Hemispheres, 1939-1944* (6th ed.): Merriam Press.

Australian Associated Press. (2009, 5 Oct). Train before trekking Kokoda Track - minister, *Herald Sun*.

Australian Associated Press. (2010, 25 May). Army chief shows off new body armour, *The Australian*.

Australian Defence Magazine. (2011). Diggerworks delivers updated SCE for MTF 3. *Australian Defence Magazine*.

Australian National Occupational Health & Safety Commission. (1990). *Manual Handling: National Standard [NOHSC:1001 (1990)]*: Australian Govt. Pub. Service.

Australian National Occupational Health & Safety Commission. (2005). *National Code of Practice for Manual Handling [NOHSC:2005 (1990)]*: Australian Govt. Pub. Service.

Australian Nursing Federation. (2008). *ANF Policy: No Lifting*.

Australian Safety and Compensation Council. (2007a). *National Code of Practice for the Prevention of Musculoskeletal Disorders from Performing Manual Tasks at Work*. Australian Safety and Compensation Council. Canberra: ACT. Australian Govt. Pub. Service.

Australian Safety and Compensation Council. (2007b). *National Standard Manual Tasks*. Australian Safety and Compensation Council. Canberra: ACT. Australian Govt. Pub. Service.

Australian Safety and Compensation Council. (2008). *Type of Occurrence Classification System* (3rd ed.). Australian Safety and Compensation Council. Canberra: ACT. Australian Govt. Pub. Service.

Babbie, E. R. (2008). *The basics of social research*: Wadsworth Pub Co.

Bachkosky, J., Andrews, M., Douglass, R., Feigley, J., Felton, L., Fernandez, F., et al. (2007). Lightening the Load. *Naval Research Advisory Committee, NRAC 07-02. Arlington, Virginia.*

Bachrach, B. S., & Aris, R. (1990). Military Technology and Garrison Organization: Some Observations on Anglo-Saxon Military Thinking in Light of the Burghal Hidage. *Technology and Culture, 31*(1), 1-17.

Baddeley, A. (2007). Combat Soldier C4I. *Military Technology, 31*(9), 34-40,42-44.

Baechle, T. R., & Earle, R. W. (2008). *Essentials of strength training and conditioning*: Human Kinetics Publishers.

Balkoski, J. (1999). *Beyond the Beachhead: The 29th Infantry Division in Normandy* (2nd ed.). Pennsylvania: Stackpole Books.

Balogun, J. A. (1986). Ergonomic comparison of three modes of load carriage. *Int Arch Occup Environ Health, 58*(1), 35-46.

Basan, T. (2007). Australia's Project "Wundurra". *Military Technology, 31*(9), 48 - 52.

Bastien, G. J., Schepens, B., Willems, P. A., & Heglund, N. C. (2005). Energetics of load carrying in Nepalese porters. *Science, 308*(5729), 1755.

Bauer, I. (2003). Inca trail porters: the health and local tourism employees as a challenge for travel medicine. *Journal of Travel Medicine, 10*(2), 94-99.

Beaudot, W. J. K. (2003). *The 24th Wisconsin Infantry in the Civil War: The Biography of a Regiment*. PA: Stackpole Brooks.

Beekley, M. D., Alt, J., Buckley, C. M., Duffey, M., & Crowder, T. A. (2007). Effects of heavy load carriage during constant-speed, simulated, road marching. *Mil Med, 172*(6), 592-595.

Beidel, E. (Producer). (2011, 01 April 2011). Army shifts focus to Dismounted Soldiers. *National Defense Magazine*. Retrieved from http://www.nationaldefensemagazine.org/archive/2011/April/Pages/ArmyShiftsFocustoDismountedSoldiers.aspx

Belmont, P. J., Goodman, G. P., Waterman, B., DeZee, K., Burks, R., & Owens, B. D. (2010). Disease and Nonbattle Injuries Sustained by a US Army Brigade Combat Team During Operation Iraqi Freedom. *Mil Med, 175*(7), 469-476.

Bennell, K., Matheson, G., Meeuwisse, W., & Brukner, P. (1999). Risk factors for stress fractures. *Sports Medicine, 28*, 91-122.

Bennett, T., Bathalon, G., Armstrong, D. r., Martin, B., Coll, R., Beck, R., et al. (2001). Effect of creatine on performance of military relevant tasks and soldier health. *Mil Med, 166*(11), 996-1002.

Berg, B. L. (2001). *Qualitative research methods for the social sciences*: Allyn & Bacon.

Berkley, S. F., McNeil, J. G., Hightower, A. W., Graves, L. M., Smith, P. B., & Broome, C. V. (1989). A cluster of blister-associated toxic shock syndrome in male military trainees and a study of staphylococcal carriage patterns. *Mil Med, 154*(10), 496-499.

Bernton, H. (2011a, 13 February). Army Struggles to Trim Troops Load, *Seattle Times*, p. A1.

Bernton, H. (2011b, 12 February). Weight of War: Gear that protects troops also injures them, *Seattle Times*, p. A1.

Bernton, H. (2011c, 15 February). Weight of War: Military struggles to lighten soldier’s load, *Seattle Times*. p. A1.

Bessen, R. J., Belcher, V. W., & Franklin, R. J. (1987). Rucksack Paralysis With and Without Rucksack Frames. *Mil Med, 152*(7), 372 - 375.

Bewick, N., & Gardner, D. (2000). Manual handling injuries in health care workers. *International journal of occupational safety and ergonomics: JOSE, 6*(2), 209.

Bhambhani, Y., Buckley, S., & Maikala, R. (1997). Physiological and biomechanical responses during treadmill walking with graded loads. *Eur J Appl Physiol, 76*(6), 544-551.

Bhambhani, Y., & Maikala, R. (2000). Gender differences during treadmill walking with graded loads: biomechanical and physiological comparisons. *Eur J Appl Physiol, 81*(1-2), 75-83.

Biemer, P. P., & Lyberg, L. E. (2003). *Introduction to survey quality* (Vol. 329): Wiley-Interscience.

Bigard, A. X. (2000). *A combination of Biomechanical and Physiological approaches for determination of optimal load distribution*. Paper presented at the RTO Meeting Proceedings 56: Soldier Mobility: Innovations in Load Carriage System Design and Evaluation, Kingston, Canada.

Billows, R. A. (1995). *Kings and Colonists: Aspects of Macedonian Imperialism*. New York: Brill Publishers.

Bilzon, J., Allsopp, A., & Tipton, M. J. (2001). Assessment of physical fitness for occupations encompassing load-carriage tasks. *Occup Med (Lond), 51*(5), 357-361.

Bilzon, J. L. J., Scarpello, E. G., Smith, C. V., Ravenhill, N. A., & Rayson, M. P. (2001). Characterization of the metabolic demands of simulated shipboard Royal Navy fire-fighting tasks. *Ergonomics, 44*(8), 766-780.

Birrell, S. A., & Haslam, R. A. (2008). The influence of rifle carriage on the kinetics of human gait. *Ergonomics, 51*(6), 816-826.

Birrell, S. A., & Haslam, R. A. (2009a). The effect of military load carriage on 3-D lower limb kinematics and spatiotemporal parameters. *Ergonomics, 52*(10), 1298-1304.

Birrell, S. A., & Haslam, R. A. (2009b). Subjective Skeletal Discomfort Measured Using a Comfort Questionnaire Following a Load Carriage Exercise. *Mil Med, 174*(2), 177-182.

Birrell, S. A., & Hooper, R. H. (2007). Initial subjective load carriage injury data collected with interviews and questionnaires. *Mil Med, 172*(3), 306-311.

Birrell, S. A., Hooper, R. H., & Haslam, R. A. (2007). The effect of military load carriage on ground reaction forces. *Gait & Posture, 26*(4), 611-614.

Blacker, S. D., Fallowfield, J. L., Bilzon, J. L. J., & Willems, M. E. T. (2009). Physiological responses to load carriage during level and downhill treadmill walking. *Medicina Sportiva, 13*(2), 116-124.

Blacker, S. D., Fallowfield, J. L., Bilzon, J. L. J., & Willems, M. E. T. (2010). Neuromuscular Function Following Prolonged Load Carriage on Level and Downhill Gradients. *Aviation, space, and environmental medicine, 81*(8), 745-753.

Bompa, T. O., & Carrera, M. (2005). *Periodisation training for sports* (2nd ed.): Human Kinetics.

Bompa, T. O., & Haff, G. G. (2009). *Periodization: Theory and Methodology of Training* (5th ed.): Human Kinetics.

Bonato, P., Kothiyal, K., & Roy, S. H. (2000). *Assessment of muscle fatigue during load carrying.* Paper presented at the Proceedings of the IEA 2000/HFES 2000 Congress.

Bonita, R., Beaglehole, R., & Kjellstrom, T. (2006). *Basic epidemiology* (2nd ed.): World Health Organisation.

Bose, P. S. (2003). *Alexander the Great's Art of Strategy*. New York: Penguin Publishers

Bossi, L. L., & Tack, D. W. (2000). *Human factors engineering in the development of a new load carriage system for the Canadian Forces*. Paper presented at the RTO Meeting Proceedings 56: Soldier Mobility: Innovations in Load Carriage System Design and Evaluation, Kingston, Canada.

Boulware, D. R. (2003). Backpacking-Induced Paresthesias. *Wilderness and Environmental Medicine, 14*, 161-166.

Bowden, M. (1999). *Black Hawk down*: Atlantic Monthly Press.

Breen, B. (2000). *Mission Accomplished, East Timor*: Allen & Unwin.

Brennan, P. H. (2003). From Amateur to Professional: The Experience of Brigadier General William Antrobus Griesbach. In B. C. Busch (Ed.), *Canada and the Great War. Western Front Association Papers* (pp. 77 - 92): McGill-Queens University Press.

Brodie, B., & Brodie, F. M. (1973). *From Crossbow to H Bomb*. Indiana: Indiana University Press.

Brothers, M., & Wilson, C. (2010). Iron Deficiency in Women and Its Potential Impact on Military Effectiveness. *Nurs Clin N Am, 45*, 95-108.

Brown, N., Hobson, S., Kerr, J., Pengelley, R., Wasserbly, D., & Williams, H. (2010). Battle of the bulge: getting to grips with the burdens of war. *Jane's International Defence Review, 43*, 40.

Bruce, N., Pope, D., & Stanistreet, D. (2008). *Quantitative methods for health research: A practical interactive guide to epidemiology and statistics*: Wiley-Interscience.

Brukner, P., & Khan, K. (2011). *Clinical sports medicine* (4th ed.): McGraw-Hill.

Brune, P. (2003). *A Bastard of a Place: The Australians in Papua*. Crows Nest: Allen & Unwin.

Brune, P. (2006). *Those ragged bloody heroes: from the Kokoda Trail to Gona Beach 1942*: Allen & Unwin.

Buckalew, L. W. (1990). Soldier performance as a function of stress and load: A review. ARI Research Report 1545. *U.S. Army Research Institute for Behavioral and Social Sciences*, 33.

Burnard, P. (1996). Teaching the analysis of textual data: an experiential approach. *Nurse education today, 16*(4), 278-281.

Burnes, T. (2008). Contributions of Women to US Combat Operations: Army War Coll, Carlisle Barracks, P. A.

Bush, R. A., Brodine, S., & Shaffer, R. (2000). The Association of Blisters with Musculoskeletal Injuries in Male Marine Recruits. *J Am Podiatr Med Assoc, 90*(4), 194-198.

Cabin, R. J., & Mitchell, R. J. (2000). To Bonferroni or not to Bonferroni: when and how are the questions. *Bulletin of the Ecological Society of America, 81*(3), 246-248.

Cadarette, B. S., Blanchard, L., Staab, J. E., Kolka, M. A., & Sawka, M. N. (2001). Heat Stress When Wearing Body Armor T-01/9. *Military Performance Division. US Army Research Institute of Environmental Medicine, Natick.*

Caine, D., Caine, C., & Maffulli, N. (2006). Incidence and distribution of pediatric sport-related injuries. *Clinical Journal of Sport Medicine, 16*(6), 500.

Caldwell, J. N., Engelen, L., van der Henst, C., Patterson, M. J., & Taylor, N. A. S. (2011). The Interaction of Body Armor, Low-Intensity Exercise, and Hot-Humid Conditions on Physiological Strain and Cognitive Function. *Mil Med, 176*(5), 488-493.

Calligeros, M. (2011, 16 March). Police trial new load bearing vests, *Brisbane Times*.

Cameron, I. T., & Raman, R. (2005). *Process systems risk management* (Vol. 6): Academic Press.

Camp, D. (2000). Toktong Ridge runners - 1st Battalion, 7th Marines. *Leatherneck, 83*(12), 40.

Campbell, B. (2004). *Greek and Roman Military Writers: Selected Readings*. New York: Routledge Publications.

Carlton, C. (1992). *Going to the Wars: The Experience of the British Civil Wars, 1638 – 1651*. New York: Routledge Press.

Carrivick, P. J. W., Lee, A. H., Yau, K. K. W., & Stevenson, M. R. (2005). Evaluating the effectiveness of a participatory ergonomics approach in reducing the risk and severity of injuries from manual handling. *Ergonomics, 48*(8), 907-914.

Carter III, R., Cheuvront, S. N., Williams, J. O., Kolka, M. A., Stephenson, L. A., Sawka, M. N., et al. (2005). Epidemiology of hospitalizations and deaths from heat illness in soldiers. *Medicine & Science in Sports & Exercise, 37*(8), 1338.

Cassidy, B. (2003). Machiavelli and the ideology of the offensive: Gunpowder in The Art of War. *The Journal of Military History, 67*(2), 381-404.

Chamoux, F. (1965). *The Civilisation of Greece*. London: George Allen & Unwin.

Chan, K., Yuan, Y., Li, C., Chien, P., & Tsang, G. (1993). Sports causing most injuries in Hong Kong. *British Journal of Sports Medicine, 27*(4), 263.

Charteris, J. (2000). Load stress; a carrier strain: Implications for military and recreational backpacking. *Ergonomics, (2000) 1*.

Charteris, J., Scott, P. A., & Nottrodt, J. W. (1989). Metabolic and kinematic responses of African women head loaded carriers under controlled conditions of load and speed. *Ergonomics, 32*(12), 1539-1550.

Cheuvront, S. N., Goodman, D. A., Kenefick, R. W., Montain, S. J., & Sawka, M. N. (2008). Impact of protective vest and spacer garment on exercise-heat strain. *Eur J Appl Physiol, 102*, 577-583.

Childs, J. (1994). The Restoration Army 1600 – 1702. In D. Chandler & I. Beckett (Eds.), *The Oxford History of the British Army*: Oxford University Press.

Christie, C. J., & Scott, P. A. (2005). Metabolic responses of South African soldiers during simulated marching with 16 combinations of speed and backpack load. *Mil Med, 170*(7), 619-622.

Chung, M. K., Lee, Y. J., Lee, I., & Choi, K. I. (2005). Physiological workload evaluation of carrying soft drink beverage boxes on the back. *Appl Ergon, 36*(5), 569-574.

Clarke, M. T. (2007). *These days of large things: The culture of size in America, 1965 - 1930*. Michigan: University of Michigan Press.

Clarke, P. M., Fiebig, D. G., & Gerdtham, U.-G. (2008). Optimal recall length in survey design. *Journal of Health Economics, 27*, 1275-1284.

Coffman, E. M. (1998). *The War to End All Wars: The American Experience in World War I*. Kentucky: University Press of Kentucky.

Coggins, J. (2004). *Arms and Equipment of the Civil War* (Dover ed.). New York: Courier Dover Publications.

Coghlan, T., Gemmell, C., & Allen, N. (2008, 18 June). Equipment offers poor protection for British soldiers in Afghanistan, *The Telegraph*.

Combined Arms Center. (2010). About CALL: Supporting the Soldier with Lessons Learned Retrieved 23 DEC, 2010, from http://usacac.army.mil/cac2/call/about.asp

Copp, T. (2003). *Fields of Fire: The Canadians in Normandy*. Toronto: University of Toronto.

Coppola, M. N., LaFrance, K. G., & Carretta, H. J. (2002). The female infantryman: a possibility? *Military Review, 82*(6), 55-60.

Corkill, G., Liberman, J. S., & Taylor, R. G. (1980). Pack Palsy in Backpackers. *The Journal of Western Medicine, 132*(6), 569-572.

Costa, D. M., & Guthrie, S. R. (1994). *Women and Sport*: Human Kinetics.

Coughlin, S. S. (1990). Recall bias in Epidemiological Studies. *J Clin Epidemiol, 43*(1), 87-92.

Couper, M.P., Traugott, M.W. & Lamias, M.J. (2001). Web Survey Design and Administration, *The Public Opinion Quarterly*, *65*(2), pp. 230-253

Creswell, J. (2003). *Research design. Qualitative, quantitative and mixed methods approaches* (2nd ed.). Thousand Oaks, CA: Sage Publications Inc.

Crowder, T. A., Beekley, M. D., Sturdivant, R. X., Johnson, C. A., & Lumpkin, A. (2007). Metabolic effects of soldier performance on a simulated graded road march while wearing two functionally equivalent military ensembles. *Mil Med, 172*(6), 596-602.

Curlier, P. (2004). The Infantry soldier as a system - French Army goes FELIN. *NATO's nations and Partners for Peace, 2004*(5), 76-78.

Cwikel, J. (2006). *Social epidemiology: strategies for public health activism*: Columbia Univ Pr.

Cymerman, A., Pandolf, K. B., Young, A. J., & Maher, J. T. (1981). Energy expenditure during load carriage at high altitude. *J Appl Physiol, 51*(1), 14-18.

Das, S. K., & Saha, H. (1966). Climbing efficiency with different modes of load carriage. *Indian J Med Res, 54*(9), 866-871.

Datta, S. R., Chatterjee, B. B., & Roy, B. N. (1975). Maximum permissible weight to be carried on the head by a male worker from Eastern India. *J Appl Physiol, 38*(1), 132-135.

Datta, S. R., & Ramanathan, N. L. (1971). Ergonomic comparison of Seven Modes of Carrying Loads on the Horizontal Plane. *Ergonomics, 14*(2), 269-278.

Davies, G. (2000). *Material choices for good load carriage design*. Paper presented at the RTO Meeting Proceedings 56: Soldier Mobility: Innovations in Load Carriage System Design and Evaluation, Kingston, Canada.

Davison, S. (2007). The Combat Exclusion of Women in the Military: Paternalistic Protection or Military Need? *Australian Army Journal, IV*(3), 59-79.

Debeliso, M., O'Shea, J. P., Harris, C., Adams, K. J., & Climstein, M. (2004). The relation between trunk strength measures and lumbar disc deformation during stoop tire lifting. *Journal of Exercise Physiology, 7*(6), 16-26.

Defence Health Services Branch. (2000). ADF Health Status. *Defence Health Services Branch: Department of Defence*. Commonwealth of Australia.

Defence Media Release. (2010). North Queensland Readies for Exercise Hamel. *Issued by Miniserial and Executive Coordination and Communication, Department of Defence*.

Defence Science and Technology Organisation. (2009). Physical Standards for Military Service to be Benchmarked, *Media Release 043/2009*

Department of Defence. (1994). *ADFP 101. Staff Duties. Glossary*: Commonwealth of Australia.

Department of Defence. (2011a). Battle casualties in Afghanistan. *Afghanistan* Retrieved 23 Nov 2011, from http://www.defence.gov.au/op/afghanistan/info/personnel.htm

Department of Defence. (2011b). Incidence Capture Retrieved 31 Jan 2011, from http://www.defence.gov.au/dpe/ohsc/Incidents/default.htm#guidance

Department of Defence. (n.d.). Airfield Defence Guard Retrieved 06 August 2010, from http://www.defencejobs.gov.au/airforce/jobs/airfielddefenceguard/

Department of the Army. (1990). *Field Manual 21-18 Foot Marches*. Washington, DC: Department of the Army.

Dillman, D.A., Tortora, R.D. & Bowker, D. (1999). *Principles for constructing web surveys*. SESRC. Technical Report No. 98-50. Washington State University.

Directorate of Strategic Personnel Policy Research. (2009). The first Australian Defence Force Families Survey. *Australian Defence Force, Commonwealth of Australia*.

Dockery, P. H. (2002). *Vietnam was more than just the killing*. Victoria: Trafford Publishing.

Dodge, T. A. (1995). *Hannibal. A History of the Art of War among the Carthaginians and Romans down to the Battle of Pydna, 168 B.C. with a detailed account of the second Punic War*. New York: Da Capo Press.

Drain, J., Orr, R. M., Billing, D., & Rudzki, S. J. (2010). *Human Dimensions of Heavy Load Carriage*. Paper presented at the Land Warfare Conference, Queensland, Australia.

Drye, C., & Zachazewski, J. E. (1996). Peripheral Nerve Injuries. In J. E. Zachazewski, D. J. Magee & W. S. Quillen (Eds.), *Athletic Injuries and Rehabilitation*: W.B. Saunders.

Dufour, G. H. (1864). *Strategy and Tactics* (W. P. Craighill, Trans.). New York: C. A. Alvord.

Dupuy, T. N. (1980). *The Evolution of Weapons and Warfare*. New York: Bobbs-Merrill Company.

Ebben, W. P., & Jensen, R. L. (1998). Strength Training for Women. *The Physician and Sports Medicine, 26*(5).

Eby, J. L. (2005). It is time for the Exoskeleton. *Marine Corps Gazette, 89*(9), 76-79.

Edlich, R. F., Hudson, M. A., Buschbacher, R. M., Winters, K. L., Britt, L. D., Cox, M. J., et al. (2005). Devastating injuries in healthcare workers: description of the crisis and legislative solution to the epidemic of back injury from patient lifting. *Journal of long-term effects of medical implants, 15*(2), 225.

Edwards, P. M. (2006). *The Korean War*. Connecticut: Greenwood Publishing Group.

Ehrman, J. K., Gordon, P., Visich, P. S., & Keteyian, S. J. (2008). *Clinical Exercise Physiology* (2nd ed.): Human Kinetics.

Ellis, J. (1989). *Eye-Deep in Hell. Trench Warfare in World War I* (1st American ed.). Maryland: John Hopkins Press.

Elo, S., & Kyngäs, H. (2007). The qualitative content analysis process. *Journal of advanced nursing, 62*(1), 107-115.

Eltis, D. (1998). *The Military Revolution in Sixteenth Century Europe*. New York: I B Tauris Publishers.

Engels, H. J., Smith, C. R., & Wirth, J. C. (1995). Metabolic and hemodynamic responses to walking with shoulder-worn exercise weights: a brief report. *Clin J Sports Med, 5*(3), 171-174.

Engkvist, I. L. (2006). Evaluation of an intervention comprising a No Lifting Policy in Australian hospitals. *Appl Ergon, 37*(2), 141-148.

English, J. A. (1991). *The Canadian Army and the Normandy Campaign. A Study of Failure in High Command*. New York: Praeger Publishers.

Epstein, Y., Rosenbaum, D., Burstein, R., & Sawka, M. N. (1988). External load can alter the energy cost of prolonged exercise. *Eur J Appl Physiol, 57*, 243-247.

Ermatinger, J. W. (2004). *The Decline and Fall of the Roman Empire*. Connecticut: Greenwood Publishing Group.

Evans, O. M., Zerbib, Y., Faria, M. H., & Monod, H. (1983). Physiological responses to load holding and load carriage. *Ergonomics, 26*(2), 161-171.

Ezell, M. W. L. (1992). Battlefield Mobility And The Soldier's Load. *United States Marine Corps, Command and Staff Course*.

Fairholt, F. W. (1847). *Costume in England. A History of Dress from the earliest period till the close of the Eighteenth Century*. London: Chapman and Hall.

Fargo, M. V., & Konitzer, L. N. (2007). Meralgia Paresthetia Due to Body Armor Wear in U.S. Soldiers Serving in Iraq: A Case Report and Review of the Literature. *Mil Med, 172*(6), 663 - 665.

Field, A. P. (2000). *Discovering Statistics Using SPSS for Windows: Advanced Techniques for Beginners*. Thousand Oaks, CA: Sage Publications Inc.

Filaire, M., Vacheron, J. J., Vanneuville, G., Poumarat, G., Garcier, J. M., Harouna, Y., et al. (2001). Influence of the mode of load carriage on the static posture of the pelvic girdle and the thoracic and lumbar spine in vivo. *Surg Radiol Anat, 23*(1), 27-31.

Fink, A. (2002). *How to ask survey questions (Vol. 2)*. Sage Publications, Incorporated.

Fink, A. (2005). *How to conduct surveys: A step-by-step guide* (3rd ed.). Thousand Oaks, CA: Sage Publications Inc.

Fos, P. J. (2010). *Epidemiology Foundations: The Science of Public Health*: Jossey-Bass.

Fowler, N. E., Rodacki, A. L., & Rodacki, C. D. (2006). Changes in stature and spine kinematics during a loaded walking task. *Gait & Posture, 23*(2), 133-141.

Frederiks, J., Swenne, C. A., Bruschke, A. V., Van Der Velde, E. T., Maan, A. C., Tenvoorde, B. J., et al. (2000). Correlated neurocardiological fitness changes in athletes interrupting training. *Medicine & Science in Sports & Exercise, 32*, 571-575.

Fremont-Barnes, G. (2005). *The French Revolutionary Wars*. Oxford: Osprey Publishing.

Frykman, P. N., Harman, E., & Pandorf, C. E. (2000). *Correlates of obstacle course performance among female soldiers carrying two different loads*. Paper presented at the RTO Meeting Proceedings 56: Soldier Mobility: Innovations in Load Carriage System Design and Evaluation, Kingston, Canada.

Gabriel, R. A. (1990). *The Culture of War: Invention and Early Development*. Connecticut: Greenwood Press.

Gabriel, R. A. (2001). *Great Captains of Antiquity*. Connecticut: Greenwood Publishing Group.

Gabriel, R. A. (2002). *The Great Armies of Antiquity*. Connecticut: Greenwood Publishing Group.

Galun, E., & Epstein, Y. (1984). Serum creatine kinase activity following a 120-km march. *Clinica Chimica Acta, 143*, 281-283.

García-Pallarés, J., Carrasco, L., Díaz, A., & Sánchez-Medina, L. (2009). Post-season detraining effects on physiological and performance parameters in top-level kayakers: comparison of two recovery strategies. *Journal of Sports Science and Medicine, 8*, 622-628.

Gardner, H. B. (2006). Fighting Afghanistan's Opium Dependency as a Means of Disrupting al Qaeda's Illicit Funding. *U.S. Army Command and Staff College*.

Gemmell, H. A. (2002). Injuries among female army recruits: A conflict of legislation. *Royal Society of Medicine (Great Britain). Journal of the Royal Society of Medicine, 95*(1), 23-27.

Genaidy, A. M., Mital, A., & Bafna, K. M. (1989). An endurance training program for frequent manual carrying tasks. *Ergonomics, 32*(2), 149-155.

Gilbert, M. (2006). *The Somme. Heroism and Horror in the First World War*. New York: Henry Holt Publishers.

Gimby, A. J. (2004). Urban Patrolling. *The Canadian Army Journal, 7,3 / 7,4 Fall / Winter*, 22-34.

Givoni, B., & Goldman, R. F. (1971). Predicting metabolic energy cost. *J Appl Physiol, 30*(3), 429-433.

Goh, J. H., Thambyah, A., & Bose, K. (1998). Effects of varying backpack loads on peak forces in lumbosacral spine during walking. *Clin Biomech (Bristol, Avon), 13*((1 Suppl 1)), S26-S31.

Goldman, R. F. (2001). Introduction to heat-related problems in military operations, in *Medical Aspects of Harsh Environments. Volume 1* (pp. 3–49): Office of the Surgeon General, United States Army.

Goldman, R. F., & Jampietro, P. F. (1962). Energy cost of load carriage. *J Appl Physiol, 17*, 675-676.

Gordon, M. J., Goslin, B. R., Graham, T., & Hoare, J. (1983). Comparison between load carriage and grade walking on a treadmill. *Ergonomics, 26*(3), 289-298.

Goslin, B. R., & Rorke, S. C. (1986). The perception of exertion during load carriage. *Ergonomics, 29*(5), 677-686.

Gourley, S. R. (2003). Equipping today's warfighters. *Army 53*(7), 49-52.

Greaney, R. B., Gerber, F. H., Laughlin, R. L., Kmet, J. P., Metz, C. D., Kilchenski, T. S., et al. (1983). Distribution and Natural History of Stress Fractures in U.S. Marine Recruits. *Radiology, 146*, 339-346.

Great Britain Office of Government Commerce. (2007). *Management of risk: guidance for practitioners*: The Stationery Office.

Gregorczyk, K. N., Hasselquist, L., Schiffman, J. M., Bensel, J. M. S., Obusek, J. P., & Gutekunst, D. (2010). The effects of a lower body exoskeleton load carriage assistive device on metabolic cost and gait biomechanics during load carriage. *Ergonomics, 53*(10), 1263-1275.

Grey, J. (2008). *A military history of Australia*: Cambridge Univ Pr.

Griffin, L. Y. E. (2003). Neuromuscular training and injury prevention in sports. *Clinical orthopaedics and related research, 409*, 53-60.

Guttman, J. (2008). Greek Aspis. *Military History, 24*(10), 21.

Hagerman, E. (1998). *The American Civil War and the origins of Modern Warfare: Ideas, Organization and Field Command*: Indiana Press.

Haisman, M. F. (1988). Determinants of load carrying ability. *Appl Ergon, 19*(2), 111-121.

Halberstadt, H. (2006). *Battle Rattle. The stuff a soldier carries*. Minnesota: MBI Publishing.

Haldon, J. F. (1999). *Warfare, State and Society in the Byzantine World 565 – 1204*. Oxford: Routledge Publishers.

Hall, R. A. (2000). *Combat Battalion: The Eighth Battalion in Vietnam*. Crows Nest: Allen & Unwin.

Hansen, P., Bicknase, S., VanSickle, K., & Bogenreif, M. (2008). Adolescents and Exercise Induced Asthma. *Strategies: A Journal for Physical and Sport Educators, 21*(5), 1-40.

Hanson, V. D. (1989). *The Western Way of War: Infantry Battles in Classical Greece*. London: University of California Press.

Hanson, V. D. (1991). *Hoplites: The Classical Greek battle experience*. London: Routledge Publications.

Hanson, V. D. (1995a). From Phalanx to Legion. In G. Parker (Ed.), *The Cambridge History of Warfare* (pp. 30 – 44). New York: Cambridge University Press.

Hanson, V. D. (1995b). Genesis of the infantry. In G. Parker (Ed.), *The Cambridge History of Warfare* (pp. 15 – 30). New York: Cambridge University Press.

Harman, E., Frykman, P., Palmer, C., Lammi, E., Reynolds, K. L., & Backus, V. (1997). Effects of a Specifically Designed Physical Conditioning Program on the Load Carriage and Lifting Performance of Female Soldiers T98-1. *Military Performance Division. US Army Research Institute of Environmental Medicine, Natick.*

Harman, E., Frykman, P. N., Pandorf, C. E., LaFiandra, M. E., Bensel, C. K., & Kirk, J. (2001). Effects of backpack volume on the biomechanics of load carriage. T01-16. *Military Performance Division. U.S. Army Research Institute of Environmental Medicine*, 71.

Harman, E., Frykman, P. N., Pandorf, C. E., Tharion, W. J., Mello, R. P., Obusek, J. P., et al. (1999). Physiological, biomechanical, and maximal performance comparisons of female soldiers carrying loads using prototype U.S. Marine Corps Modular Lightweight Load-Carrying Equipment (MOLLE) with Interceptor body armor and U.S. Army All-Purpose Lightweight Individual Carrying Equipment (ALICE) with PASGT body armor. Technical Report T99-9. *Military Performance Division. US Army Research Institute of Environmental Medicine, Natick.*

Harman, E., Gutekunst, D. J., Frykman, P. N., Nindl, B. C., Alemany, J. A., Mello, R. P., et al. (2008). Effects of two different eight-week training programs on military physical performance. *Journal of Strength and Conditioning Research, 22*(2), 524-534.

Harman, E., Gutekunst, D. J., Frykman, P. N., Sharp, M., Nindl, B. C., Alemany, J. A., et al. (2008). Prediction of Simulated Battlefield physical performance from Field-Expedient Tests. *Mil Med, 173*(1), 36-41.

Harman, E., Han, K.-H., & Frykman, P. N. (2000). *Load-speed interaction effects on the biomechanics of backpack load carriage*. Paper presented at the RTO Meeting Proceedings 56: Soldier Mobility: Innovations in Load Carriage System Design and Evaluation, Kingston, Canada.

Harper, W. H., Knapik, J. J., & de Pontbriand, R. (1997). *Equipment compatibility and performance of men and women during heavy load carriage.* Paper presented at the Proceedings of the Human Factors and Ergonomics Society 41st Annual Meeting.

Haskell, W. L., Lee, I.-M., Russell, R., Powell, K. E., Blair, S. N., Franklin, B. A., et al. (2007). Physical Activity and Public Health: Updated Recommendation for Adults from the American College of Sports Medicine and the American Heart Association. *Medicine & Science in Sports & Exercise, 39*(8), 1423-1434.

Hastings, M., & Jenkins, S. (1983). *The Battle for the Falklands*. New York: W W Norton & Coy.

Healy, S., & McPhedran, I. (2011, Jun 15). Australian women to fight Taliban next year, *Herald Sun*.

Heglund, N. C., Willems, P. A., Penta, M., & Cavagna, G. A. (1995). Energy-saving gait mechanics with head-supported loads. *Nature, 375*(6526), 52-54.

Hendrick, H. W., Paradis, P., & Hornick, R. J. (2007). *Human Factors Issues in Handgun Safety and Forensics*: CRC Press.

Hendrickson, N. R., Sharp, M. A., Alemany, J. A., Walker, L. A., Harman, E. A., Spiering, B. A., et al. (2010). Combined resistance and endurance training improves physical capacity and performance on tactical occupational tasks. *Eur J Appl Physiol*, 1-12.

Henning, P. C., & Khamoui, A. V. (2010). Physical Training Strategies to Improve Soldier Load Carriage. *Tactical Strength and Conditioning Report* (14), 14.11-14.14.

Hernandez, J., & Salazar-Rojas, W. (2004). The effect of three lower-body training programs: A verification of the specificity principle. *Medicine and Science in Sports, 36*(5), Supplement abstract 2395.

Higginbotham, D. (1961). *Daniel Morgan: Revolutionary Rifleman*. North Carolina: University of Northern Carolina Press.

Hobbes, N. (2003). *Essential Militaria: Facts, Legends and Curiosities about Warfare Through the Ages*. New York: Grove Press.

Hoffman, J. (2002). *Physiological aspects of sport training and performance*: Human Kinetics.

Holewijn, M., Heus, R., & Wammes, L. J. A. (1992). Physiological strain due to load carrying in heavy footwear. *Eur J Appl Physiol, 65*, 129-134.

Holewijn, M., & Meeuwsen, T. (2000). *Physiological strain during load carrying: effects of mass and type of backpack*. Paper presented at the RTO Meeting Proceedings 56: Soldier Mobility: Innovations in Load Carriage System Design and Evaluation, Kingston, Canada.

Holt, K. G., Wagenaar, R. C., Kubo, M., LaFiandra, M. E., & Obusek, J. P. (2005). Modulation of force transmission to the head while carrying a backpack load at different walking speeds. *J Biomech, 38*(5), 569-574.

Holt, K. G., Wagenaar, R. C., LaFiandra, M. E., Kubo, M., & Obusek, J. P. (2003). Increased musculoskeletal stiffness during load carriage at increasing walking speeds maintains constant vertical excursion of the body center of mass. *J Biomech, 36*(4), 465-471.

Howell, D. C. (2009). *Statistical methods for psychology*: Wadsworth Pub Co.

Hughes, A. L., & Goldman, R. F. (1970). Energy cost of "hard work". *J Appl Physiol, 29*(5), 570-572.

Hughes, P., & Ferrett, E. (2009). *Introduction to health and safety at work* (4th ed.): Elsevier.

Hutcheson, J. (2003). A Shield for a Hardened Army. *Australian Army Journal, I*(2), 95-102.

Hynd, C. R. (1999). Teaching students to think critically using multiple texts in history. *Journal of Adolescent & Adult Literacy, 42*(6), 428-436.

International Electrotechnical Commission. (2009). *Risk Management - Risk Assessment Techniques. International Standard (IEC/ISO 31010)*: IEC.

Jackson, M. (2004). The British Future Soldier System (FIST). *Military Technology, 28*(11), 71-73.

Jacobsen, G. (2009, 9 Mar). Police buckle under pressure, *The Sydney Morning Herald*.

Jennings, B. M., Yoder, L. H., Heiner, S. L., Loan, L. A., & Bingham, M. O. (2008). Soldiers With Musculoskeletal Injuries. *Journal of Nursing Scholarship, 40*(3), 268-274.

Johnson, B., & Christensen, L. (2010). *Educational Research: Quantitative, Qualitative, and Mixed Approaches* (4th ed.). Thousand Oaks, CA: Sage Publications, Inc.

Johnson, R. C., Pelot, R. P., Doan, J. B., & Stevenson, J. M. (2000). *The effect of load position on biomechanical and physiological measures during a short duration march*. Paper presented at the RTO Meeting Proceedings 56: Soldier Mobility: Innovations in Load Carriage System Design and Evaluation, Kingston, Canada.

Johnson, R. F., Knapik, J. J., & Merullo, D. J. (1995). Symptoms during load carrying: effects of mass and load distribution during a 20-km road march. *Perceptual Mot Skills, 81*(1), 331-338.

Johnston, M. (1996). *At the Front Line: Experiences of Australian Soldiers in World War 2*. Cambridge: Cambridge University Press.

Johnston, M. (2002). *That Magnificent 9th: An Illustrated History of the 9th Australian Division 1940 - 46*. Crows Nest: Allen & Unwin

Jones, A. (2001). *The Art of War in the Western World*. Illinois: University of Illinois Press.

Jones, B., Knapik, J. J., Daniels, W. L., & Toner, M. M. (1986). The energy cost of women walking and running in shoes and boots. *Ergonomics, 29*(3), 439-443.

Jones, B., Toner, M. M., Daniels, W. L., & Knapik, J. J. (1984). The energy cost and heart rate responses of trained and untrained subjects walking and running in shoes and boots. *Ergonomics, 27*(8), 895-902.

Jones, B. H. (1983). Overuse injuries of the lower extremities associated with marching, jogging, and running: a review. *Mil Med, 148*(10), 783-787.

Jordan, B. (2011, 17 March). Skeletal Injuries Top Afghan War Ailments Retrieved 26 May 2011, from http://www.military.com/news/article/skeletal-injuries-top-afghan-war-ailments.html

Jordan, J. W. (2001). Battle of Pharsalus: Imperator versus Imperator. *The Journal of Military History, 17*(6), 50-57.

Jumah, K. B., & Nyame, P. K. (1994). Relationship between load carrying on the head and cervical spondylosis in Ghanaians. *West Afr J Med, 13*(3), 181-182.

Karwowski, W., Shumate, C., Pongpatana, N., & Yates, J. W. (1989). *Weight discriminability and subjective assessment of load heaviness: a pilot study*, Proceeding of the Human Factors Society 33rd Annual Meeting.

Katch, V. L., Mc Ardle, W. D., & Katch, F. I. (2011). *Essentials of exercise physiology* (4th ed.): Wolters Kluwer Health.

Katcher, P. (1999). Travelling light. *Civil War Times Illustrated, 38*(6), 76-80.

Kawabata, H. (2000). Brachial plexus palsy. In H. Kawai & H. Kawabata (Eds.), *Brachial Plexus Palsy* (pp. 31-64): World Scientific.

Keegan, J., & Homes, R. (1985). *Soldiers: A History of men in battle*. London: Sphere Books.

Keene, J. D. (2006). *World War 1*. Connecticut: Greenwood Press.

Kelly, E., Jonson, S., Cohen, M., & Shaffer, R. (2000). Stress fractures of the pelvis in female Navy recruits: an analysis of possible mechanisms of injury. *Mil Med, 165*(2), 142-146.

Kennedy, D. M. (1999). *Freedom from Fear: The American People in Depression and War, 1929-1945*. New York: Oxford University Press.

Khosa, R. (2010). *Australian Defence Almanac 2010-2011*: Australian Strategic Policy Institute.

Killewo, J., Heggenhougen, K., & Quah, S. R. (2010). *Epidemiology and Demography in Public Health*: Academic Press.

King, H. (2005). *Health in Antiquity*. New York: Routledge Press.

Kinoshita, H. (1985). Effects of different loads and carrying systems on selected biomechanical parameters describing walking gait. *Ergonomics, 28*(9), 1347-1362.

Kirkpatrick, D. (2001). Revolutions in military technology, and their consequences. *RUSI Journal, 146*(4), 67.

Kirtley, C. (2006). *Clinical gait analysis*: Elsevier Health Sciences.

Kleinschmidt, H. (2000). *Understanding the Middle Ages: The Transformation of Ideas and Attitudes*. Suffolk: Baydell Press.

Knapik, J. J. (1989). Loads Carried by Soldiers: Historical, Physiological, Biomechanical and Medical Aspects. T19-89. *U.S. Army Research Institute of Environmental Medicine, Natick*, 136.

Knapik, J. J. (2000). *Physiological, Biomechanical and Medical Aspects of Soldier Load Carriage*. Paper presented at the Soldier Mobility: Innovations in Load Carriage System Design and Evaluation, Canada.

Knapik, J. J., Ang, P., Meiselman, H., Johnson, W., Kirk, J., Bensel, C. K., et al. (1997). Soldier performance and strenuous road marching: influence of load mass and load distribution. *Mil Med, 162*(1), 62-67.

Knapik, J. J., Bahrke, M., Staab, J., Reynolds, K. L., Vogel, J. A., & O'Connor, J. (1990). Frequency of Loaded Road March Training and Performance on a Loaded Road March. T13-90. *Military Performance Division. US Army Research Institute of Environmental Medicine, Natick*, 52.

Knapik, J. J., Canham-Chervak, M., Hauret, K., Hoedebecke, E., Laurin, M. J., & Cuthie, J. (2001). Discharges during US Army basic training: injury rates and risk factors. *Mil Med, 166*(7), 641-647.

Knapik, J. J., Darakjy, S., & Hauret, K. G. (2007). Ambulatory physical activity during United States Army Basic Combat Training. *International journal of sports medicine, 28*(2), 106-115.

Knapik, J. J., & Gerber, F. H. (1996). The Influence of Physical Fitness Training on the Manual Material-Handling Capability and Road-Marching Performance of Female Soldiers TR-1064. *Army Research Laboratory Aberdeen Proving Ground*.

Knapik, J. J., Harman, E., & Reynolds, K. L. (1996). Load carriage using packs: a review of physiological, biomechanical and medical aspects. *Appl Ergon, 27*(3), 207-216.

Knapik, J. J., Harper, W., Crowell, H. P., Leiter, K., & Mull, B. (2000). Standard and alternative methods of stretcher carriage: performance, human factors, and cardiorespiratory responses. *Ergonomics, 43*(5), 639-652.

Knapik, J. J., Johnson, R. F., Ang, P., Meiselman, H., Bensel, C. K., Johnson, W., et al. (1993). Road March Performance of Special Operations Soldiers Carrying Various Loads and Load Distributions. T14-93. *Military Performance Division. US Army Research Institute of Environmental Medicine, Natick*, 136.

Knapik, J. J., Reynolds, K., & Barson, J. (1998). Influence of an antiperspirant on foot blister incidence during cross-country hiking. *Journal of the American Academy of Dermatology, 39*(2), 202-206.

Knapik, J. J., Reynolds, K. L., & Barson, J. (1999). Risk factors for foot blisters during road marching: Tobacco use, ethnicity, foot type, previous illness, and other factors. *Mil Med, 164*(2), 92-97.

Knapik, J. J., Reynolds, K. L., Duplantis, K. L., & Jones, B. (1995). Friction Blisters: Pathophysiology, Prevention and Treatment. *Sports Medicine, 20*(3), 136-147.

Knapik, J. J., Reynolds, K. L., & Harman, E. (2004). Soldier load carriage: historical, physiological, biomechanical, and medical aspects. *Mil Med, 169*(1), 45-56.

Knapik, J. J., Reynolds, K. L., Staab, J., Vogel, J. A., & Jones, B. (1992). Injuries associated with strenuous road marching. *Mil Med, 157*(2), 64-67.

Knapik, J. J., Staab, J., Bahrke, M., Reynolds, K. L., Vogel, J. A., & O'Connor, J. (1991). Soldier performance and mood states following a strenuous road march. *Mil Med, 156*(4), 197-200.

Koerhuis, C. L., Veenstra, B. J., van Dijk, J. J., & Delleman, N. J. (2009). Predicting Marching Capacity While Carrying Extremely Heavy Loads. *Mil Med, 174*(12), 1300-1307.

Kokoda Trekking. (n.d.). Preparing For Your Trek Retrieved 12 Jul 11, from http://www.kokodatrail.com.au/preparation.html

Kotaniemi, J. T., Hassi, J., Kataja, M., Jönsson, E., Laitinen, L. A., Sovijärvi, A. R. A., et al. (2001). Does non-responder bias have a significant effect on the results in a postal questionnaire study? *European journal of epidemiology, 17*(9), 809-817.

Kraemer, W., Mazzetti, S., Nindl, B. C., Gotshalk, L., Volek, J., Marx, J., et al. (2001). Effect of resistance training on women's strength/power and occupational performances. *Medicine & Science in Sports & Exercise, 33*, 1011-1025.

Kraemer, W., Vescovi, J. D., Volek, J. S., Nindl, B. C., & al., e. (2004). Effects of concurrent resistance and aerobic training on load-bearing performance and the army physical fitness test. *Mil Med*, *169*(12), 994-999.

Kraft, N. G. (2002). Lessons learned from a light infantry company during Operation Anaconda. *Infantry, 91*(2), 28-31.

Kreisher, O. (2009). Gruntworks. *Leatherneck, 92*(12), 26.

Krippendorff, K. (2004). *Content analysis: An introduction to its methodology*. Thousand Oaks, CA: Sage Publications Inc.

Kuchment, A. (2010). Body Armor with Batteries. *Scientific American Magazine, 303*(6), 25-25.

Kuring, I. (2002). The Infantryman's Load Retrieved 11 May 2008, from http://www.defence.gov.au/army/AHU/books_articles/Articles/The_Infantrymans_Load.htm

LaFiandra, M. E., & Harman, E. (2004). The distribution of forces between the upper and lower back during load carriage. *Med Sci Sports Exerc, 36*(3), 460-467.

LaFiandra, M. E., Holt, K. G., Wagenaar, R. C., & Obusek, J. P. (2002). Transverse plan kinetics during treadmill walking with and without a load. *Clin Biomech (Bristol, Avon), 17*(2), 116-122.

LaFiandra, M. E., Lynch, S., Frykman, P. N., Harman, E., Ramos, H., Isome, H., et al. (2003). A comparison of the Scorpion Load Carriage System (SLCS) to the Modular Lightweight Load Carrying Equipment (MOLLE) on soldier biomechanics, metabolic cost and performance. T03/16. *Military Performance Division, U.S. Army Research Institute of Environmental Medicine*, 98.

LaFiandra, M. E., Wagenaar, R. C., Holt, K. G., & Obusek, J. P. (2002). The effect of walking speed and adding a backpack on trunk dynamics during treadmill walking. T03-3. *Military Performance Division. US Army Research Institute of Environmental Medicine, Natick*, 40.

LaFiandra, M. E., Wagenaar, R. C., Holt, K. G., & Obusek, J. P. (2003). How do load carriage and walking speed influence trunk coordination and stride parameters? *J Biomech, 36*(1), 87-95.

Landers, R. (1998). *'Saddle Up': The Australian Load Carrying Equipment of British, American & Local Origin*. Bangkok: Thau Watana Panich Press.

Law, L., & Lim, C. (2008). *Heat Acclimatisation and Active Body Cooling Strategies to Mitigate Heat Stress for Operations Involving Bullet Proof Vests*: Defence Medical & Environmental Research Institute, DSO National Laboratories, Singapore.

Lawson, C. (1998). The MOLLE: Grunts get a brand new "gal". *Leatherneck, 81*(9), 20-21.

LeBoeuf, M., & Butler, L. F. (2007). *Fit & Active: the West Point physical development program*: Human Kinetics.

Lee, J. W. I. (2007). *A Greek Army on the March: Soldiers and Survival in Xenophon’s Anabasis*. New York: Cambridge University Press.

Legg, S. J. (1985). Comparison of different methods of load carriage. *Ergonomics, 28*(1), 197-212.

Legg, S. J., & Mahanty, A. (1985). Comparison of five modes of carrying a load close to the trunk. *Ergonomics, 28*(12), 1653-1660.

Legg, S. J., Perko, L., & Campbell, P. (1997). Subjective perceptual methods for comparing backpacks. *Ergonomics, 40*(8), 809-817.

Legg, S. J., Ramsey, T., & Knowles, D. J. (1992). The metabolic cost of backpack and shoulder load carriage. *Ergonomics, 35*(9), 1063-1068.

Lehmuskallio, E., Lindholm, H., Koskenvuo, K., Sarna, S., Friberg, O., & Viljanen, A. (1995). Frostbite of the face and ears: epidemiological study of risk factors in Finnish conscripts. *BMJ, 311*(7021), 1661-1663.

Leslie, M. (2007). Real Battle-Focused PT: Physical Training Tailored for the Fight. *Infantry, 96*(5), 41.

Lewis, A. R. (2001). *Omaha Beach: A Flawed Victory*. North Carolina: University of North Carolina Press.

Leyk, D., Rohde, U., Erley, O., Gorges, W., Essfeld, D., Erren, T., et al. (2007). Maximal manual stretcher carriage: performance and recovery of male and female ambulance workers. *Ergonomics, 50*(5), 752-762.

Leyk, D., Rohde, U., Erley, O., Gorges, W., Wunderlich, M., Ruther, T., et al. (2006). Recovery of hand grip strength and hand steadiness after exhausting manual stretcher carriage. *Eur J Appl Physiol, 96*(5), 593-599.

Ling, W., Axen, K., & Houston, V. (2000). *The influence of load carrying methods on gait on healthy women*. Paper presented at the RTO Meeting Proceedings 56: Soldier Mobility: Innovations in Load Carriage System Design and Evaluation, Kingston, Canada.

Ling, W., Houston, V., Tsai, Y. S., Chui, K., & Kirk, J. (2004). Women's load carriage performance using modular lightweight load-carrying equipment. *Mil Med, 169*(11), 914-919.

Littman, A., Boyko, E., Jacobson, I., Horton, J., Gackstetter, G., Smith, B., et al. (2010). Assessing nonresponse bias at follow-up in a large prospective cohort of relatively young and mobile military service members. *BMC medical research methodology, 10*(1), 99.

Lloyd, R., & Cooke, C. B. (2000a). Kinetic changes associated with load carriage using two rucksack designs. *Ergonomics, 43*(9), 1331 - 1341.

Lloyd, R., & Cooke, C. B. (2000b). The oxygen consumption associated with unloaded walking and load carriage using two different backpack designs. *Eur J Appl Physiol, 81*(6), 486-492.

Lloyd, R., Parr, B., Davies, S., & Cooke, C. (2009). Subjective perceptions of load carriage on the head and back in Xhosa women. *Appl Ergon*.

Lloyd, R., Parr, B., Davies, S., & Cooke, C. (2010). No free ride for African women: A comparison of head-loading versus back-loading among Xhosa women. *South African Journal of Science, 106*(3/4), 5.

Lloyd, R., Parr, B., Davies, S., Partridge, T., & Cooke, C. (2010). A comparison of the physiological consequences of head-loading and back-loading for African and European women. *Eur J Appl Physiol*, 1-10.

Lobb, B. (2004). Load carriage for fun: a survey of New Zealand trampers, their activities and injuries. *Appl Ergon, 35*(6), 541-547.

Lockheed Martin. (2006). MULE / ARV-A(L): Multifunctional Utility / Logistics and Equipment. Vehicle / Armed Robotic Vehicle-Assault (Light) (pp. 2): Lockheed Martin Corporation.

Lockheed Martin. (2009). HULC Exoskeletons Enhance Mobility and Increase Endurance (pp. 2): Lockheed Martin Corporation.

Lothian, N. V. (1921). The load carried by the soldier. *J R Army Med Corps, 38*, 9-24, 241-263, 342 - 351, 448-458.

Louhevaara, V., Smolander, J., Tuomi, T., Korhonen, O., & Jaakkola, J. (1985). Effects of a SCBA on Breathing Pattern, Gas Exchange, and Heart Rate During Exercise. *Journal of Occupational Medicine, 27*(3), 213-216.

Lowell Sun. (2010). Tsongas wants to lighten body armour for troops, *Lowell Sun*.

Lucas, J. S. (1980). *War on the Eastern Front, 1941-1945: The German Soldier in Russia*: Stein and Day.

Lusk, B. (1997). Historical methodology for nursing research. *Journal of Nursing Scholarship, 29*(4), 355-360.

Lynn, J. A. (2001). Forging the Western Army in Seventeenth Centaury. In K. MacGregor & M. Williamson (Eds.), *The Dynamics of Military Revolution, 1300 – 2050*. Cambridge: Cambridge University Press

Lynn, P., Roeland, B., Johanna, L., & Jean, M. (2001). Recommended Standard Final Outcome Categories and Standard Definitions of Response Rate for Social Surveys. *Working Papers of the Institute for Social and Economic Research, paper 2001-2003*.

Lyons, J., Allsopp, A., & Bilzon, J. (2005). Influences of body composition upon the relative metabolic and cardiovascular demands of load-carriage. *Occup Med (Lond), 55*(5), 380-384.

Mackenzie, S. P. (1997). *Revolutionary Armies – the Modern Era. A Revisionist Approach*. Oxford: Routledge Publishers.

Mackie, H. W., & Legg, S. J. (2008). Postural and subjective responses to realistic schoolbag carriage. *Ergonomics, 51*(2), 217-231.

Macleod, M. A., Houston, A. S., Sanders, L., & Anagnostopoulos, C. (1999). Incidence of trauma related stress fractures and shin splints in male and female army recruits: retrospective case study. *BMJ: British Medical Journal, 318*(7175), 29.

Mahon, J. K. (1961). Civil War Infantry Assault Tactics. *Military Affairs, 25*(2), 57-68.

Mahoney, C. R., Hirsch, E., Hasselquist, L., Lesher, L. L., & Lieberman, H. R. (2007). The effects of movement and physical exertion on soldier vigilance. *Aviat Space Environ Med, 78*(5 Suppl), B51-57.

Majumdar, D., & Pal, M. S. (2010). Effects of military load carriage on kinematics of gait. *Ergonomics, 53*(6), 782-791.

Makela, J. P., Ramstad, R., Mattila, V., & Pihlajamaki, H. (2006). Brachial plexus lesions after backpack carriage in young adults. *Clin Orthop Relat Res, 452*, 205-209.

Maloiy, G. M., Heglund, N. C., Prager, L. M., Cavagna, G. A., & Taylor, C. R. (1986). Energetic costs of carrying loads: Have African women discovered an economic way? *Nature, 319*(6055), 668-669.

Malville, N. J., Byrnes, W. C., Lim, H. A., & Basnyat, R. (2001). Commercial porters of eastern Nepal: Health status, physical work capacity, and energy expenditure. *Am J Hum Biol, 13*(1), 44-56.

Manuele, F. A. (2011). *Advanced Safety Management Focusing on Z10 and Serious Injury Prevention*, John Wiley & Sons.

Markle, M. M., III. (1977). The Macedonian Sarissa, Spear, and Related Armor. *American Journal of Archaeology, 81*(3), 323-339.

Marsh, A. R. (1983). A short but distant war - the Falklands Campaign. *J R Soc Med. , November; 76*(11), 972–982.

Marsh, G. P. (1885). *The origin and history of the english language and of the early literature it embodies*: C. Scribner's sons.

Marsh, J. O. J. (1997). Values and the American soldier. *Military Review, 77*(1), 43.

Marshall, S. L. A. (1980). *The Soldier's Load and the Mobility of a Nation*. Virginia: The Marine Corps Association.

Marshall, S. L. A. (2001). *World War 1*. New York: Houghton Mifflin Books.

Martin, P. E. (1985). Mechanical and physiological responses to lower extremity loading during running. *Med Sci Sports Exerc, 17*(4), 427-433.

Martin, P. E., & Nelson, R. C. (1986). The effect of carried loads on the walking patterns of men and women. *Ergonomics, 29*(10), 1191-1202.

Maurya, S., Singh, M., Bhandari, P. S., & Bhatti, T. S. (2009). Backpack brachial plexus palsy. *Indian Journal of Neurotrauma (IJNT), 6*(2), 153-154.

May, B., Tomporowski, P. D., & Ferrara, M. (2009). Effects of Backpack Load on Balance and Decisional Processes. *Mil Med, 174*(12), 1308-1312.

Mayville, W. C. (1987). A Soldier's Load. *Infantry, Jan/Feb 87*(25 - 28).

Mc Ardle, W. D., Katch, F. I., & Katch, V. L. (2006). *Essentials of exercise physiology* (3rd ed.): Wolters Kluwer Health.

McDermott, B. P., Casa, D. J., Ganio, M. S., Lopez, R. M., Yeargin, S. W., Armstrong, L. E., et al. (2009). Acute whole-body cooling for exercise-induced hyperthermia: a systematic review. *Journal of Athletic Training, 44*(1), 84-93.

McKay, G. (1987). *In Good Company: One Man's War in Vietnam*. Crows Nest: Allen & Unwin.

McKay, G. (1996). *Delta Four: Australian Rifleman in Vietnam*. Crows Nest: Allen & Unwin.

McMahon, M. (2010). Dismounted Operations in the Green Zone. *Australian Sapper, 2010*, 59-60.

McNab, C., & Keeter, H. (2008). *Tools of Violence: Guns, Tanks and Dirty Bombs*: Osprey Publishing.

McPhedran, I. (2009a, 6 October). Body Armour puts Diggers in danger in Afghanistan, *The Daily Telegraph*.

McPhedran, I. (2009b, 5 October). Diggers in Afghanistan stew in hot and heavy armour, *Courier Mail*.

Meakin, J. R., Smith, F. W., Gilbert, F. J., & Aspden, R. M. (2008). The effect of axial load on the sagittal plane curvature of the upright human spine in vivo. *J Biomech, 41*(13), 2850-2854.

Melnik, E., & Everitt, B. S. (2008). Encyclopedia of Quantitative Risk Analysis and Assessment In E. Melnik & B. S. Everitt (Eds.), (Vol. 1 A-C, pp. 2176): John Wiley & Sons.

Melson, C. D. (1998). *U.S. Marine Rifleman in Vietnam 1965-73*. Oxford: Osprey Publishing.

Merrill, R. M. (2010). *Introduction to epidemiology*: Jones & Bartlett Learning.

Microsoft Corporation. (2003). *Microsoft Office Excel SP 3 (Professional Edition) [computer software]*. WA:USA: Microsoft Corporation.

Milgrom, C., Giladi, M., Stein, M., Kashtan, H., Margulies, J. Y., Chisin, R., et al. (1985). Stress fractures in military recruits. *British Editorial Society of Bone and Joint Surgery, 67 B*(5), 732 - 735.

Millett, A. R., & Murray, W. (1988). *Military Effectiveness*. London: Unwin Hyman.

Mongariello, S. C. (2004). *The Concise Encyclopedia of the Revolution and Wars of England, Scottish and Ireland, 1639 – 1660*. Oxford: Scarecrow Press.

Montain, S. J., Koenig, C., & McGraw, S. (2005). First Strike Ration Acceptability: Dismounted Combat Soldiers in Afghanistan. T06-02. *Military Nutrition Division, U.S. Army Research Institute of Environmental Medicine*.

Montross, L. (1960). *War through the ages* (3rd ed.). New York: Harper and Brothers Publications.

Moore, J. G. (1960). Mobility and Strategy in the Civil War. *Military Affairs, 24*(2), 68-77.

Moradi, B. (2010). Interpreting Response Rate for the 2010 Department of Defence Comprehensive Review Survey: A Research Memo. *Palm Center, University of California*.

Morrissey, S. J., & Liou, Y. H. (1988). Maximal acceptable weights in load carriage. *Appl Ergon, 31*(2), 217-226.

Mottola, M. F. (2009). Exercise prescription for overweight and obese women: Pregnancy and postpartum. *Obstetrics and gynecology clinics of North America, 36*(2), 301-316.

Murphy, P. J. (2002). *Fatigue Management During Operations: A Commander's Guide*. Puckapunyal:VIC: Doctrine Wing: Land Warfare Development Centre.

National Academy of Sports Medicine. (2009). *NASM Essentials of Sports Performance Training*: Lippincott Williams & Wilkins.

Navy News. (2004, 23 Sep). Mission Complete, *Navy: The Sailor's Paper*.

Neilberg, M. S. (2006). *Soldiers' lives through history*. Connecticut: Greenwood Publishing Group.

Neill, G. W. (2000). *Infantry Soldier: Holding the Line at the Battle of the Bulge*. Oklahoma: University of Oklahoma Press.

Nelson, A. (2006). *Safe patient handling and movement: A guide for nurses and other health care providers*: Springer Publishing Company.

Neuendorf, K. A. (2002). *The content analysis guidebook*. Thousand Oaks, CA: Sage Publications, Inc.

Neumann, D. A., Cook, T. M., Sholty, R. L., & Sobush, D. C. (1992). An electromyographical analysis of hip abductor muscle activity when subjects are carrying load in one or both hands. *Physical Therapy, 72*(3), 207-217.

Nirmalendran, R., & Ingle, L. (2010). Detraining Effect of the Post-Season on Selected Aerobic and Anaerobic Performance Variables in National League Rugby Union Players: A Focus on Positional Status. *Medicina Sportiva, 14*(4), 161-168.

Nokes, J. D., Dole, J. A., & Hacker, D. J. (2007). Teaching high school students to use heuristics while reading historical texts. *Journal of Educational Psychology, 99*(3), 492.

Nordin, M., & Frankel, V. H. (2001). *Basic Biomechanics of the Musculoskeletal System* (3rd ed.): Lippincott, Williams & Wilkins.

North, O., & Musser, J. (2004). *War Stories II: Heroism in the Pacific*. Washington: Regnery Publishing Inc.

Nottrodt, J. W., & Manley, P. (1989). Acceptable loads and locomotor patterns selected in different carriage methods. *Ergonomics, 32*(8), 945-957.

Nuciari, M. (2006). Women in the Military. *Handbook of the sociology of the military*, 279-297.

O'Connor, F. (2000). Injuries during Marine Corps Officer Basic Training. *Mil Med, 165*(7), 515-520.

O'Connor, J. S., & Bahrke, M. (1990). The Soldier's Load: Planning Smart. *Infantry, Jan-Feb*, 8-11.

Oppenheim, A. N. (2001). *Questionnaire design, interviewing and attitude measurement.* (2nd ed.): Continuum International Publishing Group.

Orloff, H. A., & Rapp, C. M. (2004). The effects of load carriage on spinal curvature and posture. *Spine, 29*(12), 1325-1329.

Orr, R. M. (2007). The Royal Military College of Duntroon. Physical Conditioning Optimisation Review. *Department of Defence. Canberra: AUST.*

Orr, R. M., & Moorby, G. M. (2006). The physical conditioning optimisation project - a physical conditioning continuum review of the Army Recruit Training Course. *Department of Defence. Canberra: AUST.*

Orr, R. M., Pope, R., Johnston, V., & Coyle, J. (2010). Load Carriage: Minimising soldier injuries through physical conditioning - A narrative review. *Journal of Military and Veterans' Health, 18*(3), 31-38.

Ortego, A. R., Dantzler, D. K., Zaloudek, A., Tanner, J., Khan, T., Panwar, R., et al. (2009). Effects of Gender Physiological Responses to Strenuous Circuit Resistance Exercise and Recovery. *Journal of Strength and Conditioning Research, 23*(3), 932-938.

Owen, W. F. (2008). The Soldiers Load. The Effect Beyond the Carried Weight. *Asian Military Review, April 2008*, 19-25.

Palmer, C. (1998). From ALICE to "Molly". *Soldiers, 53*(10), 20.

Pandolf, K. B., Givoni, B., & Goldman, R. F. (1977). Predicted energy expenditure with loads while standing or walking very slowly. *J Appl Physiol, 43*, 577-581.

Pandorf, C. E., Harman, E., Frykman, P. N., Patton, J. F., Mello, R. P., & Nindl, B. C. (2002). Correlates of load carriage and obstacle performance among women. *Work, 18*(2), 179-189.

Pappalardo, J. (2004). Robotic 'EXOSKELETONS' Could Help Soldiers Bear Heavier Loads. *National Defense, 89*(609), 42.

Park, K., Hur, P., Rosengren, K. S., Horn, G. P., & Hsiao-Wecksler, E. T. (2010). Effect of load carriage on gait due to firefighting air bottle configuration. *Ergonomics, 53*(7), 882-891.

Park, K., Hur, P., Rosengren, K. S., Horn, G. P., & Hsiao-Wecksler., E. T. (2008). *Changes In Kinetic And Kinematic Gait Parameters Due To Firefighting Air Bottle Configuration*. Paper presented at the NACOB, Ann Arbor, Michigan, U.S.A.

Parker, G. (2005). *The Cambridge history of warfare*: Cambridge Univ Press.

Parsons, C. (2007). Web-Based Surveys: Best Practice Based on the Research Literature. *Visitor Studies*, 10:1, 13-33.

Patterson, M. J., Roberts, W. S., Lau, W. M., & Prigg, S. K. (2005). Gender and Physical Training Effects on Soldier Physical Competencies and Physiological Strain. *Defence Science and Technology Organisation*, 65.

Patton, J. F., Kaszuba, J., Mello, R. P., & Reynolds, K. L. (1991). Physiological responses to prolonged treadmill walking with external loads. *Eur J Appl Physiol Occup Physiol, 63*(2), 89-93.

Paul, J. (2008). The Militarization of the American Police Force: A Critical Assessment. *Critical Issues in Justice and Politics*, 15.

Paulson, L. O. (2006). Light Infantry? A perspective on load carrying and the soldier, from past to present. *Australian Army Journal, III*(2), 81-88.

Pederson, A. V., Stokke, R., & Mamen, A. (2007). Effects of extra load position on energy expenditure in treadmill running. *Eur J Appl Physiol, 102*(1), 27-31.

Perry, C. J., Kiriella, J. B., Hawkins, K. M., Shanahan, C. J., Moore, A. E., & Gage, W. H. (2010). The effects of anterior load carriage on lower limb gait parameters during obstacle clearance. *Gait & Posture*.

Pester, S., & Smith, P. C. (1992). Stress fractures in lower extremities of soldiers in basic training. *Orthop Rev, 21*(3), 297-303.

Peterson, H. L. (1947). The Military Equipment of the Plymouth and Bay Colonies, 1620-1690. *The New England Quarterly, 20*(2), 197-208.

Pimental, N., & Pandolf, K. B. (1979). Energy expenditure while standing or walking slowly uphill or downhill with loads. *Ergonomics, 22*(8), 963-973.

Pimental, N., Shapiro, Y., & Pandolf, K. B. (1982). Comparison of uphill and downhill walking and concentric and eccentric cycling. *Ergonomics, 25*(5), 373-380.

Polcyn, A. F., Bensel, C. K., Harman, E., & Obusek, J. P. (2000). *The effects of load weight: a summary analysis of maximal performance, physiological and biomechanical results from four studies of load carriage systems*. Paper presented at the RTO Meeting Proceedings 56: Soldier Mobility: Innovations in Load Carriage System Design and Evaluation, Kingston, Canada.

Polit, D. F., & Beck, C. T. (2004). *Nursing research: Principles and methods*: Lippincott Williams & Wilkins.

Pope, R. (1999). Prevention of pelvic stress fractures in female army recruits. *Mil Med, 164*(5), 370-373.

Pope, R. (2001). *Programming in Military Physical Training: Gender, age & fitness considerations*. Paper presented at the Army Fitness Training Programs Workshop, Canberra.

Pope, R. (2007). *Review of Rates, Patterns, Causes & Potential Countermeasures for Injuries to Recruits at the Army Recruit Training Centre*. Wagga Wagga: Exersafe.

Pope, R., Herbert, R., Kirwan, J. D., & Graham, B. J. (1999). Predicting Attrition in Basic Military Training. *Mil Med, 164*(10), 710-714.

Pope, R., Herbert, R., Kirwan, J. D., & Graham, B. J. (2000). A randomized trial of preexercise stretching for prevention of lower-limb injury. *Medicine & Science in Sports & Exercise, 32*(2), 271.

Porter, S. C. (1992). The Soldier's Load. *Infantry, May-June,* 19 - 22.

Powell, A. (1995). *The Greek World*. New York: Routledge Publishers.

Powers, S. K., & Howley, E. T. (2012). *Exercise Physiology: Theory and Application to Fitness and Performance* (8th ed.): McGraw Hill.

Prince, R. (2009, 23 Jul). How Lord Malloch-Brown changed his story over helicopter shortages in Afghanistan, *The Telegraph*.

Pritchard, E. (2010, 12 Aug). Police invest in future safety, *The Daily Examiner*.

Qu, X., & Nussbaum, M. A. (2009). Effects of external loads on balance control during upright stance: Experimental results and model-based predictions. *Gait & Posture, 29*(1), 23-30.

Quesada, P. M., Mengelkoch, L. J., Hale, R. C., & Simon, S. R. (2000). Biomechanical and metabolic effects of varying backpack loading on simulated marching. *Ergonomics, 43*(3), 293-309.

Ralston, H. J. (1958). Energy-speed relation and optimal speed during level walking. *Int Z angew Physiol einschl Arbeitsphysiol, 17,* 277-283.

Rayson, M. P., Davies, A., Bell, D. G., & Rhodes-James, E. S. (1995). Heart rate and oxygen uptake relationship: a comparison of loaded marching and running in women. *Eur J Appl Physiol Occup Physiol, 71*(5), 405-408.

Redner, H. (2001). *Ethical Life: The past and present of ethical cultures*. Oxford: Rowan and Littlefield Publishers.

Reid, D. C. (1992). *Sports Injury Assessment and Rehabilitation*: Churchill Livingston.

Reid, S. A., Bryant, J. T., Stevenson, J. M., & Doan, J. B. (2000). *Biomechanical assessment of rucksack shoulder strap attachment location: effect on load distribution to the torso*. Paper presented at the RTO Meeting Proceedings 56: Soldier Mobility: Innovations in Load Carriage System Design and Evaluation, Kingston, Canada.

Reid, S. A., & Whiteside, R. A. (2000). *Biomechanical assessment of lateral stiffness elements in the suspension system of a rucksack*. Paper presented at the RTO Meeting Proceedings 56: Soldier Mobility: Innovations in Load Carriage System Design and Evaluation, Kingston, Canada.

Ren, L., Jones, R. K., & Howard, D. (2005). Dynamic analysis of load carriage biomechanics during level walking. *J Biomech, 38*(4), 853-863.

Renatus, F. V. (1996). *Vegetius: Epitome of Military Science* (N. P. Milner, Trans. 2nd ed.). Liverpool: Liverpool University Press.

Reynolds, K. L. (2000). Injuries and risk factors in an 18-day Marine winter mountain training exercise. *Mil Med, 165*(12), 905-910.

Reynolds, K. L. (2002). Injury occurrence and risk factors in construction engineers and combat artillery soldiers. *Mil Med, 167*(12), 971 - 977.

Reynolds, K. L., White, J., Knapik, J. J., Witt, C., & Amoroso, P. (1999). Injuries and risk factors in a 100-mile (161-km) infantry road march. *Preventative Medicine, 28*(2), 167-173.

Ricciardi, R., Deuster, P., & Talbot, L. A. (2007). Effects of Gender and Body Adiposity on physiological responses to physical work while wearing body armor. *Mil Med, 172*(7), 743-748.

Ricciardi, R., Deuster, P., & Talbot, L. A. (2008). Metabolic demands of Body Armor on physical performance in simulated conditions. *Mil Med, 173*(9), 817-824.

Rice, V. J., Sharp, M., Tharion, W. J., & Williamson, T. (1999). Effects of a Shoulder Harness on Litter Carriage Performance and Post-Carry Fatigue of Men and Women. *Military Performance Division. US Army Research Institute of Environmental Medicine, Natick*, 76.

Rice, V. J., Sharp, M. A., Williamson, T. L., & Nindl, B. C. (1992). *Effects of gender, lift height, direction, and load on the ability to estimate weight*. Paper presented at the Proceedings of the Human Factors Society 36th Annual Meeting.

Richmond, V. L., Rayson, M. P., Wilkinson, D. M., Carter, J. M., & Blacker, S. D. (2008). Physical demands of firefighter search and rescue in ambient environmental conditions. *Ergonomics, 51*(7), 1023-1031.

Robertson, R. J., Caspersen, C. J., Allison, T. G., Skrinar, G. S., Abbott, R. A., & Metz, K. E. (1982). Differentiated perceptions of exertion and energy cost of young women while carrying loads. *Eur J Appl Physiol Occup Physiol, 49*(1), 69-78.

Robson, C. (2002). *Real world research: A resource for social scientists and practitioner-researchers*: Blackwell Publishers.

Rome, K., Handoll, H. H. G., & Ashford, R. (2005). Interventions for preventing and treating stress fractures and stress reactions of bone of the lower limbs in young adults (Review). *The Cochrane Library*(3).

Ropp, T. (1962). *War in the Modern World* (Revised ed.). Maryland: Macmillian Publishing.

Rosenman, K. D., Kalush, A., Reilly, M. J., Gardiner, J. C., Reeves, M., & Luo, Z. (2006). How much work-related injury and illness is missed by the current national surveillance system? *Journal of Occupational and Environmental Medicine, 48*(4), 357-365.

Ross, R. A. (2002). Stress fractures in Royal Marine recruits. *Mil Med, 167*(7), 560-565.

Roth, J. (1998). *The Logistics of the Roman Army at War (264 B.C. – A.D. 235)*. Boston: Brill Publishers.

Rothenberg, G. E. (1978). *The Art of War in the Age of Napoleon*: Indiana University Press.

Rottman, G., & Shumate, J. (2011). *Kalashnikov AK-47 Assault Rifle*: Osprey Pub Co.

Rottman, G. L. (2005). *U.S. Army Infantryman in Vietnam 1965 - 73*.

Rowlinson, M. (2005). Historical Research Methods. In R. A. Swanson & E. F. Holton III (Eds.), *Research in organizations: foundations and methods of inquiry*: Berrett-Koehler.

Ruane, J. M. (2004). *Essentials of research methods: a guide to social research*: Wiley-Blackwell.

Ruby, B. C., Leadbetter III, G. W., Armstrong, D., & Gaskill, S. E. (2003). Wildland firefighter load carriage: effects on transit time and physiological responses during simulated escape to safety zone. *International Journal of Wildland Fires,* (12), 111-116.

Rudzki, S. J. (1989). Weight-load marching as a method of conditioning Australian Army recruits. *Mil Med, 154*(4), 201-205.

Rudzki, S. J. (2009). Lessons Learnt From A Heat Stroke Death: 704: May 28 9: 30 AM-9: 45 AM. *Medicine & Science in Sports & Exercise, 41*(5), 56.

SafeWork South Australia. (2006). *Major Workplace Hazards: Manual Handling*. Keswick, Adelaide: Government of South Australia.

Sagiv, M., Ben-Sira, D., Sagiv, A., Werber, G., & Rotstein, A. (1994). Left ventricular responses during prolonged treadmill walking with heavy load carriage. *Med Sci Sports Exerc, 26*(3), 285-288.

Sagiv, M., Ruddoy, J., Sagiv, A., Ben-Gal, S., & Ben-Sira, D. (2002). Effect of changes in load carriage while walking on the left ventricular function in highly trained elderly subjects. *Gerentology, 48*(5), 289-292.

Samanta, A., & Chatterjee, B. B. (1981). Energy expenditure in manual load carriage. *Ind Health, 19*(3), 145-154.

Sampson, A. (2000). *Lessons learned during the development of the modular lightweight load-carrying equipment (MOLLE) system*. Paper presented at the RTO Meeting Proceedings 56: Soldier Mobility: Innovations in Load Carriage System Design and Evaluation, Kingston, Canada.

Sandelowski, M. (1995). Qualitative analysis: What it is and how to begin. *Research in Nursing & Health, 18*(4), 371-375.

Sanders, B., & Nemeth, W. C. (1996). Hip and Thigh Injuries. In J. E. Zachazewski, D. J. Magee & W. S. Quillen (Eds.), *Athletic Injuries and Rehabilitation*: W.B. Saunders.

Santee, W. R., Allison, W. F., Blachard, L. A., & Small, M. G. (2001). A proposed model for load carriage on sloped terrain. *Aviat Space Environ Med, 72*(6), 562-566.

Santee, W. R., Blachard, L. A., Small, M. G., Gonzalez, J. A., Matthew, W. T., & Speckman, K. L. (2001). *The impact of load and grade on energy expenditure during load carriage, Part II: Field Study*: Military Performance Division. US Army Research Institute of Environmental Medicine, Natick.

Sanz, F. Q. (2006). *Not so different: individual fighting techniques and battle tactics of Roman and Iberian armies within the framework of warfare in the Hellenistic Age*. Paper presented at the L'Hellénisation en Méditerranée Occidentale au temps des guerres puniques, Actes du Colloque International de Toulouse.

Scales, R. H. (2005). Urban Warfare: A Soldier's View. *Military Review, 85*(1), 9.

Schiffman, J. M., Bensel, C. K., Hasselquist, L., Gregorczyk, K. N., & Piscitelle, L. (2005). Effects of carried weight on random motion and traditional measures of postural sway. *Appl Ergon, 37*(5), 607-614.

Schiffman, J. M., Bensel, C. K., Hasselquist, L., Norton, K., & Piscitelle, L. (2004). The effects of soldier's loads on postural sway. *Military Performance Division. US Army Research Institute of Environmental Medicine, Natick,* 1-8.

Schiffman, J. M., Chelidze, D., Adams, A., Segala, D. B., & Hasselquist, L. (2009). Nonlinear analysis of gait kinematics to track changes in oxygen consumption in prolonged load carriage walking: A pilot study. *Journal of Biomechanics, 42,* 2196-2199.

Schiffman, J. M., Gregorczyk, K. N., Bensel, C. K., Hasselquist, L., & Obusek, J. P. (2008). The effects of a lower body exoskeletal load carriage assistive device on limits of stability and postural sway. *Ergonomics, 51*(10), 1515-1529.

Schjolset, A. (2010). *NATO and the Women: Exploring the Gender Gap in the Armed Forces*. Oslo: Peace Research Institute Oslo (PRIO).

Schreiner, P. (1997). Soldiers. In G. Cavallo (Ed.), *The Byzantines*. London: The University of Chicago Press.

Schonlau, M., Fricker, R. D., & Elliott, M. N. (2002). *Conducting research surveys via e-mail and the web (No. 1480)*. Rand Corporation.

Schuster, C. R., Beusse, W. E., Chambers, C. L., Coffey, C. F., & Luna, J. A. (1998). *Gender Issues: Information on DoD's Assignment Policy and Direct Ground Combat Definition*: General Accounting Office Washington DC National, Security International Affairs, DIV.

Schwendiman, J. C. (2008). *Saving lives, saving honor: The 39th Evacuation Hospital during World War 2*. North Carolina: Lulu.

Scott, B. F., Rainey, J. C., & Hunt, A. W. (Eds.). (2000). *The logistics of war. A historical perspective*. Alabama: Diane Publishing.

Scott, P. A., & Ramabhai, L. (2000a). *Comparison of male and female responses to carrying absolute and relative loads while on a three hour military march.* Paper presented at the Proceedings of the IEA 2000/HFES 2000 Congress.

Scott, P. A., & Ramabhai, L. (2000b). Load Carrying: in situ Physiological responses of an infantry platoon. *Ergonomics, 2000*(1), 18 - 24.

Sekunda, N. V. (2000). *Greek Hoplite. 480 – 323 B.C.* Oxford: Osprey Publishing.

Sharkey, B. J., & Gaskill, S. E. (2006). *Sport physiology for coaches*: Humans Kinetics.

Sharp, M., Knapik, J. J., Hauret, K., Frykman, P. N., & Patton, J. F. (1999). *Lifting ability of army men and women in relation to occupational demands.* Paper presented at the Proceedings of the Human Factors and Ergonomics Society 43rd Annual Meeting - 1999.

Sharp, M. A. (1994). Physical fitness and occupational performance of women in the US Army. *Work, 4*(2), 80-92.

Sharpe, S. R., Holt, K. G., Saltzman, E., & Wagenaar, R. C. (2008). Effects of a hip belt on transverse plane trunk coordination and stability during load carriage. *J Biomech, 41*(5), 968-976.

Sheehan, K. M., Murphy, M. M., Reynolds, K. L., Creedon, J. F., & al., e. (2003). The response of a bone resorption marker to Marine recruit training. *Mil Med, 168*(10), 797-801.

Shek, P. N. (2001). Basic recruit training: Health risks and opportunities. *Mil Med, 166*(8), 714-720.

Sheppard, C., & Waggener, A. (2007). *Women in Combat*: Army War Coll, Carlisle Barracks, P. A.

Sherrard, J., Lenne, M., Cassell, E., Stokes, M., & Ozanne-Smith, J. (2002). *Strategic Direction and Advice for Increasing Safe Participation in Physical Activity in the Australian Defence Force: A Report for the Defence Health Services*: Monash University Accident Research Centre.

Shoenfeld, Y., Shapiro, Y., Portugeeze, D., Modan, M., & Sohar, E. (1977). Maximal backpack load for distance hiking. *J Sports Med, 17,* 147-151.

Showalter, D. E. (2004). *Tannenberg: Clash of Empires, 1914*. Virginia: Brassey's Inc.

Shrader, C. R. (1995). *Communist Logistics in the Korean War*. Connecticut: Greenwood Publishing Group.

Siebrand, M. (2002). Shaping the 21st Century Infantryman. *Military Technology, 26*(9), 38-47.

Simpson, R., Gray, S., & Florida-James, G. (2006). Physiological variables and performances markers of serving soldiers from two elite units of the British Army. *J Sports Sci, 24*(6), 597-604.

Siuru, W. S. (2010). Can Robot Helicopters Carry the Load? *Marine Corps Gazette, 94*(5), 60-62.

Smith, S. (2011, 10 May). Defence Budget overview - realigning the Budget, *Ministerial Media Release*.

Snook, S. H., & Ciriello, V. M. (1974). The effects of heat stress on manual handling tasks. *American Industrial Hygiene Association, 35*(11), 681-685.

Solgere, A. L. (1999). A soldier's load...revisited. *Marine Corps Gazette, 83*(10), 35-36.

Somarriba, G., Extein, J., & Miller, T. L. (2008). Exercise rehabilitation in pediatric cardiomyopathy. *Progress in pediatric cardiology, 25*(1), 91-102.

Soule, R. G., & Goldman, R. F. (1969). Energy cost of loads carried on the head, hands, or feet. *J Appl Physiol, 27*(5), 687-690.

Soule, R. G., & Goldman, R. F. (1972). Terrain coefficients for energy cost prediction. *J Appl Physiol, 32*(5), 706-708.

Soule, R. G., Pandolf, K. B., & Goldman, R. F. (1978). Energy expenditure of heavy load carriage. *Ergonomics, 21*(5), 373-381.

Spellman, F. R., & Bieber, R. M. (2011). *Physical Hazard Control: Preventing Injuries in the Workplace*. Plymouth, United Kingdom: Government Institutes.

SPSS Inc. (2010). *Statistical Package for the Social Sciences (Version 19.0) [computer software]*. Delaware, USA: IBM Corporation.

Stackpole, A. (2011, 28 Apr). Testing the Field, *Air Force Newspaper*.

Standards Australia. (2009). *Risk Management - Principles and guidelines (AS/NZS 31000:2009)*: Standards Australia International.

Standards Australia Working Group MB-002-01. (2004a). *OHS Risk Management Handbook (HB 205-2004)*: Standards Australia International.

Standards Australia Working Group MB-002-01. (2004b). *Risk Management (HB 4360-2004)*: Standards Australia International.

Standards Australia Working Group MB-002-01. (2004c). *Risk Management Guidelines (HB 436-2004)*: Standards Australia International.

Stanley, P. (2005). *Quinn's Post: Anzac, Gallipoli*. Crows Nest: Allen & Unwin.

Steele, O. W. (2002). Louvencourt to Eve of Battle (4 April 1916 - 30 June 1916). In D. R. Facey-Crowther (Ed.), *Lieutenant Owen William Steele of the Newfoundland Regiment: Diary and Letters*. Quebec: McGill-Queen's University Press.

Stein, M., Shlamkovitch, N., Finestone, A., & Milgrom, C. (1989). Marcher's digitalgia paresthetica among recruits. *Foot Ankle, 9*(6), 312-313.

Stevenson, J. M., Reid, S. A., Bryant, J. T., Pelot, R. P., & Morin, E. L. (2000). *Biomechanical assessment of the Canadian Integrated Load Carriage system using objective assessment measures.* Paper presented at the RTO Meeting Proceedings 56: Soldier Mobility: Innovations in Load Carriage System Design and Evaluation, Kingston, Canada.

Straker, L. (1999). An overview of manual handling injury statistics in western Australia. *International Journal of Industrial Ergonomics, 24*(4), 357-364.

Stringer, K. D. (2000). Infantry marching endurance. *Military Review, 80*(6), 81-83.

Strydom, N. B., Bredell, G. A. G., Benade, A. J. S., Morrison, J. F., Viljoen, J. H., & van Graan, C. H. (1966). The metabolic cost of marching at 3 M.P.H. over firm and sandy surfaces. *Int Z angew Physiol Arbeitsphysiol, 23*, 166-171.

Strydom, N. B., van Graan, C. H., Morrison, J. F., & Viljoen, J. H. (1968). The Influence of Boot Weight on the Energy Expenditure on Men Walking on a Treadmill and Climbing Stairs. *Int Z angew Physiol Arbeitsphysiol, 25*(1968), 191-197.

Stuempfle, K. J., Drury, D. G., & Wilson, A. L. (2004). Effect of load position on the physiological and perceptual responses during load carriage with an internal frame backpack. *Ergonomics, 47*(7), 784-789.

Sue, V.M. & Ritter, L.A. (Eds.). (2007). *Conducting Online Surveys.* SAGE Publications, Inc.

Task Force Devil Combined Arms Assessment Team. (circa 2003). *The Modern Warrior's Combat Load. Dismounted Operations in Afghanistan April - May 2003*: U.S. Army Centre for Army Lessons Learned.

Taylor, J. (2001). *Last out: 4 R.A.R. / N. Z. (ANZAC) Battalion's Second Tour in Vietnam*. Crows Nest: Allen & Unwin.

Terraine, J. (1997). *The Great War* Hertfordshire: Wordsworth Editions.

The American Association for Public Opinion Research. (2011). *Standard Definitions: Final Dispositions of Case Codes and Outcome Rates for Surveys* (7th ed.): AAPOR.

Thompson, C. (2002). *Twenty-five best World War II sites: Pacific Theatre*: AS Davis Media Group.

Tucker, S. C. (1996). *The European Powers in the First World War: An Encyclopedia*. New York Garland.

Turnock, B. J. (2009). *Public health: What it is and how it works*: Jones & Bartlett Learning.

Tyson, A. S. (2009). Weight Of Combat Gear Is Taking Toll; The Loads Are Contributing To Injuries That Are Keeping Some Troops On The Sidelines. *Washington Post*, A03.

United States Congress, Office of Technology Assessment. (1985). *Preventing illness and injury in the workplace*. DIANE Publishing.

US Army Sergeants Major Academy. (2007). Long Hard Road: NCO Experiences in Afghanistan and Iraq. *U.S. Army Sergeants Major Academy*.

Vaananen, I., Mantysaari, M., Pirkko, H., Komulainen, J., & Vihko, V. (1997). The effects of a 4-day march on the lower extremities and hormone balance. *Mil Med, 162*(2), 118-122.

Vacheron, J. J., Poumarat, G., Chandezon, R., & Vanneuville, G. (1998). Changes of contour of the spine caused by load carrying. *Surg Radiol Anat, 21*, 109-113.

Vacheron, J. J., Poumarat, G., Chandezon, R., & Vanneuville, G. (1999). The effects of load carried on the shoulders. *Mil Med, 164*(8), 597-599.

van Dijk, J. (2009). Chapter 3 - Common Military Task: Marching. *Optimizing Operational Physical Fitness. RTO-TR-HFM-080. NATO Research and Technology Organisation*.

Vanderburgh, P. M. (2000). The backpack run test: A model for a fair and occupationally relevant military fitness test. *Mil Med, 165*(5), 418-421.

Vanderburgh, P. M. (2008). Occupational relevance and body mass bias in military physical fitness tests. *Ergonomics, 40*(8), 1538-1545.

Vaz, M., Karaolis, N., Draper, A., & Shetty, P. (2005). A compilation of energy costs of physical activities. *Public Health Nutr 8*(7a), 1153-1183.

Visser, T., van Dijk, M. J., Collee, T., & van der Loo, H. (2005). *Is intensity or duration the key factor in march training?* Paper presented at the International Congress on Soldier's Performance, Finland.

Vitiello, A., & Pollard, H. (2002). Backpack Design: The use of Ratings of Perceived Exertion (Borg Scale) - A Review. *Chiropractic Journal of Australia, 32*(3), 91-98.

Voight, M. L., Hoogenboom, B. J., & Prentice, W. E. (2006). *Musculoskeletal interventions*: McGraw-Hill Professional.

von Heimburg, E. D., Rasmussen, A. K. R., & Medbo, J. I. (2006). Physiological responses of firefighters and performance predictors during a simulated rescue of hospital patients *Ergonomics, 49*(2), 111-126.

Waltz, C. F., Strickland, O., & Lenz, E. R. (2010). *Measurement in nursing and health research* (4th ed.): Springer Publishing Company.

Watson, B. B. (2002). *Far Eastern Tour: The Canadian Infantry in Korea 1950 - 1953*. Quebec: McGill-Queen's University Press

Watson, J. C., Payne, R. C., Chamberlain, A. T., Jones, R. K., & Sellers, W. I. (2008). The energetic costs of load-carrying and the evolution of bipedalism. *J Hum Evol, 54*(5), 675-683.

Wells, C. L. (1991). *Women, sport and performance* (2nd ed.). Champaign, IL: Human Kinetics.

White, H. H. (1968). Pack palsy: a neurological complication of scouting. *Pediatrics, 41*(5), 1001.

White, M. D., & Marsh, E. E. (2006). Content analysis: A flexible methodology. *Library trends, 55*(1), 22-45.

Whiter, R. H. (2004). The British soldier entered World War I with vastly improved equipment over his Boer War forebear. *Military History, 21*(1), 12.

Whitworth, D. (2009, 25 June). New UK troop body armour up close, *BBC Newsbeat*.

Whyte, G. (2006). The Physiology of Training. In N. Spurway & D. MacLaren (Eds.), *Advances in Sport and Exercise Science Series*: Elsevier

Whyte, G. P., Harries, M., & Williams, C. (Eds.). (2005). *ABC of sports and exercise medicine*: BMJ Books.

Williams, A. G., & Rayson, M. P. (2006). Can simple anthropometric and physical performance tests track training-induced changes in load-carriage ability? *Mil Med, 171*(8), 742-748.

Williams, A. G., Rayson, M. P., & Jones, D. A. (1999). Effects of basic training on material handling ability and physical fitness of British Army recruits. *Ergonomics, 42*(8), 1114-1124.

Williams, A. G., Rayson, M. P., & Jones, D. A. (2004). Training diagnosis for a load carriage task. *J Strength Cond Res, 18*(1), 30-34.

Wilmore, J. H., Costill, D. L., & Kenney, L. (2008). *Physiology of sport and exercise* (4th ed.). Champaign, IL: Human Kinetics.

Wilson, G. J. (1995). The effect of age and gender on the development of muscular function. *Strength and Conditioning Coach, 3*(1), 3-6.

Wilson, W. J. (1987). Brachial Plexus Palsy in Basic Trainees. *Mil Med, 152*(10), 519 - 522.

Wright, A. (2009). Smart Vests Take Pressure Off troops. *National Defense, 94*(672), 19.

Xu, X., Hsiang, S. M., & Mirka, G. A. (2009). The effects of a suspended-load backpack on gait. *Gait & Posture, 29*(1), 151-153.

Yamasaki, M., Sasaki, T., & Torii, M. (1991). Sex differences in the pattern of lower limb movement during treadmill walking. *Eur J Appl Physiol, 62,* 99-103.

Zatsiorsky, V. M., & Kraemer, W. (2006). *Science and practice of strength training* (2nd ed.). Champaign, IL: Human Kinetics.

Zentner, J. (2005). Adrianople: Last Great Battle of Antiquity. *The Journal of Military History, 22*(7), 54-60.

Zernicke, R. F., Wohl, G. R., & LaMothe, J. M. (2005). The Skeletal-Articular System. In C. M. Tipton, American College of Sports Medicine, M. N. Sawka, R. L. Terjung & C. A. Tate (Eds.), *ACSM's Advanced Exercise Physiology* (pp. 41-94): Lippincott, Williams & Wilkins.

Zhang, X. A., Ye, M., & Wang, C. T. (2010). Effect of unilateral load carriage on postures and gait symmetry in ground reaction force during walking. *Computer Methods in Biomechanics and Biomedical Engineering, 13*(3), 339-344.

Zieger, R. H. (2000). *America's Great War: World War I and the American Experience*. Maryland: Rowan and Littlefield.

Zultowski, I., & Aruin, A. (2008). Carrying loads and postural sway in standing: The effect of load placement and magnitude. *Work, 30*(4), 359-368.

12. APPENDICES

APPENDIX A: AN INTRODUCTION TO THE AUSTRALIAN REGULAR ARMY

The Australian Regular Army (ARA) is the land arm of the Australian Defence Force (ADF). The largest of the three services, staffing of the ARA at June 10, 2010 was 29, 339 personnel (Department of Defence, 2010a). The ARA force is supplemented by the Army Reserves. Staffed by personnel serving on a part-time basis, the Army Reserves (ARes) have 16, 227 personnel (Department of Defence, 2010a). However, the focus of this program of research is within the ARA setting only.

ARA Corps

Each serving member, unless in initial recruit training, belongs to a designated corps. These corps are akin to trades, with Army personnel undertaking training for skills relevant to their corps. The corps can be subdivided into Combat Arms (e.g. Infantry, Artillery etc.), Combat Support Arms (e.g. Signals) and Combat Service Support (e.g. Medical corps). The support corps function to assist arms corps, and the nature of the current combat arena has members of these support corps working in the same battlespace as arms corps personnel and exposed to similar risks (e.g. ambush and improvised explosive devices). As with different trades, different corps have different tasks. For example, the role of the infantry is to *'seek out and close with the enemy, to kill or capture him, to seize and to hold ground, to repel attack, by day or by night, regardless of season, weather or terrain'* (Department of Defence, 2010b). For combat engineers their field of expertise and responsibilities lie in *'assisting our own forces to move whilst also denying mobility to the enemy'* (Department of Defence, 2011c).

ARA Units

Units within which Army personnel serve can be corps-specific (e.g. an Infantry Battalion) or an integrated corps unit, containing personnel from a variety of corps (e.g. Combat Services Support Battalion). Corps-specific units can also have corps specialists from other corps embedded (e.g. Corps of Signals personnel embedded into an Infantry battalion) to optimise certain functions (in this example, communications).

Outlining the structure and size of army units, the following provides a generic framework. It is important to note that nomenclatures and exact structures can vary within corps and units. The smallest functioning unit within the ARA is typically a ‘fire team’ which generally consists of four personnel. Two fire teams constitute a ‘section’ of 8–10 personnel. Three sections combine to make up a ‘platoon’ which includes additional platoon staff, increasing the total platoon size approximately 30 personnel. Three platoons make up a ‘company’, which again has additional company staff and constitutes 94–100 personnel. Four to six companies and a headquarters element are collectively called a ‘battalion’, which consists of anywhere from 400 to 700 personnel. A ‘regiment’ can be akin to a battalion in size or, as in the case of the Royal Australian Regiment, could consist of a collection of battalions.

ARA Bases and Operations

Geographically these units are organised into larger structures and dispersed throughout Australia, with key larger bases in Sydney, Brisbane, Townsville and Darwin. At this time Australia has no permanent bases on foreign soil, although Army personnel may be seconded or posted on exchange to bases of foreign military forces around the world. Likewise, Australian soldiers, as part of the greater ADF, are currently involved in 13 operations in theatres around the world as peace monitors, peace keepers, and mentors, (Australian Defence Force, 2011). A list of operations, ARA involvement, location and force strength is provided in Table A-1 with areas of operations provided in Table A-2.

Table A-1: ADF operational deployments 2010, sourced from the Australian Defence Force (2011).

2010 Operational Commitments **Operation**	**Theatre**	**Number of Persons**
Operation SLIPPER (Afghanistan)	Afghanistan	1550
Operation SLIPPER (Middle East)	Afghanistan	800
Operation PALATE II	Afghanistan	2
Operation ASTUTE	East Timor	400
Operation TOWER	East Timor	4
Operation MAZURKA	Egypt	25
Operation KRUGER	Iraq	33
Operation RIVERBANK	Iraq	2
Operation PALADIN	Middle East	12
Operation ANODE	Solomon Islands	80
Operation AZURE	Sudan	17
Operation HEDGEROW	Sudan	8
Operation RESOLUTE	Australia (Border Protection)	400
TOTAL		**3333**

Table A-2: ADF operational deployments since 1992 to present sourced from the Australian Defence Force (2011).

Year	Area of Operations
1992	Croatia, Bosnia-Herzegovina and Macedonia
1994	Haiti
1997	Guatemala
1981-present	Egypt
1992-1994	Somalia
1992-2004	Bosnia
1993-1997	Cambodia
1994-1995	Rwanda
1994-2002	Mozambique
1997-2003	Bougainville
1998, 2003-2009	Iraq
1999-present	Kosovo
1999-present	East Timor
2000-2003	Sierra Leon
2000-Present	Solomon Islands
2001, 2004-present	Afghanistan
2001-2005	Ethiopia and Eritrea
2011-present	Sudan

ARA Ranks

Australian Army ranks (both ARA and ARes) are divided into two classes, enlisted soldiers and officers. For the enlisted soldier the base rank is private. However, the classification of a private-ranked soldier varies among corps. For example, a private soldier in the Royal Australian Corps of Engineers is entitled a ‘sapper’, and in the Royal Australian Armoured Corps, a ‘trooper’. Due to this variability the term ‘Other Ranks’ or OR is used. Following completion of both ‘all corps’ courses and ‘corps specific’ courses, a private is awarded rank and progresses into the classification of Junior Non Commissioned Officer (JNCO), progressing from a Lance Corporal to Corporal. Again, corps-specific classifications of these ranks exist. Lance Bombardier and Bombardier are examples from the Royal Australian Artillery. Following additional training, soldiers are awarded more senior ranks and enter the grouped classification of Senior Non Commissioned Officer (SNCO). Typically, ranks in this SNCO classification progress from Sergeant to Warrant Officer Class Two and Warrant Officer Class One. Warrant Officer Class One is the most senior non-commissioned rank.

On completion of initial training, officers enter service as Junior Officers, generally ranked as Lieutenants and Captains. Within units, a key appointment for a Captain is the position of Adjutant, who is the principal aid to the Commanding Officer (CO) of a unit. Following completion of additional training courses, officers can progress on promotion to Senior Officer level, ranked from Major to Lieutenant Colonel (LTCOL). In units, officers with a rank of Major typically hold the position of Officer Commanding (OC) and can command sub-units of larger units (e.g. commander of a company). Typically among command positions, the LTCOL rank is the most senior rank within a unit, with the member designated as the unit’s CO.

ARA Training

Enlisted soldiers commence initial training at the Army Recruit Training Centre in Wagga Wagga, Australia. Over the 80-day course, recruits take part in military drill, weapons training, physical training, and field craft. The recruit training program is the same for both genders.

On completion of recruit training, private soldiers undertake trade training for their designated corps at specific corps training institutions. The length of this corps training varies depending on trade training requirements. For example, training as an Infantry Rifleman is around 71 days in length whereas training as an Artillery Light Gunner is around 42 days (6 weeks). On completion of corps training soldiers are posted to units throughout Australia as qualified private soldiers. After a period of approximately a year of on-the-job training within their units, soldiers are promoted to ‘private (or equivalent) proficient’.

Commissioned officers in the ARA typically commence training at one of two officer training institutions: the Royal Military College of Duntroon (RMC-D) or the Australian Defence Force Academy (ADFA). Direct entry officers complete an 18-month training program which is divided into three 6-month blocks, III Class, II Class, and I Class. Training progresses from individual skills to leading a platoon size force. ADFA officer cadets complete a 3 year academic degree at the tri-service training academy before transferring across to complete ARA specific training at RMC-D. Due to their military immersion at ADFA, officer cadets are not required to complete the first 6 months of RMC-D training, commencing training with RMC cadets in II Class to complete the last 12 months of the RMC course. On completion of training, RMC-D staff cadets are promoted to the rank of Lieutenant and commence employment within their units. While within a unit, officers are required to attend additional training courses specific to their corps.

An additional entry method is applicable for direct entry officers who already have an academic qualification and wish to serve in a specialist field (e.g. physiotherapy, psychology, etc.). These Army personnel enter at a given rank (dependent on corps and qualification) and complete a 32-day course before being posted to their respective units.

ARA Load Carriage Systems Orders-of-Dress

In the ARA there are two load carriage systems orders-of-dress, Patrol Order and Marching Order. Both these systems are worn over the soldier’s standard field uniform which generally consists of combat fatigue uniform, socks, and boots. Additional items, such as identity tags, identity cards, and watches, are often also worn.

Patrol Order

Patrol order typically includes the soldier’s standard field uniform plus the webbing load carriage system. Webbing used in the Australian Army can be either waist webbing with an H-harness worn over the shoulders or in a chest webbing configuration (Figure A-1). The webbing is used to carry stores sufficient to last the soldier for up to a day on patrol and includes items of lethality (ammunition, grenades), survivability (water, small quantity of food, small first aid kit, personal communications radio) and protection (camouflage cream, hearing protection).

Figure A-1: An Australian soldier on operations in Afghanistan dressed in Patrol Order (chest webbing configuration), with personal weapon, secondary weapon, body armour, helmet and patrol pack. (Photographer unknown: Photograph provided by Defence Media).

Additional stores that can be carried with Patrol Order and Marching Order include:

- a personal weapon
- a specialist weapon
- body armour
- a secondary weapon
- patrol backpack
- helmet
- section stores (section radio, section medical kit and flares)

Marching Order

The Marching Order load carriage system order-of-dress is designed to sustain the soldier in the field for extended periods (up to several days without resupply). Marching Order consists of the Patrol Order load carriage system in conjunction with a large field pack (Figure A-2). The addition of a field backpack provides the solider with the ability to carry further stores for lethality (additional ammunition), survivability (additional rations and water, environmental clothing, sleeping bag) and protection (shelter individual, entrenching tool).

Figure A-2: Australian soldiers on operations in Afghanistan dressed in Marching Order, with personal weapon, body armour and helmet. (Photographer CPL Rachel Ingram: Photograph provided by Defence Media).

Sources

The key documents used in this brief overview of the Australian Army were:

Department of Defence. (2011a). Global Operations. Retrieved 01 March, 2011, from http://www.defence.gov.au/op/index.htm

Department of Defence (2011b). Artillery Light Gunner. 08 March, 2011, from http://www.defencejobs.gov.au/army/jobs/ArtilleryLightGunner/Entry/

Department of Defence (2011c). Rifleman. Retrieved 08 March, 2011, from http://www.defencejobs.gov.au/army/jobs/Rifleman/EmploymentTraining/

Department of Defence (2011d). Welcome to the Royal Military College of Australia. Retrieved 08 March, 2011, from http://www.army.gov.au/rmc/Home.asp

Department of Defence. (2010a). *The Defence Annual Report 2009-10 (Volume 1)*: Department of Defence.

Department of Defence (2010b). Infantry Officer. Retrieved 06 August 2010, from http://www.defencejobs.gov.au/army/jobs/infantryofficer/

Department of Defence (2010c). Combat Engineer. Retrieved 06 August 2010, from http://www.defencejobs.gov.au/army/Jobs/CombatEngineer/?entryTypeId=17

Department of Defence (2010d). Army Recruit Training Centre. Home of the soldier. Retrieved 06 August 2010, from http://www.army.gov.au/artc/course.cfm

Dupuy, T. N., Johnson, C., & Hayes, G. P. (1986). *Dictionary of military terms: a guide to the language of warfare and military institutions*: HW Wilson.

APPENDIX B: PAPERS EXCLUDED FROM THE LITERATURE REVIEW

Exclusion criteria

a. age (outside of military service age of 17 – 55 years);
b. study included a form of mobility aid;
c. study included supplementation (e.g. vitamins);
d. study included medically unfit (e.g. obese) or diversified participants (e.g. idiopathic scoliosis);
e. study included components in an altered environment (e.g. micro-gravity);
f. studies, not published in English and unable to be translated by software (Babylon 9)[176] or linguistic support available to the researcher (being Dutch, French and German);
g. studies which:
  - did not include a load carriage variable (dependent or independent),
  - were focussed on generating or evaluating mathematical equations,
  - were not specifically related to a load carriage activity,
  - used manikins, or
  - involved no carriage of physical loads;
h. commercial interest (a certain brand of equipment) or focused on a specific piece of equipment (mountain carriage stretchers);
i. conference papers or abstracts printed in journals without full text; or
j. defence department documents rated above “unclassified”.

Paper	**Reason for exclusion**
*Akers, W. A., & Sulzberger, Z. B. (1972). The Friction Blister. *Mil Med, 137*, 1-7.	G
Al-Hazzaa, H. M. (2007). School backpack. How much load do Saudi school boys carry on their shoulders? *Saudi Med J, 27*(10), 1567-1571.	A
*Almeida, S., Williams, K., Shaffer, R., & Brodine, S. (1999). Epidemiological patterns of musculoskeletal injuries and physical training. *Medicine and Science in Sports and Exercise, 31*(8), 1176-1182.	G
Ashkenazi, I., & Epstein, Y. (1998). Alterations in plasma volume and protein during and after a continuous 110-kilometer march with 20-kilogram backpack load. *Mil Med, 163*(10), 687-691.	G
Balogun, J. A. (1988). Prediction of energy expenditure during load carriage on the head and by yoke. Indian J Med Sci, 42(10), 235-241.	G

---

[176] ‘Babylon 9’ translation software and dictionary tool from Babylon LTD.

Paper	Reason for exclusion
Bauer, D. H., & Freivalds, A. (2009). Backpack load limit recommendation for middle school students based on physiological and psychophysical measurements. *Work: A Journal of Prevention, Assessment and Rehabilitation, 32*(3), 339-350.	A
Bell, D. G., McLellan, T. M., & Boyne, S. (2002). Commercial sports drinks versus light meal combat rations: effect on simulated combat maneuvers. *Mil Med, 167*(8), 692-691.	C
*Bennell, K., Matheson, G., Meeuwisse, W., & Brukner, P. (1999). Risk factors for stress fractures. *Sports Medicine, 28,* 91-122.	G
Bennett, T., Bathalon, G., Armstrong, D. r., Martin, B., Coll, R., Beck, R., et al. (2001). Effect of creatine on performance of military relevant tasks and soldier health. *Mil Med, 166*(11), 996-1002.	C
*Bereket, S. (2005). Effects of anthropometric parameters and stride frequency on estimation of energy costs of walking. *J Sports Med Phys Fitness 45*(2), 152-161.	G
*Berkley, S. F., McNeil, J. G., Hightower, A. W., Graves, L. M., Smith, P. B., & Broome, C. V. (1989). A cluster of blister-associated toxic shock syndrome in male military trainees and a study of staphylococcal carriage patterns. *Mil Med, 154*(10), 496-499.	G
Bettany-Saltikov, J., Warren, J., & Stamp, M. (2008). Carrying a rucksack on either shoulder or the back, does it matter? Load induced functional scoliosis in "normal" young subjects. *Stud Health Technol Inform.*(140), 221-224.	A
Blacker, S. D., Fallowfield, J. L., Bilzon, J. L. J., & Willems, M. E. T. (2010). Within-day and between-days reproducibility of isokinetic parameters of knee, trunk and shoulder movements. *Isokinetics and Exercise Science, 18*(1), 45-55.	G
Blacker, S. D., Wilkinson, D. M., Bilzon, J., & Rayson, M. P. (2008). Risk factors for training injuries among British Army Recruits. *Mil Med, 173*(3), 278-286.	G
Blacker, S. D., Williams, N. C., Fallowfield, J. L., Bilzon, J. L. J., & Willems, M. E. T. (2010). Carbohydrate vs protein supplementation for recovery of neuromuscular function following prolonged load carriage.	C
Bohne, M., & Abendroth-Smith, J. (2007). Effects of hiking downhill using trekking poles while carrying external loads. *Med Sci Sports Exerc, 39*(1), 177-183.	B
Bossi, L. L., & Tack, D. W. (2000). *Human factors engineering in the development of a new load carriage system for the Canadian Forces*. Paper presented at the RTO Meeting Proceedings 56: Soldier Mobility: Innovations in Load Carriage System Design and Evaluation.	G
Bossi, L. L., Stevenson, J. M., Bryant, J. T., Pelot, R. P., & Morin, E. L. (2000). *Development of a suite of objective biomechanical measurement tools for personal load carriage system assessment*. Paper presented at the Soldier Mobility: Innovations in Load Carriage System Design and Evaluation.	G
Brackley, H. M., Stevenson, J. M., & Selinger, J. C. (2009). Effect of backpack load placement on posture and spinal curvature in prepubescent children. *Work: A Journal of Prevention, Assessment and Rehabilitation, 32*(3), 351-360.	A
*Bush, R. A., Brodine, S., & Shaffer, R. (2000). The Association of Blisters with Musculoskeletal Injuries in Male Marine Recruits. *J Am Podiatr Med Assoc, 90*(4), 194-198.	G
Byrne, C., Lim, C., Chew, S., & Ming, E. (2005). Water versus carbohydrate-electrolyte fluid replacement during load marching under great stress. *Mil Med, 170*(8), 715-721.	C
*Cadarette, B. S., Blanchard, L., Staab, J. E., Kolka, M. A., & Sawka, M. N. (2001). Heat Stress When Wearing Body Armor. USARIEM Technical Report T-01/9.	H
Catena, R. D., Didomenico, A., Banks, J. J., & Dennerlein, J. T. (2010). The effect of load weight on balance control during lateral box transfers. Ergonomics, 53(11), 1359.	G

Paper	**Reason for exclusion**
Cheng, T. S., & Lee, T. H. (2006). Maximum acceptable weight of manual load carriage for young Taiwanese males. Ind Health, 44(1), 200-206.	A
Cheung, C. H., Shum, S. T., Tang, S. F., Yau, P. C., & Chiu, T. T. W. (2009). The correlation between craniovertebral angle, backpack weights, and disability due to neck pain in adolescents. *Journal of Back and Musculoskeletal Rehabilitation, 22*(4), 197-203.	A
Chow, D. H. K., Ou, Z. Y., Wang, X. G., & Lai, A. (2010). Short-term effects of backpack load placement on spine deformation and repositioning error in schoolchildren. *Ergonomics, 53*(1), 56-64.	A
Chow, D. H. K., Ting, J. M. L., Pope, M. H., & Lai, A. (2009). Effects of backpack load placement on pulmonary capacities of normal schoolchildren during upright stance. *International Journal of Industrial Ergonomics, 39*(5), 703-707.	A
Chow, D. H., Kwok, M. L., Au-Yang, A. C., Holmes, A. D., Cheng, J. C., Yao, F. Y., et al. (2005). The effect of backpack load on the gait of normal adolescent girls. *Ergonomics, 48*(6), 642-656.	A,D
Chow, D. H., Kwok, M. L., Au-Yang, A. C., Holmes, A. D., Cheng, J. C., Yao, F. Y., et al. (2006). The effect of load carriage on the gait of girls with adolescent idiopathic scoliosis and normal controls. *Med Eng Phys, 28*(5), 430-437.	A,D
Chow, D. H., Leung, D. S., & Holmes, A. D. (2007). The effects of load carriage and bracing on the balance of schoolgirls with adolescent idiopathic scoliosis. *Eur Spine J, 16*(9), 1351-1358.	A
Chow, D. H., Leung, K. T., & Holmes, A. D. (2007). Changes in spinal curvature and proprioception of schoolboys carrying different weights of backpack. *Ergonomics, 50*(12), 2148-2156.	A
Chow, D. H., Ng, X. H., Holmes, A. D., Cheng, J. C., Yao, F. Y., & Wong, M. S. (2005). Effects of backpack loading on the pulmonary capacities of normal schoolgirls and those with adolescent idiopathic scoliosis. *Spine, 30*(21), E694-654.	A,D
Christou, E. A., & Enoka, R. M. (2010). Aging and movement errors when lifting and lowering light loads. Age, epub (ahead of print), 1-15.	G
Cottalorda, J., Bourelle, S., & Gautheron, V. (2004). Effects of backpack carrying children. *Orthopedics, 27*(11), 1172-1175.	A
Coyne, M. E., Hasselquist, L., Schiffman, J. M., Gregorczyk, K. N., Nobes, K. M., Adams, A., et al. (2009). Oxygen Consumption Output Increases During Steady-State Submaximal Prolonged Heavy Load Carriage: 1704: Board# 54 May 27 2: 00 PM-3: 30 PM. *Medicine & Science in Sports & Exercise, 41*(5), 102.	I
Cymerman, A., Pandolf, K. B., Young, A. J., & Maher, J. T. (1981). Energy expenditure during load carriage at high altitude. *J Appl Physiol, 51*(1), 14-18.	E
de Wild, G. M., Peeters, M. P. D., Hoefnagels, W. H. L., Oeseburg, B., & Blinkhorst, R. A. (1997). Relative exercise intensity of long-distance marching (120 km in 4 days) in 153 subjects aged 69-87 years. *Eur J Appl Physiol, 76*, 510-516.	A
Deuster, P., Bennett, T., Bathalon, G., Armstrong, D., Martin, B., Coll, R., et al. (2001). Effect of creatine on performance of military relevant tasks and soldier health. *Mil Med, 47*(7), 784-789.	C
Farley, C. T., & McMahon, T. A. (1992). Energetics of walking and running: insights from simulated reduced-gravity experiments. *J Appl Physiol, 73*(6), 2709-2712.	E
Feingold, A. J., & Jacobs, K. (2002). The effect of education on backpack wearing and posture in a middle school population. *Work, 18*(3), 287-294.	A
Franko, O., Heinonen, A., & Laamanen, A. (1954). Effects of diet and weight of pack during a march of 25 kilometers. *Sotilaslaak Aikak, 29*(2), 108-114.	F
Freudenthal, P. (1952). [Medical views on marching, field pack and morale.]. *Militaerlaegen, 58*(4), 122-127.	F

Paper	**Reason for exclusion**
*Galun, E., & Epstein, Y. (1984). Serum creatine kinase activity following a 120-km march. *Clinica Chimica Acta, 143*, 281-283.	G
Galun, E., Tur-Kaspa, I., Assia, E., Burstein, R., Strauss, N., Epstein, Y., et al. (1991). Hyponatremia induced by exercise: a 24-hour endurance march study. *Miner Electrolyte Metab, 17*(5), 315-320.	G
Garciaguirre, J. S., Adolph, K. E., & Shrout, P. E. (2007). Baby carriage: infants walking with loads. *Child Dev, 78*(2), 664-680.	A
Gillette, J. C., Stevermer, C. A., Meardon, S. A., Derrick, T. R., & Schwab, C. V. (2009). Upper Extremity and Lower Back Moments During Carrying Tasks in Farm Children. *Journal of applied biomechanics, 25*, 149ñ155.	A
*Givoni, B., & Goldman, R. F. (1971). Predicting metabolic energy cost. *J Appl Physiol, 30*(3), 429-433.	G
Goffar, S., Naylor, J., Reber, R. J., Rodriguez, B. M., Christiansen, B. C., Walker, M. J., et al. (2010). Effects of Load Carriage on Foot Anthropometrics. US Army Medical Department journal, 76.	D
Greaney, R. B., Gerber, F. H., Laughlin, R. L., Kmet, J. P., Metz, C. D., Kilchenski, T. S., et al. (1983). Distribution and Natural History of Stress Fractures in U.S. Marine Recruits. *Radiology, 146*, 339-346.	G
Gregorczyk, K. N., Hasselquist, L., Schiffman, J. M., Bensel, J. M. S., Obusek, J. P., & Gutekunst, D. (2010). The effects of a lower body exoskeleton load carriage assistive device on metabolic cost and gait biomechanics during load carriage. Ergonomics, 53(10), 1263-1275.	B
Grimmer, K., Dansie, B., Milanese, S., Pirunsan, U., & Trott, P. (2002). Adolescent standing postural responses to backpack loads: a randomised controlled experimental study. *BMC Musculoskelet Disord, 3*, 10.	A
Guyer, R. L. (2001). Backpack = back pain. *American Journal of Public Health, 91*(1), 16-20.	A
Hansen, A. H., & Childress, D. S. (2005). Effects of adding weight to the torso on roll-over characteristics of walking. Journal of Rehabilitation Research and Development, 42(3), 381-390.	G
Haselgrove, C., Straker, L., Smith, A., O'Sullivan, P., Perry, M., & Sloan, N. (2008). Perceived school bag load, duration of carriage, and method of transport to school are associated with spinal pain in adolescents: an observational study. *J Biomech, 41*(13), 2850-2854.	A
Hasselquist, L. (2009). Lower Extremity Exoskeleton for Load-Carriage Assistance: Human Performance Evaluation: 116: 4: 25 PM-4: 55 PM. *Medicine & Science in Sports & Exercise, 41*(5), 17.	B
Hasselquist, L., Bensel, C. K., Norton, K., Piscitelle, L., & Schiffman, J. M. (2004). Characterizing Centre of Mass and Movement of Inertia of Soldier*'s load*s Packed for Combat. Paper presented at the Army Science Conference (24th).	G
Hignett, S., Willmott, J. W., & Clemes, S. (2009). Mountain rescue stretchers: Usability trial. Work: A Journal of Prevention, Assessment and Rehabilitation, 34(2), 215-222.	H
Hinrichs, R. N., Lallemant, S. R., & Nelson, R. C. (1982). An investigation of the inertial properties of backpacks loaded in various configurations TR-82/023. *Military Performance Division. US Army Research Institute of Environmental Medicine, Natick.*	G
Hinz, P., Henningsen, A., Matthes, G., Jager, B., Ekkernkamp, A., & Rosenbaum, D. (2008). Analysis of pressure distribution below the metatarsals with different insoles in combat boots of the German Army for prevention of march fractures. *Gait Posture, 27*, 535-538.	G
Hong, Y., Li, J. X., & Fong, D. T. (2007). Effect of prolonged walking with backpack loads on trunk muscle activity and fatigue in children. *J Electromyog Kinesiol*.	A
Hong, Y., Li, J. X., Wong, M. S., & Robinson, P. D. (2000). Effects of load carriage on heart rate, blood pressure and energy expenditure in children. *Ergonomics, 43*(6), 356-359.	A

Paper	**Reason for exclusion**
Howatson, G., Hough, P., Pattison, J., Hill, J. A., Blagrove, R., Glaister, M., et al. Trekking Poles Reduce Exercise-Induced Muscle Injury during Mountain Walking. *Medicine & Science in Sports & Exercise*.	B
Jacobson, B. H., Wright, T., & Dugan, B. (2000). Load carriage energy expenditure with and without hiking poles during inclined walking. *Int J Sports Med*, *21*(5), 356-359.	B
*Jennings, B. M., Yoder, L. H., Heiner, S. L., Loan, L. A., & Bingham, M. O. (2008). Soldiers with musculoskeletal injuries. *J Nura Scholarsh*.	G
*Kelly, E., Jonson, S., Cohen, M., & Shaffer, R. (2000). Stress fractures of the pelvis in female Navy recruits: an analysis of possible mechanisms of injury. *Mil Med*, *165*(2), 142-146.	G
Korovessis, P., Repantis, T., & Baikousis, A. Factors Affecting Low Back Pain in Adolescents. *Journal of Spinal Disorders & Techniques*.	A
*Kram, R. (1991). Carrying loads with springy poles. *J Appl Physiol, 71*(3), 1119-1122.	B
Lang, Y. Y. (1992). [Biomechanics study during march with different military equipment of equal carrying load]. *Chinese Journal of Medicine, 26*(2), 74-76.	F
Lee, M., Roan, M., & Smith, B. (2009). An application of principal component analysis for lower body kinematics between loaded and unloaded walking. Journal of Biomechanics.	G
Lee, M., Roan, M., Smith, B., & Lockhart, T. E. (2009). Gait analysis to classify external load conditions using linear discriminant analysis. Human movement science, 28(2), 226-235.	G
Li, J. X., Hong, Y., & Robinson, P. D. (2003). The effect of load carriage on movement kinematics and respiratory parameters in children during walking. *Eur J Appl Physiol, 90*(1-2), 35-43.	A
Lindstrom-Hazel, D. (2009). The backpack problem is evident but the solution is less obvious. *Work: A Journal of Prevention, Assessment and Rehabilitation, 32*(3), 329-338.	A
Lloyd, R., Hind, K., Micklesfield, L. K., Carroll, S., Truscott, J. G., Parr, B., et al. A pilot investigation of load-carrying on the head and bone mineral density in premenopausal, black African women. *Journal of bone and mineral metabolism, 28*(2), 185-190.	G
Lloyd, R., Hind, K., Parr, B., Davies, S., & Cooke, C. (2010). The Extra Load Index as a method for comparing the relative economy of load carriage systems. Ergonomics, 53(12), 1500-1504.	G
Mackie, H. W., & Legg, S. J. (2008). Postural and subjective responses to realistic schoolbag carriage. *Ergonomics, 51*(2), 217-231.	A
Mackie, H. W., Legg, S. J., & Beadle, J. (2004). Development of activity monitoring for determining load carriage patterns in school students. *Work, 22*(3), 460-467.	A
Mackie, H. W., Stevenson, J. M., Reid, S. A., & Legg, S. J. (2005). The effect of simulated school load carriage configurations on shoulder strap tension forces and shoulder interface pressure. *Appl Ergon*, *36*(2), 199-206.	A
*Milgrom, C., Giladi, M., Stein, M., Kashtan, H., Margulies, J. Y., Chisin, R., et al. (1985). Stress fractures in military recruits. *British Editorial Society of Bone and Joint Surgery, 67 B*(5), 732 - 735.	G
Minetti, A. E., Formenti, F., & Ardigo, L. P. (2006). Himalayan porter's specialization: metabolic power, economy, efficiency and skill. Proc. R. Soc. B., 273, 2791-2797.	E
Montain, S. J., Shippee, R. L., & Tharion, W. J. (1997). Carbohydrate-electrolyte solution effects on physical performance of military tasks. *Aviat Space Environ Med*, *68*(5), 384-391.	G
*Morrissey, S. J., & Liou, Y. H. (1988). Maximal acceptable weights in load carriage. Appl Ergon, 31(2), 217-226.	G
Motmans, R. R., Tomlow, S., & Vissers, D. (2006). Trunk muscle activity in different modes of carrying schoolbags. *Ergonomics*, *49*(2), 127-138.	A

Paper	Reason for exclusion
Mramprasad, J., & Raghuveer, A. K. (2009). Effect of Backpack Weight on Postural Angles in Preadolescent Children. *Indian pediatrics*.	A
Nayar, H. S. (1964). Load carriage, physical efficiency and Vitamin E. *Indian J Physiol Pharmacol, 8*, 49-52.	C
Negrini, S., & Negrini, A. (2007). Postural effects of symmetrical and asymmetrical loads on the spines of schoolchildren. *Scoliosis, 2*, 8.	A
Negrini, S., Carabalona, R., & Sibilla, P. (1999). Backpack as a daily load for schoolchildren. *Lancet, 354*(9194), 1974.	A
Norton, K., Hasselquist, L., Shiffman, J., LaFiandra, M. E., Piscitelle, L., & Bensel, C. K. (2003). Inertial Properties of an External-Frame Backpack Device TR-03/020. *Military Performance Division. US Army Research Institute of Environmental Medicine, Natick*.	G
Obusek, J. P., Harman, E. A., Frykman, P. N., Palmer, C. J., & Bills, R. K. (1997). The Relationship of Backpack Center of Mass Location To the Metabolic Cost of Load Carriage 1170. *Medicine & Science in Sports & Exercise, 29*(5), 205.	I
*O'Connor, F. (2000). Injuries during Marine Corps officer basic training. *Mil Med, 165*(7), 515-520.	G
O'Shea, C., Bettany-Saltikov, J., & Warren, J. (2006). Effect of same-sided and cross-body load carriage on 3D back shape in young adults. *Stud Health Technol Inform., 123*, 159-163.	A
Pau, M. (2010). Postural sway modifications induced by backpack carriage in primary school children: a case study in Italy. Ergonomics, 53(7), 872-881.	A
Pau, M., Corona, F., & Leban, B. (2010). Effects of backpack carriage on foot- ground relationship in children during upright stance. Gait & Posture.	A
Pelot, R. P., Rigby, A., Stevenson, J. M., & Bryant, J. T. (2000). *A static biomechanical load carriage model*. Paper presented at the Soldier Mobility: Innovations in Load Carriage Systems Design and Evaluation.	G
*Pester, S., & Smith, P. C. (1992). Stress fractures in lower extremities of soldiers in basic training. *Orthop Rev, 21*(3), 297-303.	G
*Pope, R. (1999). Prevention of pelvic stress fractures in female army recruits. *Mil Med, 164*(5), 370-373.	G
Rayson, M. P., Davies, A., Bell, D. G., & Rhodes-James, E. S. (1995). Heart rate and oxygen uptake relationship: a comparison of loaded marching and running in women. *Eur J Appl Physiol Occup Physiol, 71*(5), 405-408.	G
Reid, C. R., & Bush, M. C. Occupational postural activity and lower extremity discomfort: A review. *International Journal of Industrial Ergonomics*.	G
Ren, L., Jones, R. K., & Howard, D. (2005). Dynamic analysis of load carriage biomechanics during level walking. J Biomech, 38(4), 853-863.	G
*Reynolds, K. L. (2000). Injuries and risk factors in an 18-day Marine winter mountain training exercise. *Mil Med, 165*(12), 905-910.	G
*Ross, R. A. (2002). Stress fractures in Royal Marine recruits. *Mil Med, 167*(7), 560-565.	G
Saha, R., Dey, N. C., Samanta, A., & Biswas, R. (2008). A comparison of physiological strain of carriers in underground coal mines in India. Int J Occup Environ Health, 14(3), 210-217.	E
Saibene, F. (1990). The mechanics for minimizing energy expenditure in human locomotion. *Eur J Clin Nutr, 32*(2), 149-155.	G
Santee, W. R., Kraning, K. K., & Matthew, W. T. (1999). Modelling analysis of women litter bearers during heat stress. *Aviat Space Environ Med, 70*(4), 340-345.	G

Paper	Reason for exclusion
* Schiffman, J. M., Chelidze, D., Adams, A., Segala, D. B., & Hasselquist, L. (2009). Nonlinear analysis of gait kinematics to track changes in oxygen consumption in prolonged load carriage walking: A pilot study. *Journal of Biomechanics*.	G
Schiffman, J. M., Gregorczyk, K. N., Bensel, C. K., Hasselquist, L., & Obusek, J. P. (2008). The effects of a lower body exoskeletal load carriage assistive device on limits of stability and postural sway. *Ergonomics, 51*(10), 1515-1529.	B
Sheehan, K. M., Murphy, M. M., Reynolds, K. L., Creedon, J. F., & al., e. (2003). The response of a bone resorption marker to Marine recruit training. *Mil Med, 168*(10), 797-801.	G
Shen, Y. H., & Hao, J. Q. (2008). Study on optimum load carriage for soldiers under different march speed. *Zhonghua lao dong wei sheng zhi ye bing za zhi= Zhonghua laodong weisheng zhiyebing zazhi= Chinese journal of industrial hygiene and occupational diseases, 26*(12), 743.	F
Shoenfeld, Y., Udassin, R., Shapiro, Y., Birenfeld, C., Magazanik, A., & Sohar, E. (1978). Optimal back-pack load for short distance hiking. *Arch Phys Med Rehabil, 59*(6), 281-284.	F
Simpson, R. J., Graham, S. M., Florida-James, G. D., Connaboy, C., Clement, R., & Jackson, A. S. (2010). Perceived exertion and heart rate models for estimating metabolic workload in elite British soldiers performing a backpack load-carriage task. Applied Physiology, Nutrition, and Metabolism, 35(5), 650-656.	G
Singh, T., & Koh, M. (2008). Effects of backpack load position on spatiotemporal parameters and trunk forward lean. *Gait & Posture, 29*(1), 49-53.	A
Singh, T., & Koh, M. (2009). Lower limb dynamics change for children while walking with backpack loads to modulate shock transmission to the head. *Journal of Biomechanics, 42*(6), 736-742.	A
Smith, B., Roan, M., & Lee, M. (2010). The effect of evenly distributed load carrying on lower body gait dynamics for normal weight and overweight subjects. Gait & Posture, 32(2), 176-180.	D
Smith, J. D., Kinser, K. B., Dugan, E., & Reed, M. (2005). Physiological and biomechanical responses while running with and without a stroller. *J Sports Med Phys Fitness 45*(3), 270-276.	B
Steele, E., Bialocerkowski, A., & Grimmer, K. (2003). The postural effects of load carriage on young people --a systematic review. *BMC Musculoskelet Disord, 4*(12).	A
* Stein, M., Shlamkovitch, N., Finestone, A., & Milgrom, C. (1989). Marcher's digitalgia paresthetica among recruits. *Foot Ankle, 9*(6), 312-313.	G
Stevenson, J. M., Bossi, L. L., Bryant, J. T., Reid, S. A., Pelot, R. P., & Morin, E. L. (2004). A suite of objective biomechanical measurement tools for personal load carriage system assessment. *Ergonomics, 47*(11), 1160-1179.	G
Stevenson, J. M., Bryant, J. T., Reid, S. A., Pelot, R. P., Morin, E. L., & Bossi, L. L. (2004). Development and assessment of the Canadian personal load carriage system using objective biomechanical measures. *Ergonomics, 47*(12), 1255-1271.	G
Stevenson, J. M., I. A. Kudryk, et al. (2009). "Strategies Used By Professional Movers To Reduce The Impact Of Carrying Loads And Ways To Assist Them: 1557: Board# 159 May 27 11: 00 AM-12: 30 PM." Medicine & Science in Sports & Exercise **41**(5): 52.	B, I
Stevenson, J. M., Reid, S. A., Bryant, J. T., Pelot, R. P., & Morin, E. L. (2000). *Biomechanical assessment of the Canadian Integrated Load Carriage system using objective assessment measures.* Paper presented at the RTO Meeting Proceedings 56: Soldier Mobility: Innovations in Load Carriage System Design and Evaluation.	G
Tiggelen, D., Wickes, S., Coorevits, P., Dumalin, M., & Witvrouw, E. (2009). Sock Systems to Prevent Foot Blisters and the Impact on Overuse Injuries of the Knee Joint. *Military Medicine, 174*(2), 183-189.	G
* Trank, T., Ryman, D., Minagawa, R., Trone, D., & Schaffer, R. (2001). Running mileage, movement mileage, and fitness in male U.S. Navy recruits. *Medicine and Science in Sports and Exercise, 33*(6), 1033-1038.	G

Paper	**Reason for exclusion**
* Vaz, M., Karaolis, N., Draper, A., & Shetty, P. (2005). A compilation of energy costs of physical activities. *Public Health Nutr 8*(7a), 1153-1183.	G
* Watson, J. C., Payne, R. C., Chamberlain, A. T., Jones, R. K., & Sellers, W. I. (2008). The energetic costs of load-carrying and the evolution of bipedalism. *J Hum Evol, 54*(5), 675-683.	G
Xu, X., Hsiang, S. M., & Mirka, G. A. (2009). The effects of a suspended-load backpack on gait. *Gait & Posture*, *29*(1), 151-153.	B
Zivotic-Vanovic, M., Dimitrijevic, B., Ivosevic, D., Pajevic, D., & Nesic, L. (1982). [Adaptation reaction of the body in an experimental model of march training]. *Vojnosanit Pregl*, *39*(4), 311-313.	F

* These articles, whilst not meeting the inclusion criteria, were used to expand detail and provide supporting information.

APPENDIX C: LITERATURE REVIEW: ELECTRONIC JOURNAL DATA EXTRACTION AND CRITIQUE SHEET

Article				
Authors / Date				
Focus				
Participants	**Background**		**Gender**	**Age**
Study description	**Load**			
	Dist/Dur		**Terrain**	
	Speeds		**Gradient**	
Measures				
Alpha Level				
Study Design				
Potential confounders /biases				
Findings				

APPENDIX D: VOLUME OF SUPPORTING EVIDENCE

Evidence supporting increases in load weight found to increase the energy cost of standing, walking (forwards and backwards, up and down stairs) and running:

> (Beekley, et al., 2007; Bhambhani, Buckley, & Maikala, 1997; Bhambhani & Maikala, 2000; Bilzon, Allsopp, et al., 2001; Blacker, et al., 2009; Charteris, et al., 1989; Chung, et al., 2005; Datta, et al., 1975; Engels, Smith, & Wirth, 1995; Goslin & Rorke, 1986; Lyons, et al., 2005; Patton, et al., 1991; Pederson, et al., 2007; Pimental, et al., 1982; Polcyn, et al., 2000; Robertson, et al., 1982; Samanta & Chatterjee, 1981; Vaz, et al., 2005).

Evidence supporting increases in speed increasing the energy cost of carrying a given load:

> (Abe, et al., 2004; Balogun, 1986; Charteris, et al., 1989; Christie & Scott, 2005; Givoni & Goldman, 1971; Goslin & Rorke, 1986; Maloiy, et al., 1986; Robertson, et al., 1982; Samanta & Chatterjee, 1981; Soule & Goldman, 1969; Soule, et al., 1978).

Evidence supporting increases in energy expenditure while carrying loads up an incline

> (Crowder, et al., 2007; Givoni & Goldman, 1971; Goldman & Jampietro, 1962; Legg, et al., 1992; Lyons, et al., 2005; Pimental & Pandolf, 1979; Scott & Ramabhai, 2000b; Vaz, et al., 2005).

Evidence supporting increases in postural forward lean with increases in load carried:

> (Attwells, et al., 2006; Fowler, et al., 2006; Goh, et al., 1998; Ling, et al., 2000; Majumdar & Pal, 2010; Polcyn, et al., 2000; Vacheron, et al., 1998).

APPENDIX E: A DOT POINT SUMMARY OF THE LITERATURE REVIEW OF MILITARY LOAD CARRIAGE

The Physiological Response to Load Carriage

- Increased loads have been reported to lead to an increase in energy expenditure during static standing, walking and running.
- The position of the load in a backpack influences the energy cost of a load carriage task.
- Head load carriage for lighter loads might be less energy costly than carrying the same load on the back.
- The cost of carrying loads in the hands is nearly twice as high as the same load on the torso and may impact on a soldier’s weapon fire accuracy.
- The energy costs of carrying loads on the feet were found to involve the highest overall energy cost when compared to the remainder of the body.
- Increasing movement speed generally increases the energy cost of carrying a given load, perhaps even more than increasing load.
- Set or ‘forced’ speeds may be more detrimental to energy costs than ‘self-selected’ speeds where participants can adjust work levels to maintain a given output.
- Speed has an inverse relationship with load in that heavier loads can be tolerated at slower speeds and lighter loads at faster speeds.
- Heavier loads and faster speeds were found to progressively increase the energy cost of load carriage over time.
- Both terrain gradients (e.g. incline, decline) and terrain type (e.g. road, bush, sand) influence the energy cost of carrying loads.
- Cold, hot and/or wet weather have been observed to increase the energy costs of load carriage.

The Biomechanical Response to Load Carriage

- Increased loads during walking were found to increase forward trunk lean, increase spinal compression and shearing forces, and alter spinal shape.
- Carried unilaterally, loads were found to accentuate the lumbar curve.
- Increases in load have been reported to increase postural sway, increase energy expenditure, and impact on gait parameters.
- Stride length was found to decrease and the duration of double support to increase as load weight increased.

- Stride frequency typically increased to offset the decrease in stride length and maintain a given speed.
- These gait parameters (stride length, stride frequency, etc.), appear to be less affected when participants can self-select their speeds.
- Increases in load and rifle carriage were found to increase ground reaction forces during gait and increase the amount of force transmitted through the joints.

The Influence of Physical Composition on Load Carriage Ability

- When the loads carried by participants were normalised to a percentage of body weight, they generally induced less load carriage stress.
- Although varying with the nature of the load carriage task being performed, body fat was found to impact on load carriage performance.
- Stronger, taller and heavier females with greater aerobic fitness may perform better at load carriage tasks than their female counterparts.
- Better performing females may out-perform poorer performing males at load carriage tasks.
- When carrying load, the average female when compared to the average male has a shorter stride length and a higher stride frequency at a given speed. Stride frequency was found to increase further in response to increases in load and speed.
- Physiological and biomechanical differences may explain why female soldiers in general have higher injury rates during basic training (which typically includes load carriage activities) and why injury rates may increase when training is changed from a ‘gender fair’ to a ‘gender free’ regime.

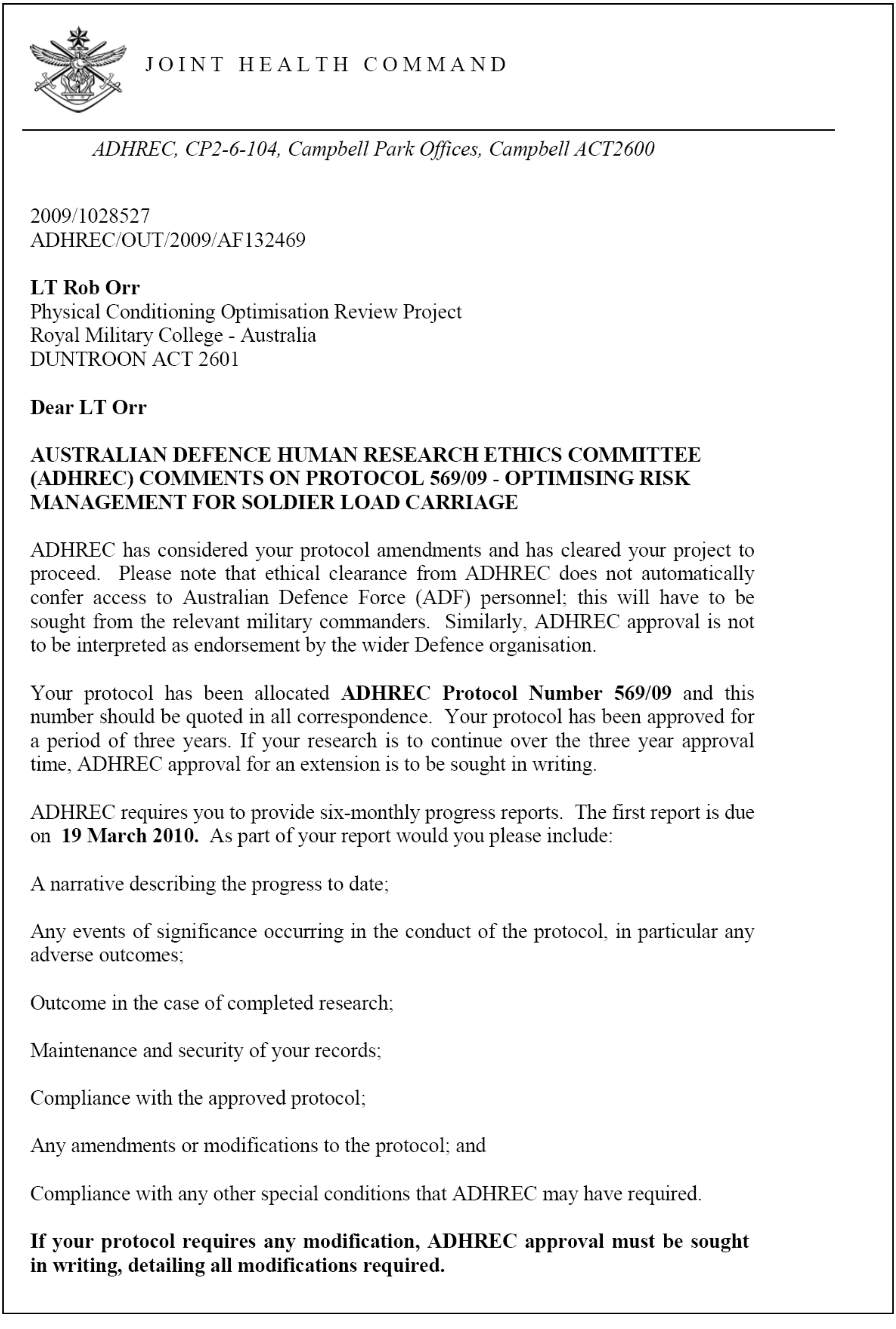
The Impact of Load Carriage on the Soldier

- Wearing loads as light as 10 kg of body armour has been found to decrease soldiers’ mobility including reducing their speed of march and obstacle negotiation.
- Shooting accuracy has been found to decrease, at least in the short term, following a load carriage activity, and grenade throwing ability has been found to be impaired in some instances.
- Reduced alertness and reduced feelings of well-being have been identified in participants following load carriage tasks.
- Acute injuries, occurring during or immediately following a load carriage activity, and overuse injuries, although tenuously linked to load carriage in training environments, include foot blisters, stress fractures, back, knee and foot pain, and neurological conditions (brachial plexus palsy, digitalgia, etc.).

Physical Conditioning for Soldier Load Carriage

- Optimal frequency for load carriage conditioning requires a load carriage conditioning session once every 10–14 days.
- Specific load carriage conditioning may provide additional benefits to military tasks which involve load carriage.
- Complementary physical conditioning, preferably consisting of both resistance and aerobic training, may provide some value to a load carriage conditioning program.
- The intensity of the load carriage session must be sufficient to elicit the required training response.
- Regardless of the amount of conditioning undertaken, there is still a point beyond which the load carriage task will become too much for the carrier to physiologically withstand.

APPENDIX F: ETHICS APPROVALS



JOINT HEALTH COMMAND

ADHREC, CP2-6-104, Campbell Park Offices, Campbell ACT2600

2009/1028527
ADHREC/OUT/2009/AF132469

LT Rob Orr
Physical Conditioning Optimisation Review Project
Royal Military College - Australia
DUNTROON ACT 2601

Dear LT Orr

AUSTRALIAN DEFENCE HUMAN RESEARCH ETHICS COMMITTEE (ADHREC) COMMENTS ON PROTOCOL 569/09 - OPTIMISING RISK MANAGEMENT FOR SOLDIER LOAD CARRIAGE

ADHREC has considered your protocol amendments and has cleared your project to proceed. Please note that ethical clearance from ADHREC does not automatically confer access to Australian Defence Force (ADF) personnel; this will have to be sought from the relevant military commanders. Similarly, ADHREC approval is not to be interpreted as endorsement by the wider Defence organisation.

Your protocol has been allocated **ADHREC Protocol Number 569/09** and this number should be quoted in all correspondence. Your protocol has been approved for a period of three years. If your research is to continue over the three year approval time, ADHREC approval for an extension is to be sought in writing.

ADHREC requires you to provide six-monthly progress reports. The first report is due on **19 March 2010.** As part of your report would you please include:

A narrative describing the progress to date;

Any events of significance occurring in the conduct of the protocol, in particular any adverse outcomes;

Outcome in the case of completed research;

Maintenance and security of your records;

Compliance with the approved protocol;

Any amendments or modifications to the protocol; and

Compliance with any other special conditions that ADHREC may have required.

If your protocol requires any modification, ADHREC approval must be sought in writing, detailing all modifications required.

For Clinical trials, ADHREC is to be notified in writing of all Serious Adverse Events (SAE) within 72 hours of the event occurring.

For completeness, would you please sign and initial the enclosed **Researcher's Agreement** and return it to me at your convenience.

I have also attached ADHREC's *Guidelines for Volunteers*, a copy of which is to be given to each study participant.

The Committee wishes you well with your research. Please contact me if I can be of any assistance.

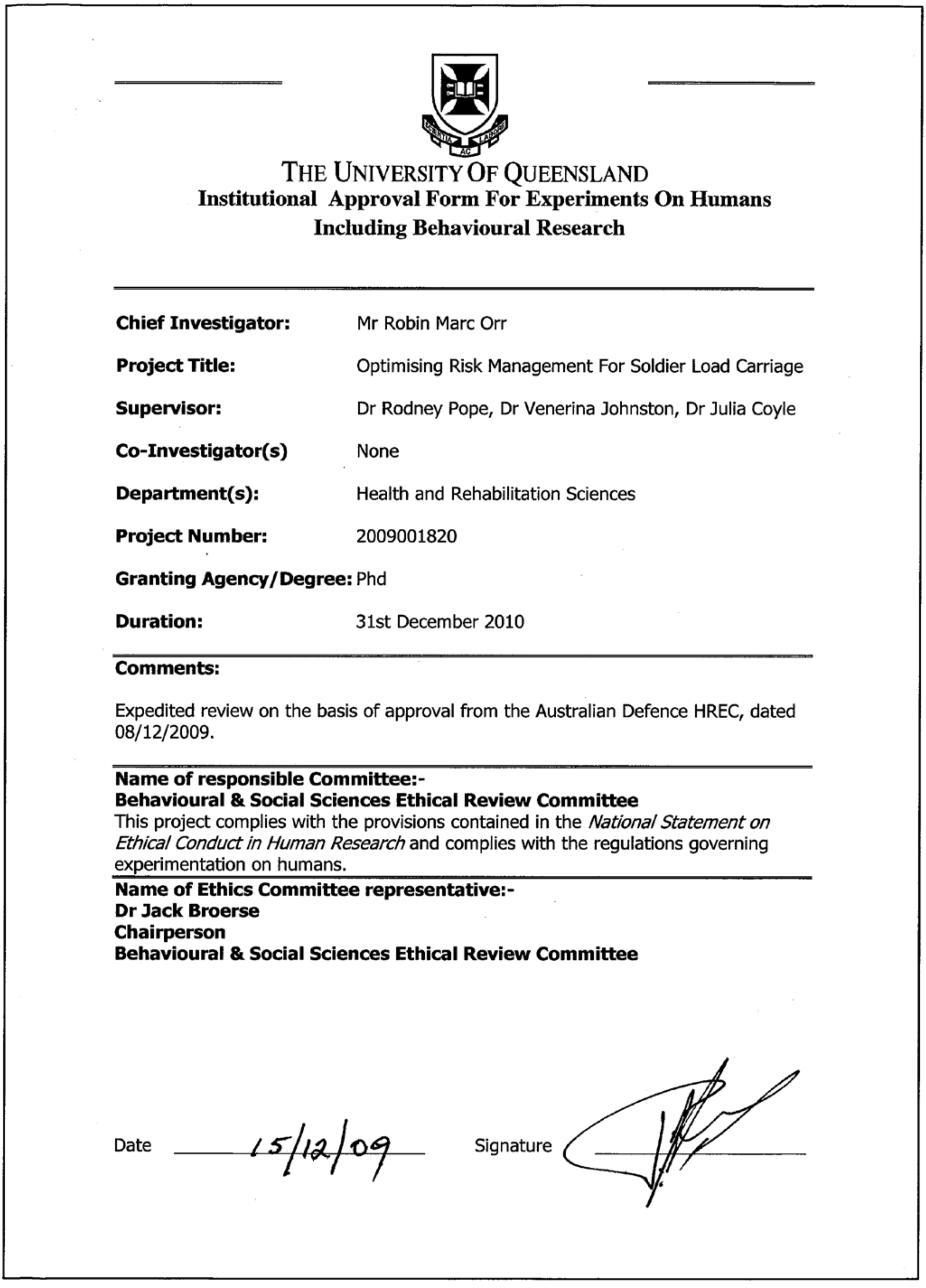
Yours sincerely,

Lieutenant Colonel Rosemary A. Landy
Executive Secretary
Australian Defence Human Research Ethics Committee
CP2-6-105
Campbell Park Offices
CANBERRA ACT 2600

Tel (02) 62663837
Fax (02) 62663881
E-mail: ADHREC@defence.gov.au

02 December 2009

Attachment:
A. ADHREC *Researchers Agreement*
B. ADHREC *Guidelines for Volunteers*



THE UNIVERSITY OF QUEENSLAND

Institutional Approval Form For Experiments On Humans Including Behavioural Research

Chief Investigator:	Mr Robin Marc Orr
Project Title:	Optimising Risk Management For Soldier Load Carriage
Supervisor:	Dr Rodney Pope, Dr Venerina Johnston, Dr Julia Coyle
Co-Investigator(s)	None
Department(s):	Health and Rehabilitation Sciences
Project Number:	2009001820
Granting Agency/Degree:	Phd
Duration:	31st December 2010

Comments:

Expedited review on the basis of approval from the Australian Defence HREC, dated 08/12/2009.

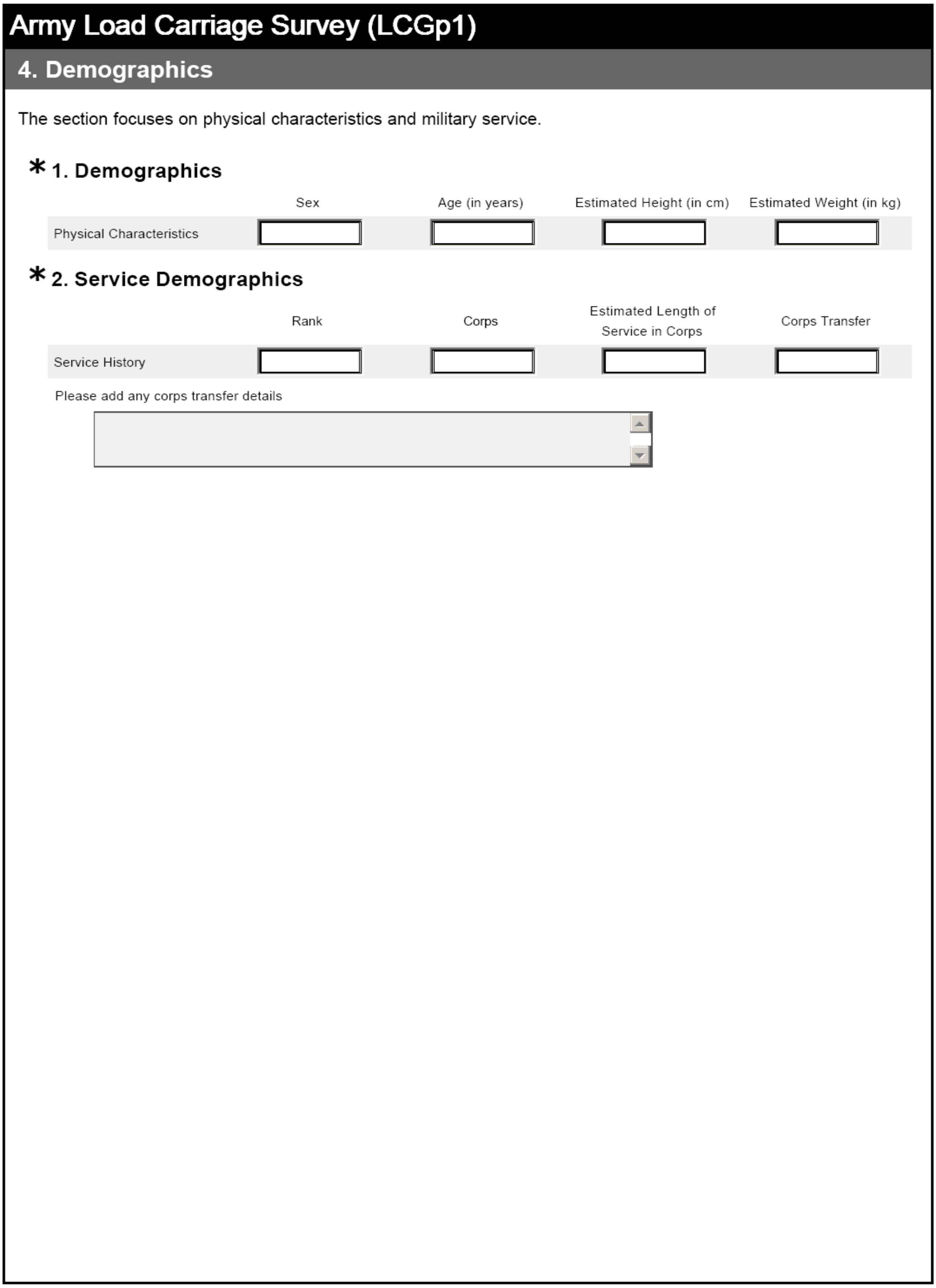
Name of responsible Committee:-
Behavioural & Social Sciences Ethical Review Committee
This project complies with the provisions contained in the *National Statement on Ethical Conduct in Human Research* and complies with the regulations governing experimentation on humans.

Name of Ethics Committee representative:-
Dr Jack Broerse
Chairperson
Behavioural & Social Sciences Ethical Review Committee

Date 15/12/09 Signature

APPENDIX G: THE ONLINE SURVEY QUESTIONNAIRE

NOTE: Sections 1-3 of the survey contained the introductory and ethical statements akin to those in Annex F and have therefore been excluded for the sake of brevity.



Army Load Carriage Survey (LCGp1)

4. Demographics

The section focuses on physical characteristics and military service.

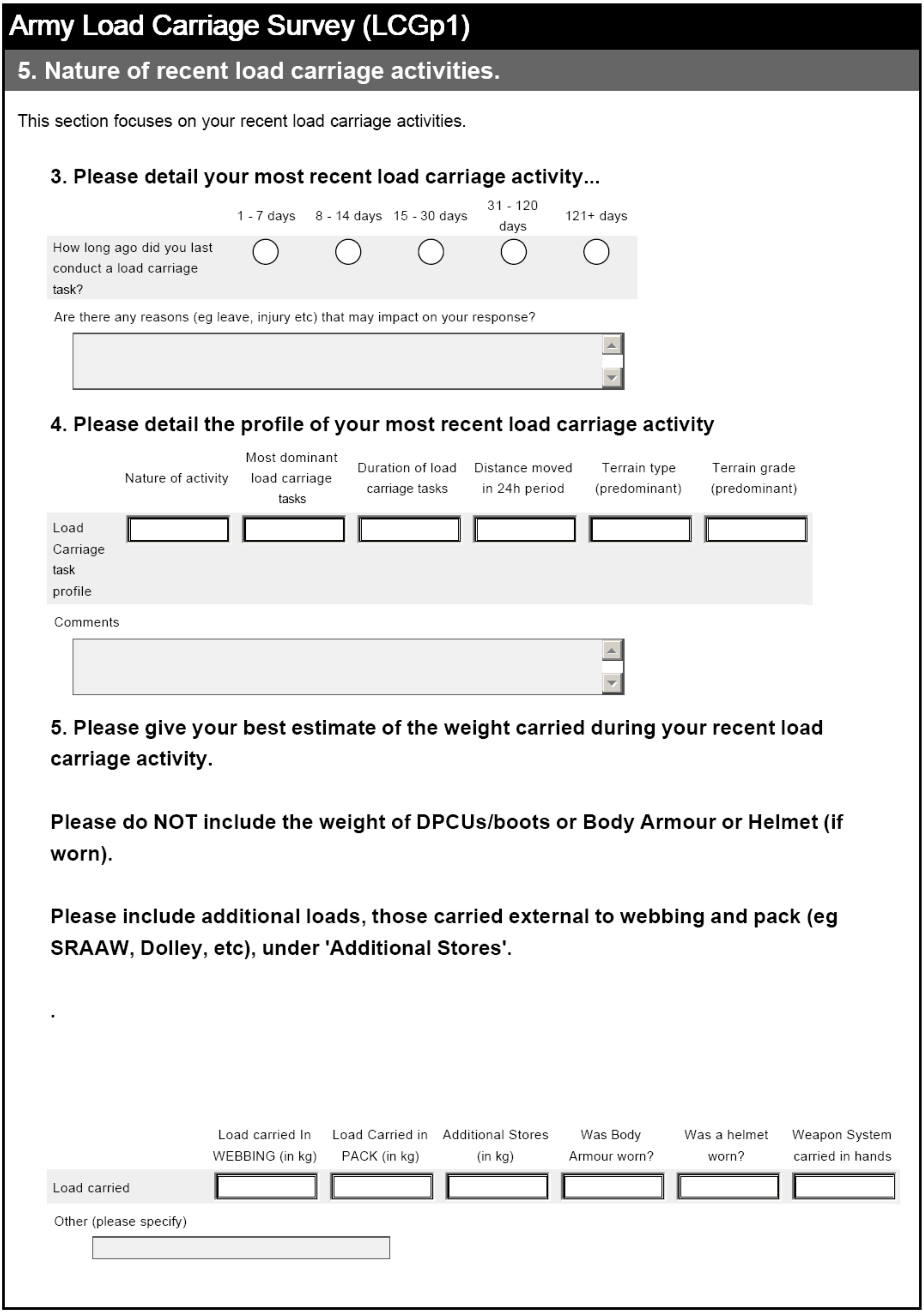
*** 1. Demographics**

	Sex	Age (in years)	Estimated Height (in cm)	Estimated Weight (in kg)
Physical Characteristics	☐	☐	☐	☐

*** 2. Service Demographics**

	Rank	Corps	Estimated Length of Service in Corps	Corps Transfer
Service History	☐	☐	☐	☐

Please add any corps transfer details



Army Load Carriage Survey (LCGp1)

5. Nature of recent load carriage activities.

This section focuses on your recent load carriage activities.

3. Please detail your most recent load carriage activity...

	1 - 7 days	8 - 14 days	15 - 30 days	31 - 120 days	121+ days
How long ago did you last conduct a load carriage task?	○	○	○	○	○

Are there any reasons (eg leave, injury etc) that may impact on your response?

4. Please detail the profile of your most recent load carriage activity

	Nature of activity	Most dominant load carriage tasks	Duration of load carriage tasks	Distance moved in 24h period	Terrain type (predominant)	Terrain grade (predominant)
Load Carriage task profile						

Comments

5. Please give your best estimate of the weight carried during your recent load carriage activity.

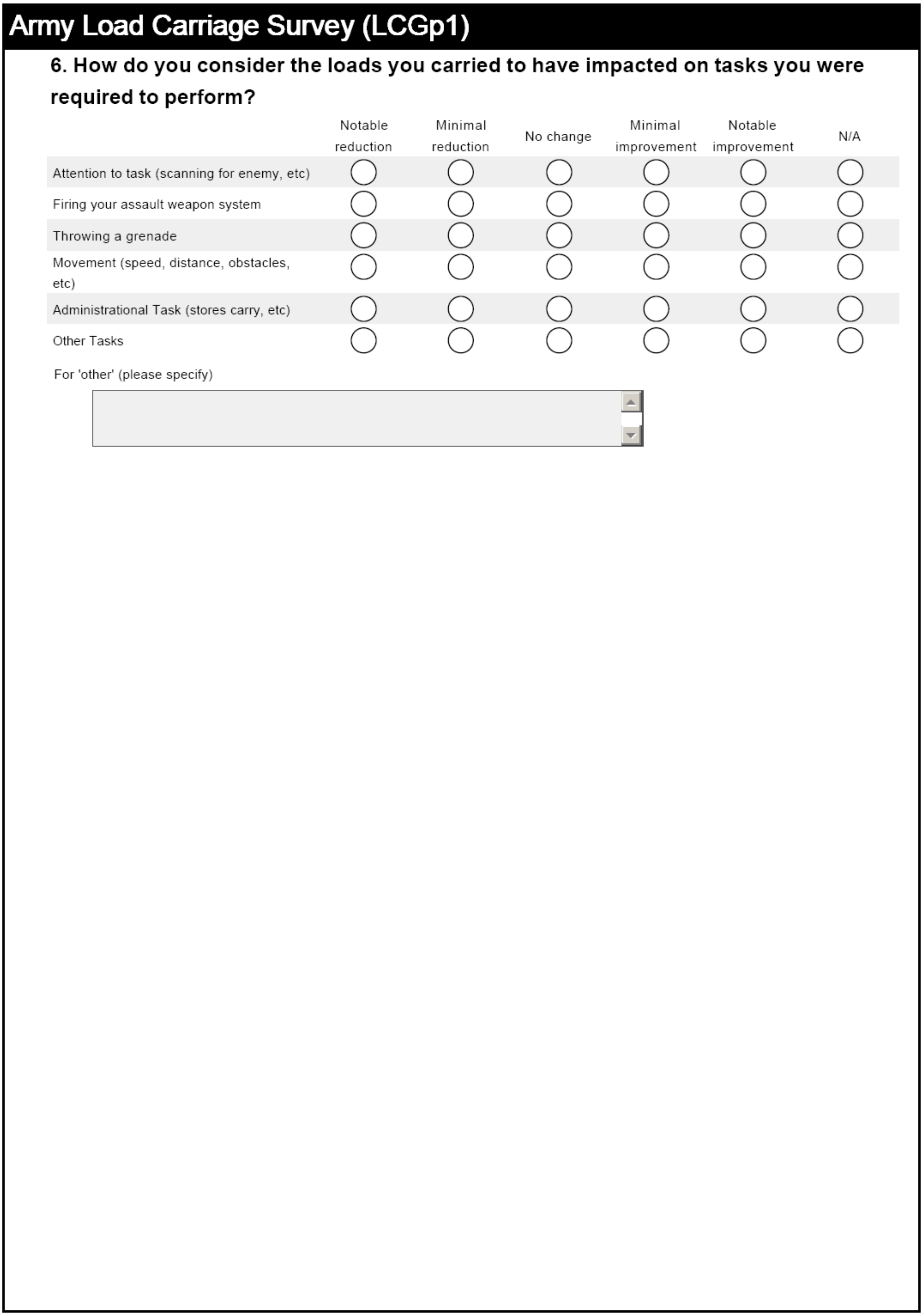
Please do NOT include the weight of DPCUs/boots or Body Armour or Helmet (if worn).

Please include additional loads, those carried external to webbing and pack (eg SRAAW, Dolley, etc), under 'Additional Stores'.

.

	Load carried In WEBBING (in kg)	Load Carried in PACK (in kg)	Additional Stores (in kg)	Was Body Armour worn?	Was a helmet worn?	Weapon System carried in hands
Load carried						

Other (please specify)

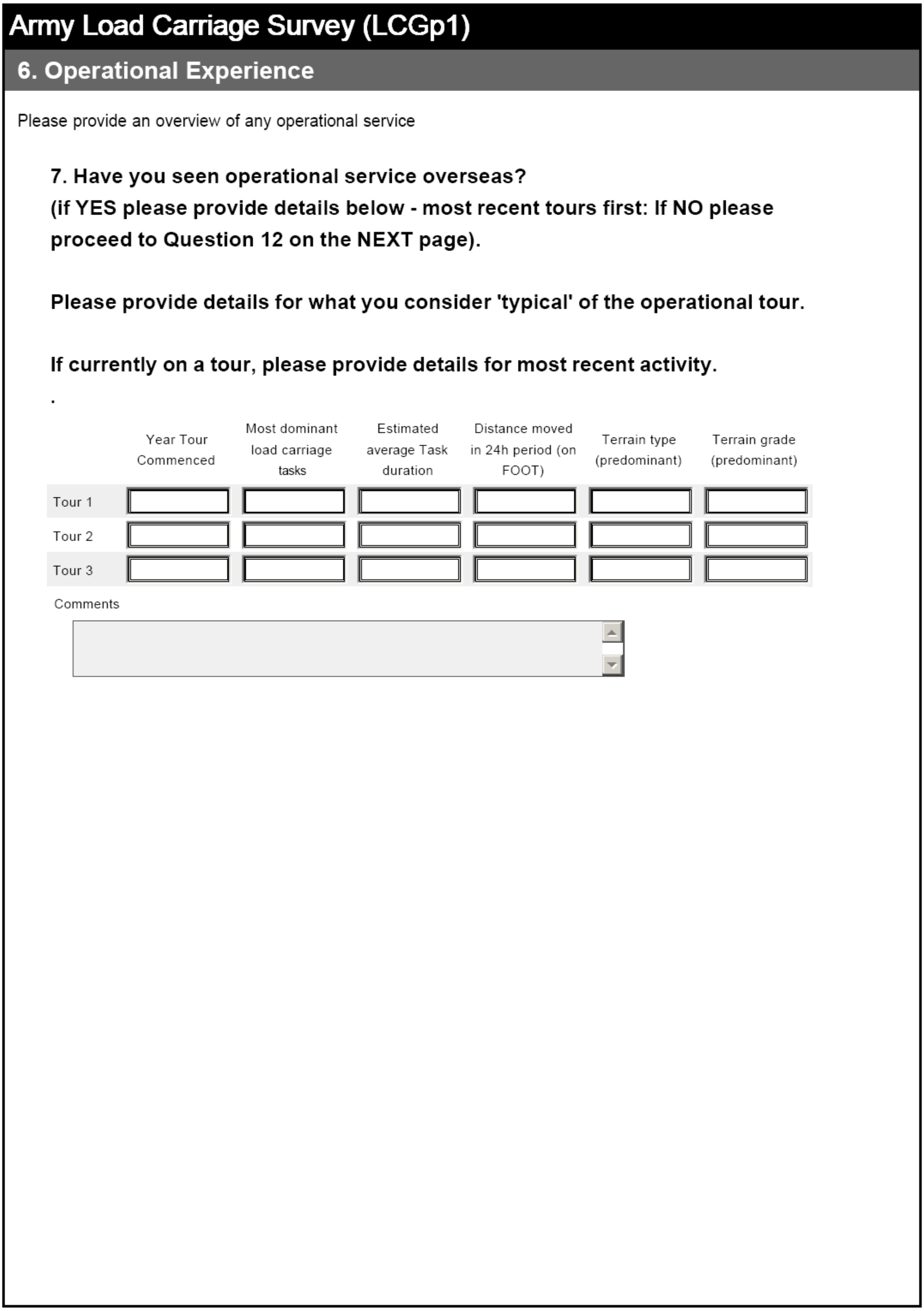


Army Load Carriage Survey (LCGp1)

6. How do you consider the loads you carried to have impacted on tasks you were required to perform?

	Notable reduction	Minimal reduction	No change	Minimal improvement	Notable improvement	N/A
Attention to task (scanning for enemy, etc)	○	○	○	○	○	○
Firing your assault weapon system	○	○	○	○	○	○
Throwing a grenade	○	○	○	○	○	○
Movement (speed, distance, obstacles, etc)	○	○	○	○	○	○
Administrational Task (stores carry, etc)	○	○	○	○	○	○
Other Tasks	○	○	○	○	○	○

For 'other' (please specify)



Army Load Carriage Survey (LCGp1)

6. Operational Experience

Please provide an overview of any operational service

7. Have you seen operational service overseas?
(if YES please provide details below - most recent tours first: If NO please proceed to Question 12 on the NEXT page).

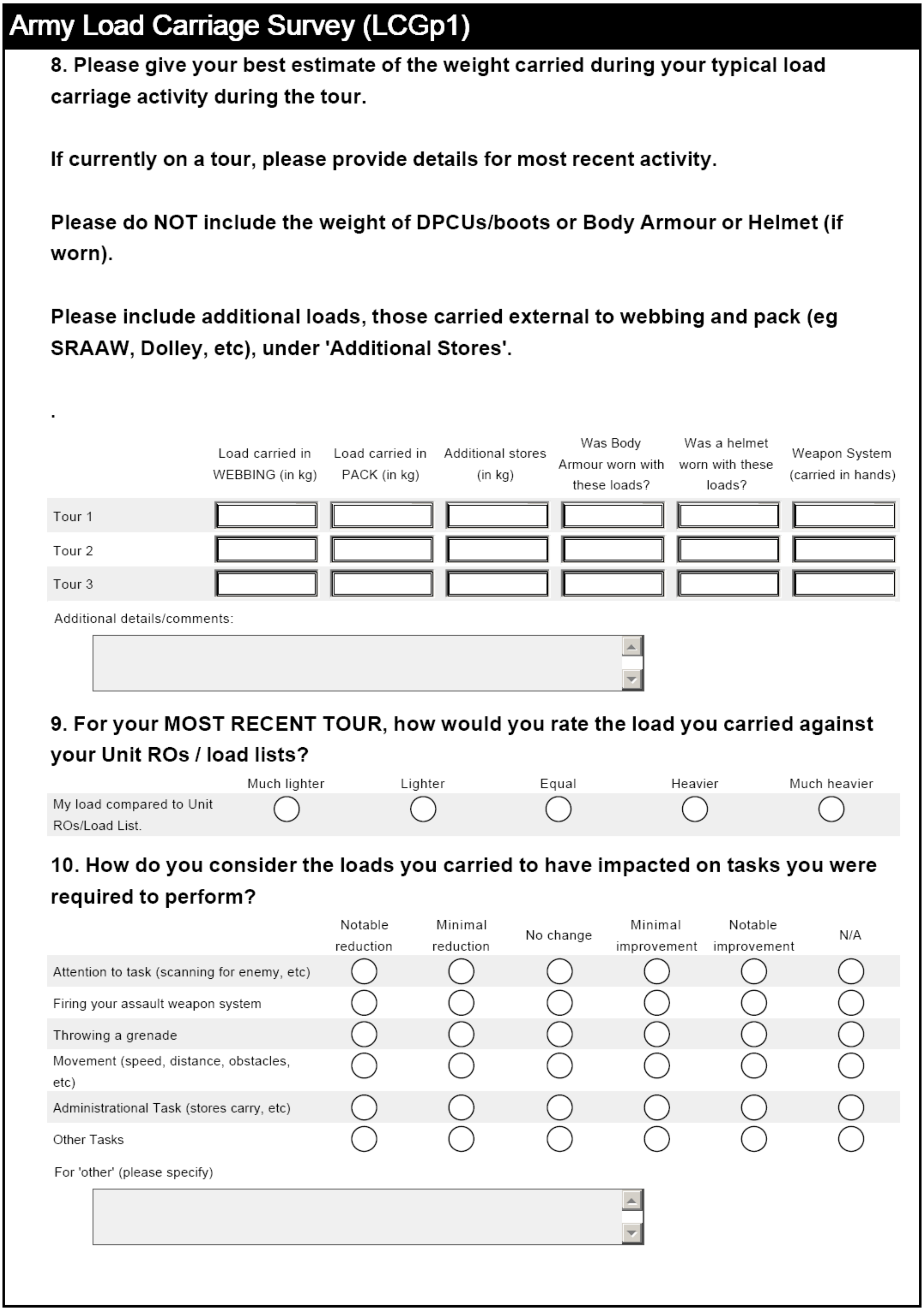
Please provide details for what you consider 'typical' of the operational tour.

If currently on a tour, please provide details for most recent activity.

.

	Year Tour Commenced	Most dominant load carriage tasks	Estimated average Task duration	Distance moved in 24h period (on FOOT)	Terrain type (predominant)	Terrain grade (predominant)
Tour 1						
Tour 2						
Tour 3						

Comments



Army Load Carriage Survey (LCGp1)

8. Please give your best estimate of the weight carried during your typical load carriage activity during the tour.

If currently on a tour, please provide details for most recent activity.

Please do NOT include the weight of DPCUs/boots or Body Armour or Helmet (if worn).

Please include additional loads, those carried external to webbing and pack (eg SRAAW, Dolley, etc), under 'Additional Stores'.

.

	Load carried in WEBBING (in kg)	Load carried in PACK (in kg)	Additional stores (in kg)	Was Body Armour worn with these loads?	Was a helmet worn with these loads?	Weapon System (carried in hands)
Tour 1	☐	☐	☐	☐	☐	☐
Tour 2	☐	☐	☐	☐	☐	☐
Tour 3	☐	☐	☐	☐	☐	☐

Additional details/comments:

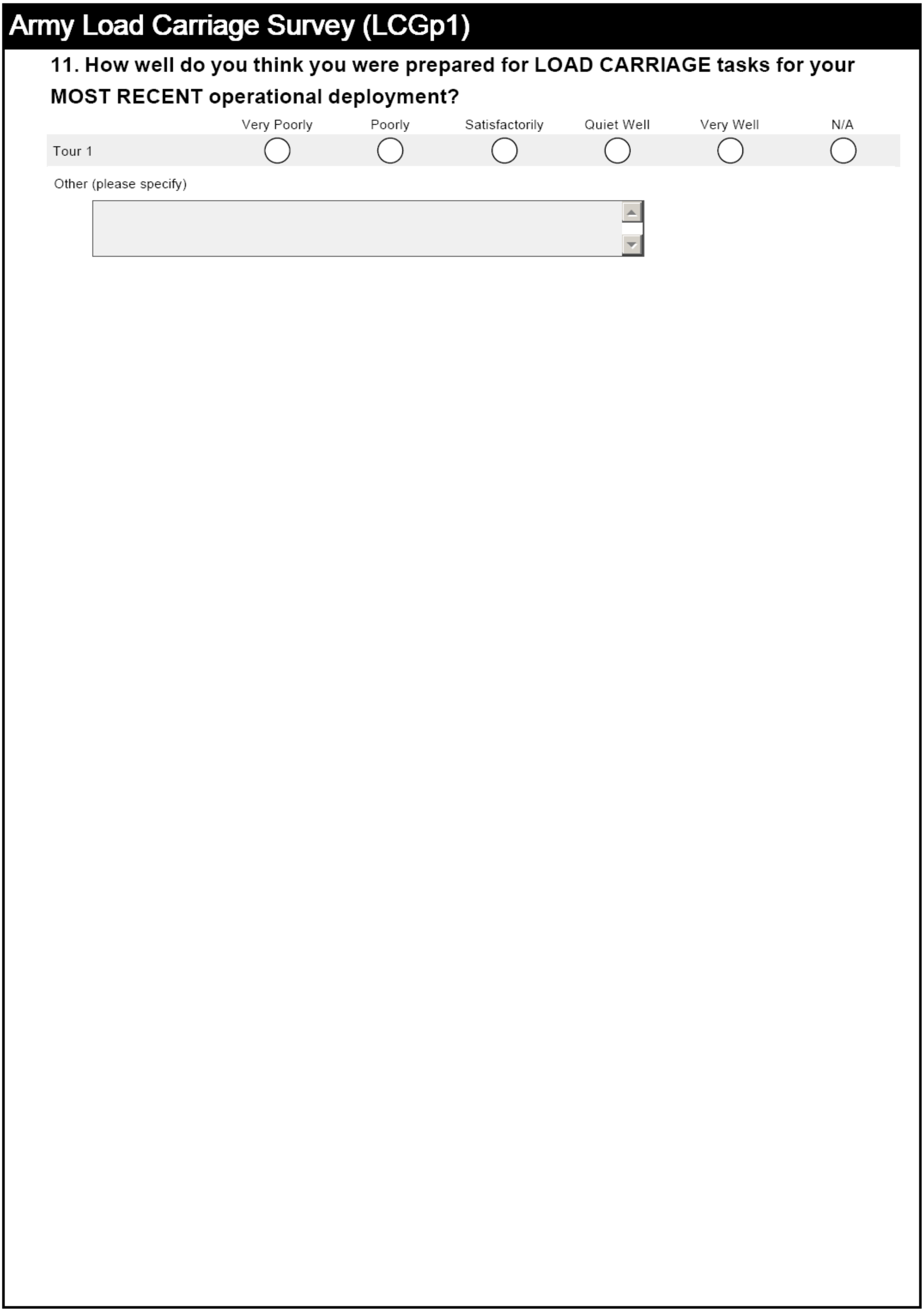
9. For your MOST RECENT TOUR, how would you rate the load you carried against your Unit ROs / load lists?

	Much lighter	Lighter	Equal	Heavier	Much heavier
My load compared to Unit ROs/Load List.	○	○	○	○	○

10. How do you consider the loads you carried to have impacted on tasks you were required to perform?

	Notable reduction	Minimal reduction	No change	Minimal improvement	Notable improvement	N/A
Attention to task (scanning for enemy, etc)	○	○	○	○	○	○
Firing your assault weapon system	○	○	○	○	○	○
Throwing a grenade	○	○	○	○	○	○
Movement (speed, distance, obstacles, etc)	○	○	○	○	○	○
Administrational Task (stores carry, etc)	○	○	○	○	○	○
Other Tasks	○	○	○	○	○	○

For 'other' (please specify)

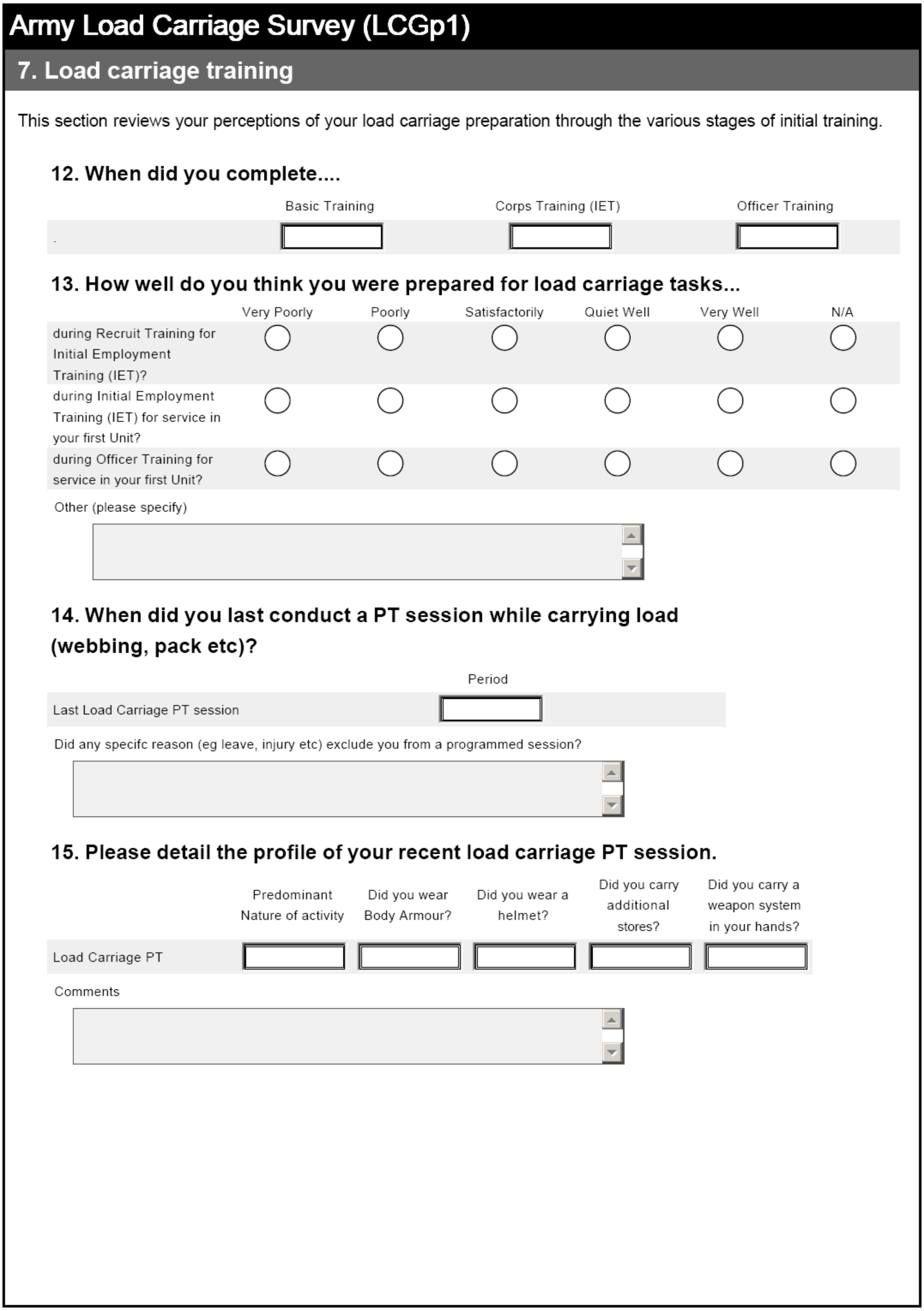


Army Load Carriage Survey (LCGp1)

11. How well do you think you were prepared for LOAD CARRIAGE tasks for your MOST RECENT operational deployment?

	Very Poorly	Poorly	Satisfactorily	Quiet Well	Very Well	N/A
Tour 1	○	○	○	○	○	○

Other (please specify)



Army Load Carriage Survey (LCGp1)

7. Load carriage training

This section reviews your perceptions of your load carriage preparation through the various stages of initial training.

12. When did you complete....

	Basic Training	Corps Training (IET)	Officer Training
.			

13. How well do you think you were prepared for load carriage tasks...

	Very Poorly	Poorly	Satisfactorily	Quiet Well	Very Well	N/A
during Recruit Training for Initial Employment Training (IET)?	○	○	○	○	○	○
during Initial Employment Training (IET) for service in your first Unit?	○	○	○	○	○	○
during Officer Training for service in your first Unit?	○	○	○	○	○	○

Other (please specify)

14. When did you last conduct a PT session while carrying load (webbing, pack etc)?

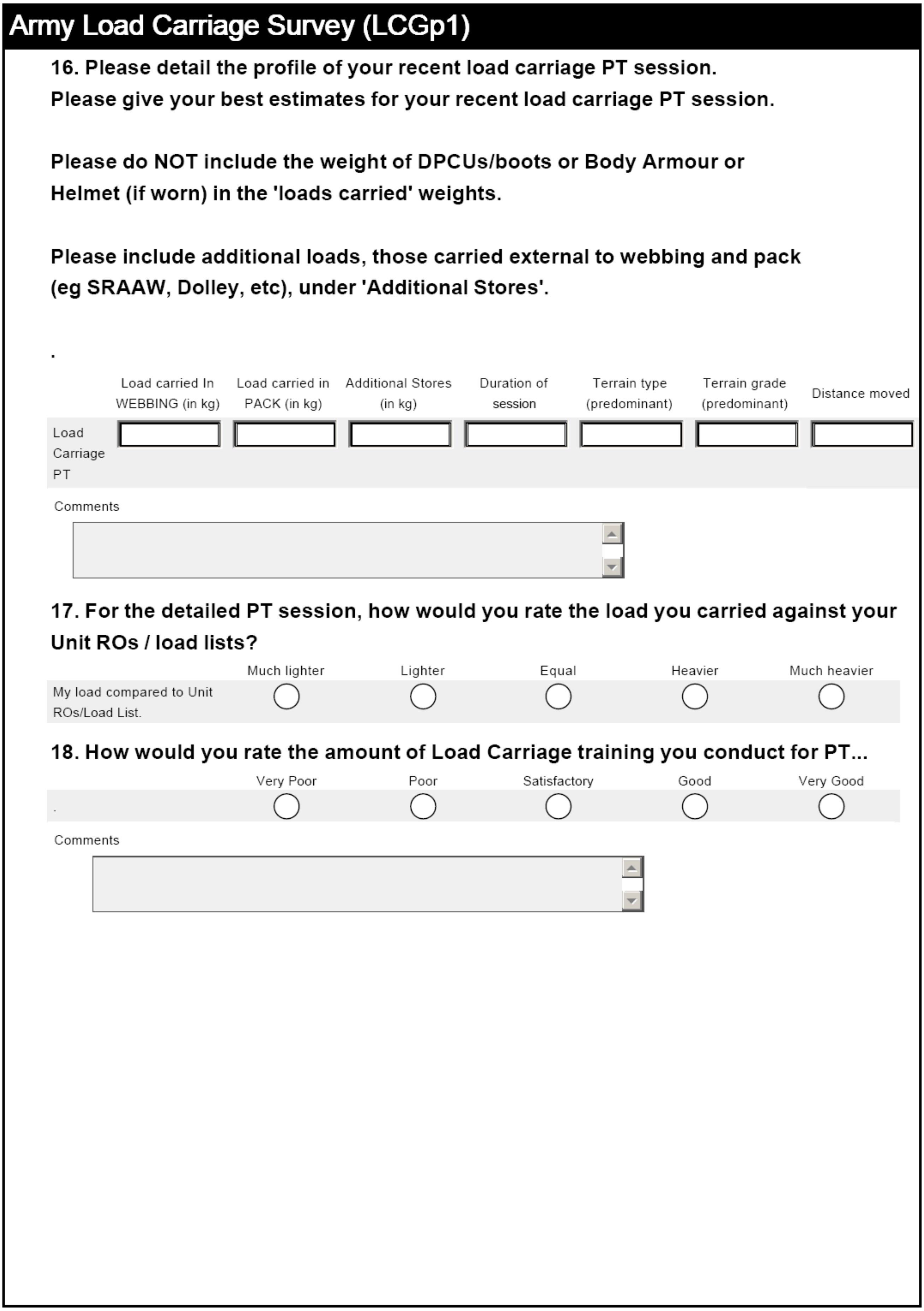
	Period
Last Load Carriage PT session	

Did any specifc reason (eg leave, injury etc) exclude you from a programmed session?

15. Please detail the profile of your recent load carriage PT session.

	Predominant Nature of activity	Did you wear Body Armour?	Did you wear a helmet?	Did you carry additional stores?	Did you carry a weapon system in your hands?
Load Carriage PT					

Comments



Army Load Carriage Survey (LCGp1)

16. Please detail the profile of your recent load carriage PT session.
Please give your best estimates for your recent load carriage PT session.

Please do NOT include the weight of DPCUs/boots or Body Armour or Helmet (if worn) in the 'loads carried' weights.

Please include additional loads, those carried external to webbing and pack (eg SRAAW, Dolley, etc), under 'Additional Stores'.

.

	Load carried In WEBBING (in kg)	Load carried in PACK (in kg)	Additional Stores (in kg)	Duration of session	Terrain type (predominant)	Terrain grade (predominant)	Distance moved
Load Carriage PT	☐	☐	☐	☐	☐	☐	☐

Comments

☐

17. For the detailed PT session, how would you rate the load you carried against your Unit ROs / load lists?

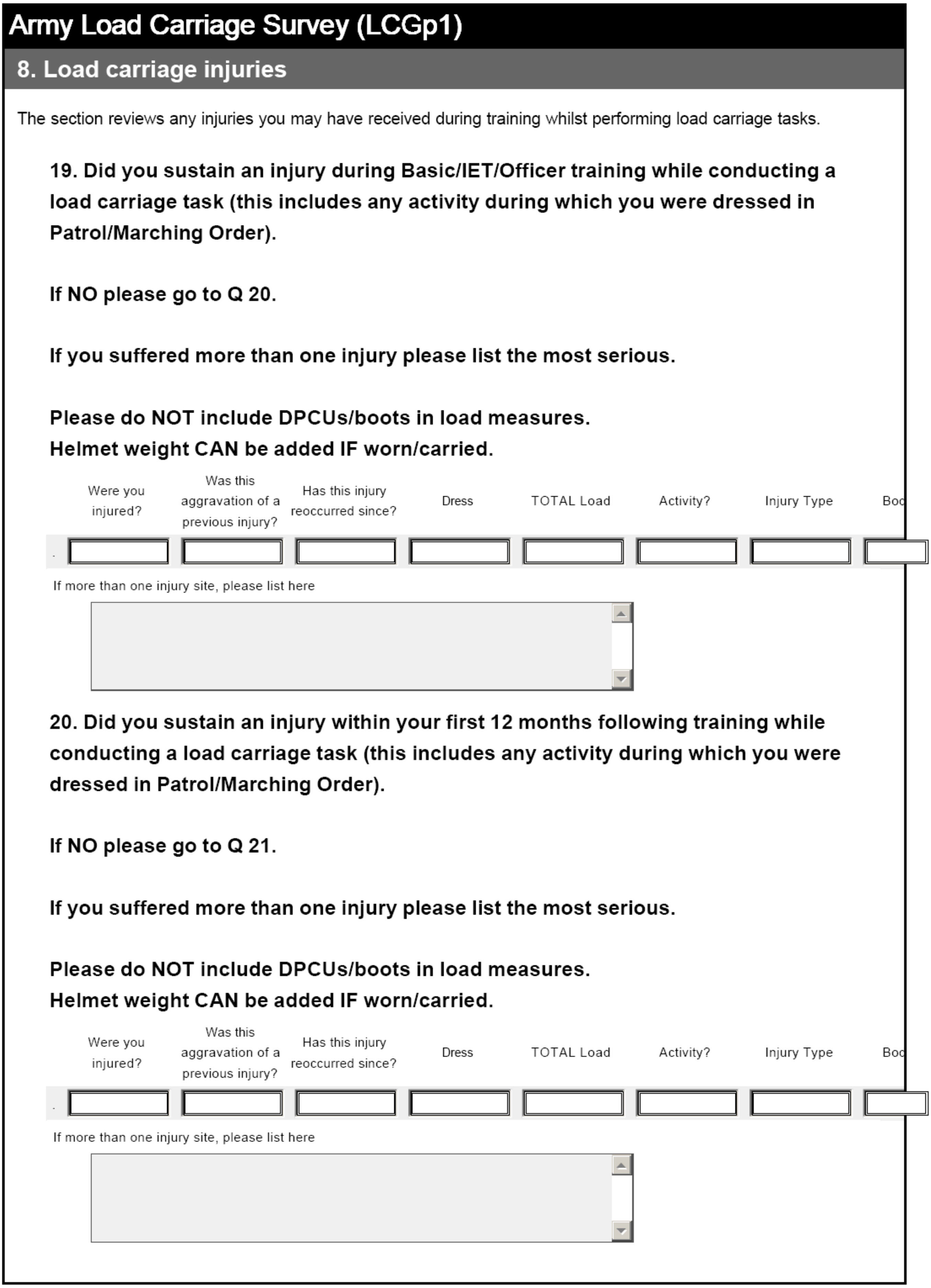
	Much lighter	Lighter	Equal	Heavier	Much heavier
My load compared to Unit ROs/Load List.	○	○	○	○	○

18. How would you rate the amount of Load Carriage training you conduct for PT...

	Very Poor	Poor	Satisfactory	Good	Very Good
.	○	○	○	○	○

Comments

☐



Army Load Carriage Survey (LCGp1)

8. Load carriage injuries

The section reviews any injuries you may have received during training whilst performing load carriage tasks.

19. Did you sustain an injury during Basic/IET/Officer training while conducting a load carriage task (this includes any activity during which you were dressed in Patrol/Marching Order).

If NO please go to Q 20.

If you suffered more than one injury please list the most serious.

Please do NOT include DPCUs/boots in load measures.
Helmet weight CAN be added IF worn/carried.

Were you injured?	Was this aggravation of a previous injury?	Has this injury reoccurred since?	Dress	TOTAL Load	Activity?	Injury Type	Bo

If more than one injury site, please list here

20. Did you sustain an injury within your first 12 months following training while conducting a load carriage task (this includes any activity during which you were dressed in Patrol/Marching Order).

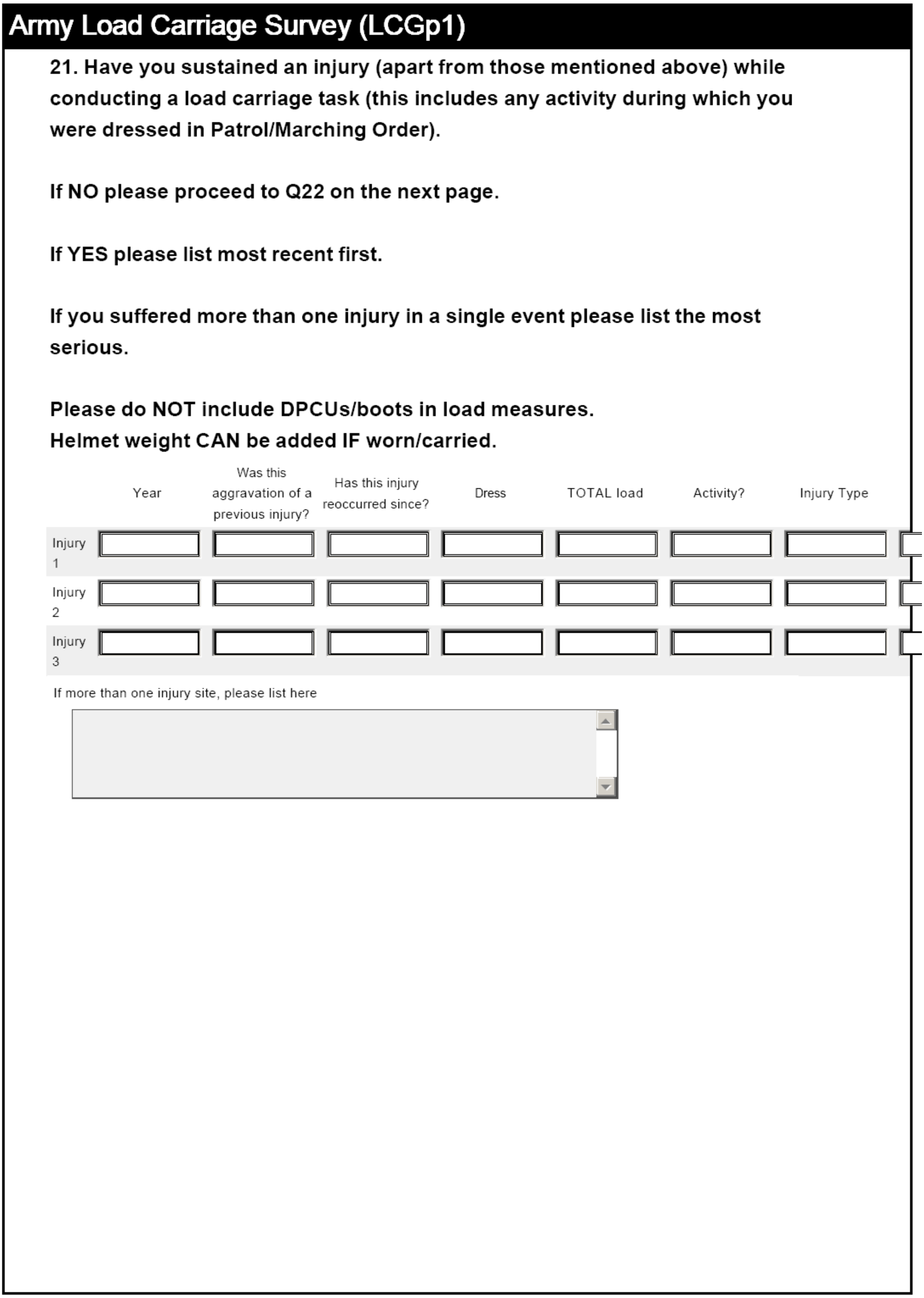
If NO please go to Q 21.

If you suffered more than one injury please list the most serious.

Please do NOT include DPCUs/boots in load measures.
Helmet weight CAN be added IF worn/carried.

Were you injured?	Was this aggravation of a previous injury?	Has this injury reoccurred since?	Dress	TOTAL Load	Activity?	Injury Type	Bo

If more than one injury site, please list here



Army Load Carriage Survey (LCGp1)

21. Have you sustained an injury (apart from those mentioned above) while conducting a load carriage task (this includes any activity during which you were dressed in Patrol/Marching Order).

If NO please proceed to Q22 on the next page.

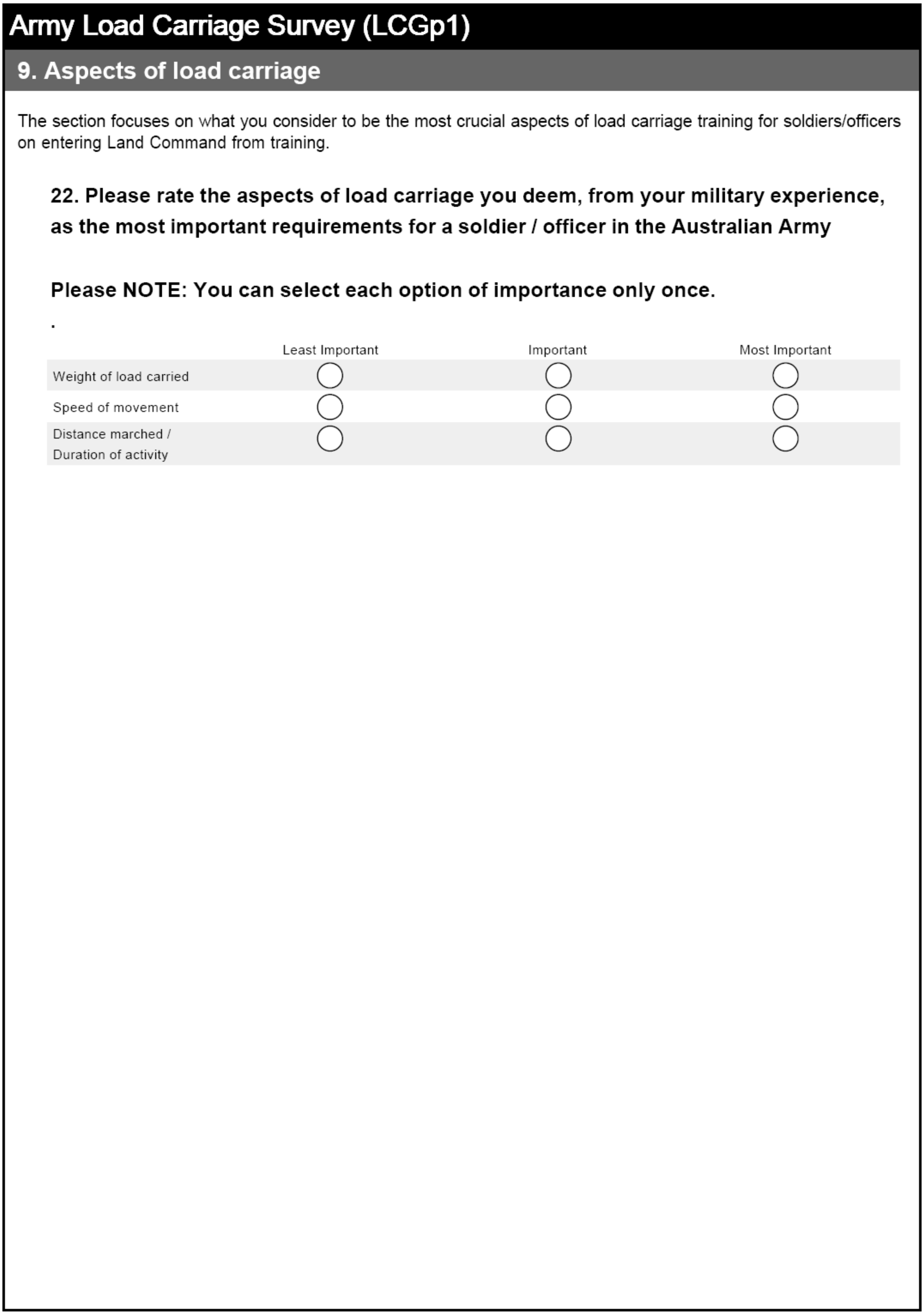
If YES please list most recent first.

If you suffered more than one injury in a single event please list the most serious.

Please do NOT include DPCUs/boots in load measures.
Helmet weight CAN be added IF worn/carried.

	Year	Was this aggravation of a previous injury?	Has this injury reoccurred since?	Dress	TOTAL load	Activity?	Injury Type
Injury 1							
Injury 2							
Injury 3							

If more than one injury site, please list here



Army Load Carriage Survey (LCGp1)

9. Aspects of load carriage

The section focuses on what you consider to be the most crucial aspects of load carriage training for soldiers/officers on entering Land Command from training.

22. Please rate the aspects of load carriage you deem, from your military experience, as the most important requirements for a soldier / officer in the Australian Army

Please NOTE: You can select each option of importance only once.

.

	Least Important	Important	Most Important
Weight of load carried	○	○	○
Speed of movement	○	○	○
Distance marched / Duration of activity	○	○	○

APPENDIX H: UNIT COOPERATION AND SURVEY RESPONSE RATES – NOMENCLATURE AND FORMULAS

Definitions of nomenclature

Anticipated Error (AE)

Anticipated Error (AE) is an estimation of errors, like distribution errors (e.g. disruption in internet service, email captured in spam filter, etc.) that might have affected survey distribution and therefore survey responses. The AE for this study was determined at 10% based on feedback from Unit POCs.

Survey Completion (C) Standard

Over 80% of all applicable responses were answered (excluding no answer required, ‘no’ responses or ‘blank’ additional comments).

Survey Partial (P) Standard

Completion of 51% to 80% of all applicable responses were answered (excluding no answer required, ‘no’ responses or ‘blank’ additional comments).

Distributed Emails (DEm)

The number of emails distributed.

Declined to Participate (DEC)

Units that received the invitation but declined to participate.

Declined to Participate (units potentially unaware) (DEC[U])

Higher command elements declined invitation for the units within their realm of responsibility to participate in the study. These units may have or may not have been informed of the invitation.

Unit Agreed Participation (UAP)

Units willing to participate in the study having received the invitation.

Unknown / No return from units (UN)

Following the issuing of the invitation, no responses from the units (or their higher command) were returned to the investigator. These responses might have been returned to higher elements of command and not to the investigator. Alternatively, the invitation might not have progressed down to the individual units from higher command elements.

Rate Definitions and Formula

Unit Cooperation Rate

The percentage of units from those identified for approach that volunteered to participate in the study.

$$\text{Unit Cooperation Rate} = \frac{UAP}{UAP + DEC + DEC\,(U) + UN} \times 100$$

Unit Decline Rate

The percentage of units from those identified for approach that declined, either directly or by proxy, the invitation to participate in the study.

$$\text{Unit Decline Rate} = \frac{DEC + DEC(U)}{DEC + DEC(U) + UAP + UN} \times 100$$

Unit Non-Contact Rate

The percentage of units from those identified for approach whose responses were not received by the investigator.

$$\text{Non-Contact Rate} = \frac{UN}{DEC + DEC(U) + UAP + UN} \times 100$$

Survey Response Rate (RR)

The percentage of volunteers that met the criterion of having completed or partially completed the survey in relation to the number of invitations distributed.

$$RR = \frac{C + P}{DEm} \times 100$$

Response Rate (corrected)

The percentage of respondents that met the criteria of having completed or partially completed the survey in relation to the number of invitations distributed, corrected for any anticipated errors (e.g. internet failure, invitation captured in spam filter, etc.).

$$\text{RR (corrected)} = \frac{C + P}{(DEm \times 0.9)} \times 100$$

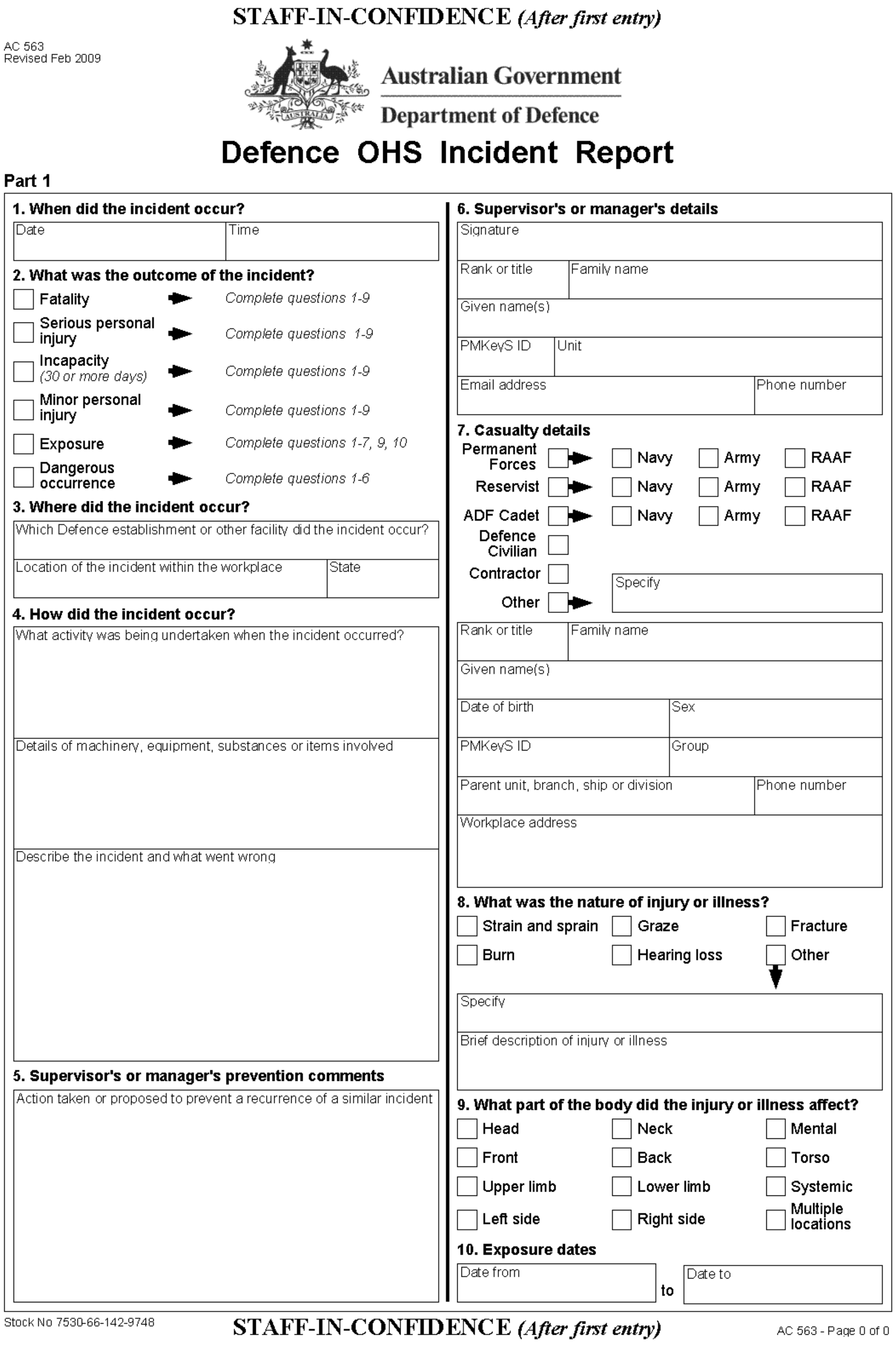
Sources

The key documents used in development of these definitions and formulas were:

Lynn, P., Roeland, B., Johanna, L., & Jean, M. (2001). Recommended Standard Final Outcome Categories and Standard Definitions of Response Rate for Social Surveys. *Working Papers of the Institute for Social and Economic Research, paper 2001-2003*.

The American Association for Public Opinion Research. (2011). *Standard Definitions: Final Dispositions of Case Codes and Outcome Rates for Surveys. 7th edition*: AAPOR.

APPENDIX I: FORM AC563. DEFENCE OHS INCIDENT REPORT



STAFF-IN-CONFIDENCE *(After first entry)*

AC 563
Revised Feb 2009

Australian Government
Department of Defence

Defence OHS Incident Report

Part 1

1. When did the incident occur?

Date	Time

2. What was the outcome of the incident?

☐ Fatality	*Complete questions 1-9*
☐ Serious personal injury	*Complete questions 1-9*
☐ Incapacity *(30 or more days)*	*Complete questions 1-9*
☐ Minor personal injury	*Complete questions 1-9*
☐ Exposure	*Complete questions 1-7, 9, 10*
☐ Dangerous occurrence	*Complete questions 1-6*

3. Where did the incident occur?

Which Defence establishment or other facility did the incident occur?

Location of the incident within the workplace	State

4. How did the incident occur?

What activity was being undertaken when the incident occurred?

Details of machinery, equipment, substances or items involved

Describe the incident and what went wrong

5. Supervisor's or manager's prevention comments

Action taken or proposed to prevent a recurrence of a similar incident

6. Supervisor's or manager's details

Signature

Rank or title	Family name

Given name(s)

PMKeyS ID	Unit
Email address	Phone number

7. Casualty details

Permanent Forces	☐	☐ Navy	☐ Army	☐ RAAF
Reservist	☐	☐ Navy	☐ Army	☐ RAAF
ADF Cadet	☐	☐ Navy	☐ Army	☐ RAAF
Defence Civilian	☐			
Contractor	☐	Specify		
Other	☐			

Rank or title	Family name

Given name(s)

Date of birth	Sex
PMKeyS ID	Group
Parent unit, branch, ship or division	Phone number

Workplace address

8. What was the nature of injury or illness?

☐ Strain and sprain	☐ Graze	☐ Fracture
☐ Burn	☐ Hearing loss	☐ Other

Specify

Brief description of injury or illness

9. What part of the body did the injury or illness affect?

☐ Head	☐ Neck	☐ Mental
☐ Front	☐ Back	☐ Torso
☐ Upper limb	☐ Lower limb	☐ Systemic
☐ Left side	☐ Right side	☐ Multiple locations

10. Exposure dates

Date from **to** Date to

Stock No 7530-66-142-9748 STAFF-IN-CONFIDENCE *(After first entry)* AC 563 - Page 0 of 0

Part 2

11. Work lost time

Total number of days lost	

12. Safety coordinator, advisor or safety manager to complete

Comments	
Signature	Date
Rank or title	Family name
Given name(s)	
PMKeyS ID	Phone number
Email address	

13. Commander or manager to complete

Comments	
Signature	Date
Rank or title	Family name
Given name(s)	
PMKeyS ID	Phone number
Email address	

APPENDIX J: MODIFICATIONS TO OHSCAR CODING

Original OHSCAR Bodily Location Classifications and the Reclassifications for the Current Program of Research

OHSCAR Classifications	Revised Classification
Cranium Eye	Head
Neck and Shoulder Neck bones, muscles, tendons Neck and trunk Shoulder	Neck and shoulder
Chest Upper back	Upper Torso
Upper limb-multiple locations Upper limb-unspecified	Upper limb
Hand Fingers	Hand
Abdomen Abdomen-other and multiple	Abdomen
Lower back Back-unspecified Back-other and multiple Trunk – multiple locations	Back
Hip	Hip
Lower leg	Lower limb - General Shins Gastroc-Soleus Complex
Lower limb – multiple locations	Lower limb – multiple locations
Upper leg	Thigh
Knee	Knee
Ankle	Ankle
Foot Toes	Foot
Other specific multiple locations	Multiple
Trunk and limbs	Back/Lower Limb
Circulatory system Digestive system Other multiple systemic condition Unspecified systemic condition	Systemic

Original OHSCAR Mechanism of Incidence Classifications and the Reclassifications for the Current Program of Research

OHSCAR Classifications	Revised Classifications
Being hit by moving objects Hitting stationary objects	Contact with moving or stationary object
Being trapped between stationary and moving object	Being trapped between stationary and moving object
Exposure to environmental heat	Exposure to environmental heat
Falls from a height Falls on the same level	Fall
Muscular stress while handling objects other than Muscular stress while lifting carrying or putting Muscular stress with no objects being handled	Muscular stress while lifting carrying or putting
Other and multiple mechanisms of injury	Other and multiple mechanisms of injury
Rubbing and chafing	Rubbing and chafing
Stepping kneeling or sitting on objects	Stepping kneeling or sitting on objects
Unspecified mechanisms of injury	Unspecified mechanisms of injury

APPENDIX K: PHYSICAL TRAINING CLASS DESCRIPTORS

Endurance Marching

Endurance marching can be conducted as part of field training (e.g. an ‘administration move’) or physical training (PT). PT sessions typically involve marching a given distance or for a given duration wearing either Patrol Order, Marching Order or a derivative thereof (e.g. webbing, running shoes, and a rugby jumper). Weapons or mock weapons and other stores (e.g. ammunition boxes, ropes, stretchers, etc.) may also be carried.

As an example: Marching 5 km in Patrol Order weighing 10 kg carrying a weapon each and two ammunition boxes per section (group of 10) at a speed of 5.5 km/h along the road.

Lift and Carry

Lift and Carry sessions can be lifestyle (lifting boxes) or military (lifting artillery shells) in focus. Weights lifted are classified as ‘dead’ (e.g. inanimate objects like a box) or ‘live’ (e.g. a person), with formal classes typically including both types of weight. Loads may be lifted and carried by individuals, two persons, or larger groups.

As an example: Lift 1: Lift an artillery shell onto the shoulder and walk 10m before lowering the shell back onto the ground, repeat 5 times. Lift 2: Using a two-person lift, lift an ‘injured’ soldier and carry the soldier 10m, lower the soldier to the ground and rotate positions, then repeat twice.

Obstacle Course

Obstacle courses can be indoor or outdoor. Typically, indoor obstacle courses are built for a temporary period in a gymnasium as a teaching or technique practice tool. Dress for these activities progresses from ‘clean skin’, being shirt, pants and running shoes to Patrol Order. Outdoor obstacle courses are generally longer and more technically challenging, involving ‘wet’ (‘bear pit’) and ‘dry’ (A-frame, rope swing) obstacles. Outdoor obstacle courses can be up to 2 km in length and sessions may be individually focused or progress to using tactical section movements (e.g. stopping after obstacles and setting up defensive positions to protect fellow soldiers as they negotiate the obstacle). Obstacles range in size, shape and construct, with each military base having a different obstacle course layout and overall design.

As an example: Complete the obstacle course dressed in 'clean skin' working as a section team, repeat dressed in Patrol Order, repeat dressed in Patrol Order carrying section weapons (mines, anti-armour weapons, light/heavy machine gun).

'Other' Sessions

'Other' sessions include a variety of different training sessions, while dressed in Patrol Order. Circuit training, rope runs, game form exercises, rope climbing, strength games, all provide examples of sessions that can be conducted while carrying load, due to the dress requirements of the session (for example, rope climbing dressed in Patrol Order as opposed to rope climbing dressed in PT uniform).

'Combination' Sessions

'Combination' sessions can include two or more of the above elements.

As an example: Marching 5 km in Patrol Order weighing 10 kg carrying a weapon at a speed of 5.5 km/h along the road, pick up two ammunition boxes per section at the 4 km point, carry to the obstacle course, complete the obstacle course.