Military Load Carriage:
The effect of increased load, gender and load carriage duration on gait and posture

by

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Abstract

The work presented in this thesis is concerned with the measurement of gait and posture parameters and their variation due to load weight, gender and load carriage duration when carrying military loads. In particular it examines the load carriage system as a whole rather than the backpack alone, which has been the concentration of previous biomechanical load carriage research. The aims of the thesis work were to (1) develop a protocol for examining the effect of the military LCS on gait and posture; (2) investigate the changes in gait and posture parameters in response to load weight, load position, gender and duration of load carriage; and (3) to gain a better understanding of the contributors to good load carriage system design through assessment with end users.

Using Coda™ motion analysis a protocol was developed to investigate gait and posture of a participant by examining changes to lower limb and upper body movement. In order to address aims 2 and 3, the thesis consists of 2 parts. The first part concentrates on short term load carriage. The first trial examined the effect of military boots, indicating restricted ankle movement when wearing such footwear. Three other experimental trials examining the effect of load, gender and load carriage design were also conducted. In the lower limb increased load resulted in increased range of motion of all joints measured. The increase in ankle and femur movement, and decrease in knee movement was greatest for females. However, anthropometric data show that the gender effect could be due to body size alone. The factors studies all altered the range of motion of the lower limb, with increases in range of motion associated with an increased energy cost when carrying loads. Change in the forward lean of the participants was also noted, with greater forward lean as load was increased. Gender differences were seen, with females experiencing a greater range of motion of the trunk than their male counterparts; regardless of body size.

Whilst these issues are important to consider, short term load carriage rarely occurs within Defence tasks. Therefore, the second half of the thesis concentrates on longer duration load carriage. Two experimental trials, one in the laboratory and one in the field, were completed. Longer duration carriage resulted in increased range of motion of the lower limb, greater forward lean, a more forward head position and increased discomfort over time. This increased discomfort was particularly evident in the shoulders and the feet. The work highlights the importance of collecting subjective data as discomfort is often the limiting factor when considering the ability to complete a load carriage task.

Two different load carriage system designs (webbing + backpack) were considered as part of this work. Experimental work examining the effect on short term and long term load carriage is discussed. Two systems were examined, the Standard Issue system (currently in service in the British Army) and a prototype system (Airmesh). The Airmesh design presents a system that includes a hip belt and redistributes some of the load onto the front of the body via vest webbing as opposed to the standard design were the predominant amount of the load is on the back and supported by the shoulders. During short term load carriage minimal change was seen between systems, with the exception of less forward lean when carrying the Airmesh design and less trunk range of motion. When longer duration carriage was examined again a more upright walking posture was noted when carrying the Airmesh system, however greater trunk movement was seen. This may have serious implications for the physiological strain that an individual is placed under during longer term carriage. However, the more upright posture may present a safer option in terms of lower back stress and injury.

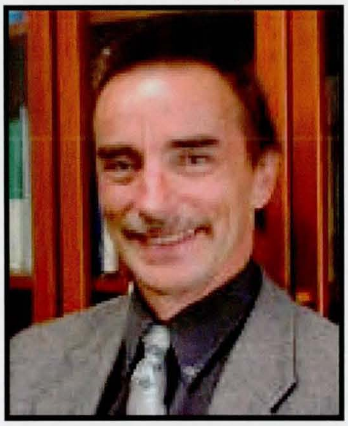
This thesis concludes that a methodology is now in place to examine the changes in gait and posture whilst carrying military loads. The response due to increased load weight, gender, design and increased load carriage duration has also been studied with significant outcomes observed. Concentration in future research should be on including the entire load carriage system and examining the subjective response of individuals as well as important biomechanical and physiological data. This will allow a more complete assessment of the effect military load has on the human body.

Dedication

I would like to dedicate this thesis to my late supervisor Dr Robin Hooper who was taken from us under sudden circumstances in the summer of 2005. It is a credit to him that this thesis even began, let alone was finished. Enrolling was never an idea when I left Australia to travel to the UK, but after starting working with Robin he supported the idea and did everything he could to make it run as smoothly as possible. His enthusiasm for the work made undertaking the task so much easier…and his ability to remove away from it and head to the local for a drink and socialise made it so much more enjoyable.

Some have said Robin was one of life's "good guys", a "genuine nice bloke" and no other words really can be used to describe him. He has been greatly missed, and I hope he is up there with a grin on his face, glass of red in hand, with jazz buzzing in the background, enjoying the fact that the work he was involved in has carried on in his honour.

To Robin……



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In addition to the dedication, I would like to thank my DoR come supervisor Dr Neil Mansfield for his support throughout the whole process and for taking on my supervision in the final stages. Without his help the final product would not have been as it is today.

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Finally to my family and the rest of the crew back down under. Thanks to you for your support, and the understanding as to why I was away for so long.

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Chapter 1 – Introduction

1.1 Introduction

As part of military operations and/or training, members of the British Armed Forces, whether they be Army, Air Force or Navy, are required to carry loads upon the human body using load carriage systems (LCS). Research and design factors associated with such equipment are overseen by the Defence Science and Technology Laboratory (Dstl), part of the Ministry of Defence (MoD). Dstl, formed on 2nd July 2001, was created to ensure the UK Armed Forces and Government were supported by world-class scientific advice. It comprises of the defence laboratories and capabilities that existed previously from the Defence Evaluation and Research Agency (DERA), as well as cooperative research centres set up at selected UK universities.

Loughborough University has been involved in work in this area for the last decade. Previously, work has concentrated on pressure measurements in the shoulder, hip and back regions and the effect of clothing (Martin, 2001), or design changes (Jones, 2005a) in load carriage equipment, may have on these pressures. Measurement of subjective information has also been key in determining the effectiveness of such design changes. As a product of these investigations, human factors requirements for new load carriage system design have been created.

Load carriage is a military necessity. It needs to be as efficient and injury-free as possible. Loads carried include ammunition, food, water, clothing and weaponry and are essential for the survival of military personnel. They may range in weight depending on the environment in which the soldier is working, the exact nature of the mission they are undertaking, and the requirements of each soldier's individual role, and it is not uncommon for a soldier to have to carry a load well in excess of 50% of their own body weight.

The examination of the physiology of load carriage has been well established with many papers and reviews written on the subject (Bhambhani et al., 1997; Datta & Ramanathan, 1971; Harman et al., 1997; Harman et al., 1999b; Kirk & Schneider, 1992; Lloyd & Cooke, 2000b; Martin & Nelson, 1986; Quesada et al., 2000; Vacheron et al., 1999a). Whilst the examination of pressure response gives some insight into ergonomic design factors associated with load carriage, the biomechanical response of the user is also crucial in assessing requirements for design. Previous work in this area has been concentrated in the United States (Harman et al., 1994; Harman et al., 2000a; Holewijn & Lotens, 1992; Johnson et al., 1995; Knapik et al., 1991; Knapik et al., 1997; Martin & Nelson, 1985, 1986) with minimal reported examination of British equipment. Whilst there are some similarities in design of military equipment across the Atlantic, and the world, each country utilises specific load carriage systems (detailed explanation in Chapter 2), which have been developed in tune with the end user's needs and the environments in which they must operate.

As part of the next stage of the ongoing research programme Dstl commissioned an investigation into the effect military loads have on both the gait and posture of an individual. The development of a protocol to measure such variables and examination of response due to load, gender and duration of load carriage forms the basis of this work. The measurement of such data on those with military load carriage experience will provide crucial insight into the body's response to the specific LCS designs that are currently distributed to the serving British defence force.

The outcomes of this research will assist Dstl in reducing the most severe discomfort caused by carrying heavy loads, enhance soldier performance by minimising fatigue caused by load carriage and develop ergonomic specifications for individual items of load carriage equipment. This can only be determined by gaining an understanding of the effect of habitual carriage of heavy loads. This data will then aid Dstl to develop human factors specifications to feed into the next design cycle of military LCSs for inclusion in the FIST (Future Integrated Soldier Technology) programme which is due to be delivered in 2010.

1.2 Research Objectives

The research objectives of this thesis are as follows;

1. To develop a protocol for examination of the effect of the military LCS on gait and posture.
2. To investigate the change in gait and posture in response to alterations in load weight, load position (via use of different LCS designs), gender and duration of load carriage.
3. To gain a better understanding of the contributors to good LCS design through assessment of LCSs with end users.

The intention is to record this data with military personnel in order to represent fully the effect any military training may have on the response to load carriage, and that the loads carried are representative of those that may be experienced as part of military training and operational exercises.

1.3 Structure of the thesis

This thesis consists of 11 chapters, split into two distinct parts. Chapter 2 presents a review of relevant literature in relation to the carriage of load (both military and non-military), the effect of gender; (particularly in the military context); and the reasoning behind this research. Chapter 3 examines the available methods for conducting this work and the development of the protocol in order to make the examination possible. Chapters 4, 5 and 6 report laboratory based studies into the effect of boots, increasing loads, and gender respectively on gait and posture. Chapter 6 also includes an initial investigation into different load carriage system designs.

The duration of load carriage in the initial studies was brief and is not representative of periods that a member of the military may be exposed to both during training or on military exercise. Therefore in part 2 of the thesis longer duration load carriage is examined. Chapter 7 is an in-depth review of the literature relevant to longer duration load carriage and the subjective response of individuals whilst carrying loads. The investigation into carrying loads for longer duration and changes due to different LCS design then follows in Chapter 8 with Chapter 9 examining the discomfort experienced in a similar load carriage task in the field. Chapter 10 presents a final discussion of the research work. Chapter 11 includes an overall summary and conclusions from the thesis work, and finally Chapter 12 contains suggestions for future work in this field.

Chapter 2 – Literature Review

2.1 Introduction

Military operations are complex in nature. They involve the movement of equipment and personnel across varying terrain and environments. The ability to transport food, ammunition, shelter, weapons, water, communication and medical equipment in these situations is crucial for survival. It is often the soldier who has to carry these loads on their person in a LCS. Ergonomic considerations run across a wide variety of areas in the military domain, including the use of vehicles/aircraft as well as the equipment used and carried. The environment in which this equipment is used is highly variable ranging from extremes of temperature and humidity. In these situations the quality deficiencies in equipment are highlighted to a greater extent, and this in itself has the possibility of serious consequences (McCraig & Gooderson, 1986).

The ability to carry loads when only manpower, rather than vehicles or other transport is available, results in the soldier being required to carefully consider the equipment they are carrying. This, at times, may result in the removal of some items (e.g. clothing for specific weather conditions) in order to make room for more ammunition and more food, thus placing the soldier at an increased risk of illness related to the environment. The total weight of the load carried is associated as the main problem during military campaigns, such as the Falklands in 1982 (McCraig & Gooderson, 1986). In this land campaign (25 days) most movement of personnel was on foot due to the difficult terrain encountered and environmental conditions included low temperatures, high winds and heavy rainfall. As a result loads became wet, additional ammunition had to be carried as replenishment of supplies was limited, and fatigue due to weight carried was encountered.

Although there has been a significant reduction in the need to manually transport loads on the body due to changes in technology and mechanisation, in some countries this is still important for labour and economic reasons (Datta & Ramanathan, 1971). A number of techniques of carrying heavy load have been developed throughout history as the need has arisen. These include the Korean A-frame, the milkmaid's yoke, head load carriage, and more recently the load carriage system (Figure 2.1)

Figure 2.1: Modes of load carriage (from L to R): Korean A-frame, yoke, head load carriage and British military LCS

A military load carriage system consists of a combination of several pieces of equipment rather than a backpack alone. This is an important consideration when examining any effect of carrying military loads on the soldier. The majority of previous research has concentrated on examining only the effect of the backpack. A military LCS consists of webbing, and a backpack (or Bergen). In the case of the Army a rifle is also carried in almost all situations. The webbing, when considering standard issue kit, consists of a number of pouches worn on a waist belt that is supported by a harness over the shoulders. This contains all items that are essential for survival and is ALWAYS worn by the soldier during operational or training activities that include load carriage. In such activities the soldier will also ALWAYS be carrying a rifle. In addition to this a Bergen (military term for backpack) is worn in combination. Items carried in the Bergen include those considered non-essential and also some larger items that are unable to be carried in the webbing. During any hostile encounter with the enemy the Bergen will be discarded and soldiers will advance wearing only the webbing and carrying the rifle. It is therefore important to consider all of these items of kit and the effect they have on the body rather than simply the Bergen/backpack alone.

It has been suggested by Legg & Mahanty (1985) that the "optimum method of load carriage should compliment stability, bring the load centre of gravity as close to the body as possible and make use of the larger leg muscles". The backpack is one of several available forms of manual load carriage that is often used by backpackers, hikers, and members of the military. It is seen as an appropriate way to load the body as close to the centre of gravity as possible while maintaining stability (Chansirinukor et al., 2001). When considering the military in particular, marching whilst carrying loads is a substantial component of training and combat. This marching frequently utilises backpacks (+ webbing) loaded with military equipment and these loads often amount to a large percentage of a soldier's body mass. There is a tendency for the mass of the load to increase as advancements in technology require soldiers to carry more equipment for increased firepower, improved communications and better protection (Knapik et al., 1996).

Several reviews have concluded that possible determinants of load carriage ability include age, anthropometry, training, strength, body composition and gender (Haisman, 1988; Knapik et al., 1996). Other relevant determinants include placement of the LCS and its dimensions (Bobet & Norman, 1984; Datta & Ramanathan, 1971; Ghori & Luckwill, 1985; Legg & Mahanty, 1985), biomechanical factors, the terrain and gradient over which the individual is carrying the load (Gordon et al., 1983) and the effect of climate (McCraig & Gooderson, 1986).

2.2 Background

Early work examining the history of military load carriage includes that of Lothian (1922) and Cathcart et al., (1923). In the 19^{th} century military equipment carried by soldiers was stiff, cumbersome, and bore no relation to the climate in which it was to be used. Knapsacks used were rolled onto the back, supported by shoulder straps and later a chest strap, which restricted free breathing once ammunition was added, thus restricting movement and compromising the fighting soldier. As we moved into the 20^{th} century new designs of webbing were introduced (1907/08), with the military load ever increasing as conflicts occurred. New equipment, such as offensive weapons (grenades etc), protective equipment (e.g. helmet, respirator), and clothing required for the mission led to these increases in load. This was thought to impact the ability of the soldier's marching power, possibly alter war tactics and to cause breakdown and injury of those soldiers who were less physically fit. The review by Lothian (1922) demonstrates throughout history there has been a conflict between loading the soldier and the tactical requirements necessary to keep the soldier mobile. This is still of concern today. A soldier's efficiency and health suffers much less from not having items than the stress on the body created by carrying them in the first place (Cathcart et al., 1923). Srivastava et al., (1968) suggests two things that are essential for success in wars: the ability to undertake marches without loosing men, and the ability of these soldiers to engage in combat once they reach their desired destination.

The increases in loads carried by soldiers as technology has developed are indicated in Figure 2.2. It was not until the Crimean War from 1854-1856 that loads began to exceed 20kg. Following this there has been a steady increase to the very heavy loads that are carried by soldiers today. Actions to reduce the stress on the soldier have included developing specialised LCSs and attempting to determine an acceptable soldier load based on the physical ability of the soldier and the operational requirements. Moving into the present day, in 1987 the U.S. Army development and employment agency proposed a number of new approaches for improving soldier mobility. These included making technical components lighter in weight; using a computer programme to model a soldier's load based on mission, enemy, terrain, troops and time; developing specialised equipment to carry loads; re-evaluating the current load carriage doctrine; and concentrating on the soldiers themselves by developing physical training programmes to increase physical capability. Similar proposals are currently being undertaken within the British Armed forces through the development of their FIST programme. This is a tri-service project aiming to provide the British Armed forces with an integrated fighting system for dismounted, close combat troops. It is envisaged that the initial operating capability will take place in 2009 with a target of 2015-2020 being placed on all soldiers being supplied with this new equipment. Work leading up to this involves testing of new equipment if and when it becomes available, specifically with the intended end users.

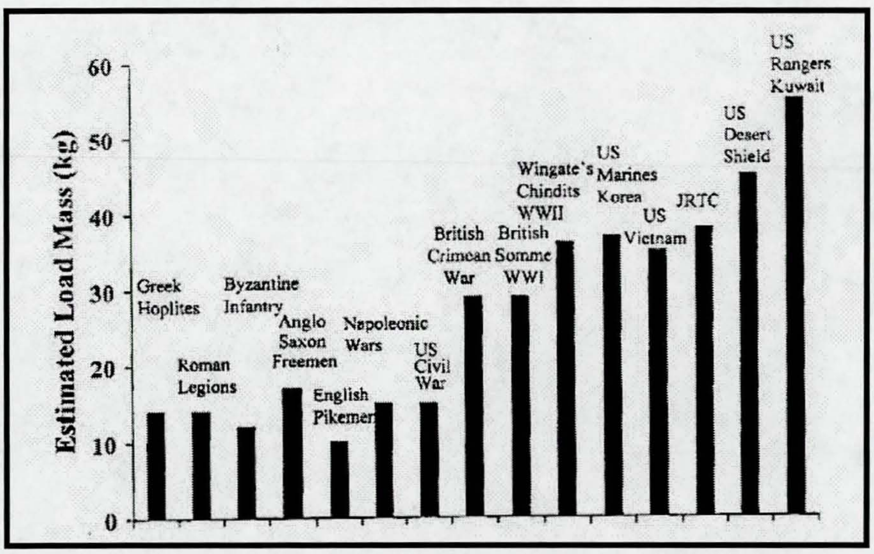


Figure 2.2: Loads carried by infantry units throughout history (Knapik et al., 2004)

The current British LCS, as mentioned previously, is a combination of webbing and a backpack (Bergen). The design of this combination has neglected to take into account several ergonomic factors which may place strain on the individual. Whilst the standard issue webbing is useful in housing ammunition, food etc and being located near the body's centre of mass (although predominantly on the back), its design means the webbing rests on the hips, supported by a yoke over the shoulders. Therefore when a backpack is worn in combination (i.e. total LCS) there is no ability to utilise a hip belt on the backpack (such as is the case in commercial backpack design). As a result these heavy loads that soldiers are required to carry as part of infantry missions (approximately 50-100% bodyweight) are solely supported on the shoulders. At present a typical backpack/Bergen contains a single large central compartment which in turn forces the weight of the load to position itself at the bottom of the pack (Jacobson et al., 2003), therefore as far away from the load bearing structure as possible. Knapik et al., (2004) suggests that in order to improve soldier mobility, equipment modifications should be concentrating on redistributing the load closer to the centre of mass (i.e. around the hips). This area is also the natural weight bearing position on the body. Therefore it is logical to suggest that the development of a LCS that redistributes weight to the hips, but still allows the soldier to complete their operations successfully would be beneficial.

In the past, emphasis has been placed on determining the correct clothing, sustenance and firepower capabilities of the soldier. Less attention has been given to the development of a LCS that will meet and assist the soldier in completing their mission. Importance has been placed on individual pieces of equipment, rather than the integration of the system as a whole. Jones (2005a) was the first to consider the LCS as a whole from a perspective of pressure and comfort. The focus of this work lies in assessing the biomechanical response of the individual to carrying the current issue equipment (as a system), and the possible changes that may occur as a result of development of a new prototype LCS. Previously work of this nature (i.e. biomechanics) has been concentrated in the United States and has only examined the effect of carrying the backpack alone. There are no biomechanical studies that have looked specifically at carrying the LCS as a whole, and in particular examining the equipment used by the British Armed Forces.

2.3 Physiological response to load carriage

Physiological aspects of load carriage have been a focus of previous research (Bhambhani et al., 1997; Datta & Ramanathan, 1971; Harman et al., 1997; Harman et al., 1999b; Kirk & Schneider, 1992; Lloyd & Cooke, 2000b; Martin & Nelson, 1986; Quesada et al., 2000; Vacheron et al., 1999a). These studies have predominantly concentrated on the effect of load carriage on energy cost, but have also examined the effects on speed and training. In most cases the experimental conditions have included treadmill walking with data from the expired air analysis, heart rate and perceived exertion being collected.

2.3.1 Energy cost

When considering energy cost, location of load and load mass have been shown to have significant effects on the body. The position of the load relative to the body's centre of mass (COM) is a key factor with loads placed closer to the COM resulting in lower energy cost and the individual becoming more economical (Harman et al., 1997; Martin & Nelson, 1986; Vacheron et al., 1999a). As early as 1969 Soule and Goldman examined the effect of different load positions on energy cost. Using loads on the head, hands and feet it was noted carrying loads on the head is the most economical, with large loads on the feet (6kg each) being the least. This increased efficiency would therefore serve to explain why many cultures still use head load carriage as a means of transport in the current day. However, there are limitations to the amount of load that may be carried due to the musculature supporting the head and its ability to tolerate load. Conversely the removal of the load from the body's COM to the extremities of the feet results in greater energy cost (Soule & Goldman, 1969).

In regards to positioning within a LCS, Stuempfle et al., (2004) notes significantly lower oxygen consumption with a high placed load than a low placed load (25% body weight (BW) on untrained individuals). Participants also rated the load in the high position easier to carry. Examination of backpack loads compared to double packs (front pack and backpack) also produce alterations in energy cost (Datta &

Ramanathan, 1971; Legg & Mahanty, 1985). A smaller energy cost is seen when carrying a load in a double pack. Although advantageous in energy cost double packs have been shown to restrict ventilation, increase body temperature and possibly cause decreases in performance of military tasks such as firing weapons, especially when in a prone position. Soldiers have also complained of interference to natural arm movements due to the front pack oscillating during movement (Johnson et al., 1995).

Legg and Mahanty (1985) state "the optimum method of load carriage should complement stability, bring the load centre of gravity as close to the body as possible and make use of the larger leg muscles". This task of load carrying encompasses a variety of muscle groups which rely on both oxidative and glycolytic pathways as an energy source. The large muscle groups of the legs work predominantly at a sub maximal level whilst specific muscles such as hip extensors and trunk extensors are recruited as a result of carrying a backpack. These muscles perform isometric contractions and are therefore more prone to fatigue during a load carriage exercise (Warber et al., 2000).

As load mass increases energy cost also increases in a systematic (linear) manner. Gordon et al., (1983) indicated this load increase is equivalent to an increase in body weight, hence having the same proportional metabolic effect. Yu and Lu (1990) examined the effect of five load conditions ranging from 0-30kg during an experimental march of 10 hours. The load was carried both on the waist (50%) and on the back in a rucksack (50%). Heart rates were significantly different for the men carrying the 20kg as opposed to the 25kg load and during the 25kg load the food energy balance was negative. Harman et al., (2000b) also found a significant difference in energy cost when load was increased from 17kg to 30kg to 43kg. When compared to loads of 20kg and 25kg, loads of 30kg have also been shown to decrease the ability for an individual to do work (Shoenfeld et al., 1977). It was thought that this decrease (due to a decrease in VO_2max) was mostly dependant on the absolute weight of the load carried, as results indicated no effect of subject weight or load percentage to body weight.

Perceived exertion rates have also been examined whilst carrying loads, however they do not follow the same proportional increase as central metabolic factors. Goslin & Rorke (1986) report an increase from 0% to 20% BW load resulted in a 1.5 to 2 times increase in response in comparison to the central physiological response. However when this load was then increased to 40% there was little further effect, suggesting a saturation point had been reached. Other factors result in increases in energy cost such as increased velocity, increase in grade and increase in difficulty of the type of terrain (Gordon et al., 1983; Harman et al., 2000b; Lloyd & Cooke, 2000b).

2.3.2 Speed and training

When considering how rapidly a task can be completed whilst carrying a load, the anaerobic and aerobic fitness of an individual is an important factor. Studies by Knapik et al. (1990 quoted in Knapik et al.,(1996)) have shown that individuals with more fat free mass (assumed as muscle mass) can perform tasks whilst carrying a load more rapidly than those with a greater fat mass. Training whilst carrying loads can also improve aerobic fitness and, as a consequence, improve load carrying capability. Loads carried by Australian military recruits during an 11-week training program also resulted in an increase in fitness of the recruits when compared to initial performance tests (Rudzki, 1989).

2.4 Pressure at the LCS interface

Previous work conducted at Loughborough University has concentrated on examining interface pressure whilst carrying British military LCSs (Jones, 2005a; Martin, 2001). This follows on from work conducted in Canada by the Ergonomics Research Group at Queens University making measurements using a load carriage simulator (Bryant et al., 1996; Doan et al., 1998a; Doan et al., 1998b; Johnson et al., 1998). This simulator utilised a 50th percentile mannequin covered in a skin-like material oscillating vertically to simulate normal human movement. Main findings were when load is split between the front and back of the body as opposed to backpack alone the pressure at the interface is reduced (Johnson et al., 1998) and all pressures measured were in excess of the recommended 14kPa for continued contact with the skin (Stevenson et al., 1995). Whilst these studies begin to examine pressure at the LCS interface, conduction of trials using a mannequin rather than a real end-user may impact on the results obtained.

Initial work by Martin (2001) developed a protocol by which to measure on-body interface pressures whilst carrying military backpacks. When combined with subjective comfort measures, this allowed collection of data sensitive to changes in military backpack design. In order to increase the comfort experienced by the end users, further investigation into shoulder strap materials took place. Of the 7 materials investigated the least effective (in terms of pressure experienced at the shoulder and subjective discomfort) was that of the standard issue British military backpack at that time. Whilst this work by Martin gave new insight into pressure when carrying military loads, once again it did not consider the military LCS as a whole, therefore not representing a true military load carriage scenario. This work was also conducted on civilians in a laboratory environment.

To take this work further Jones (2005a) developed an in-field pressure measurement system to assess pressure at the body-LCS interfaces (shoulders and hips) and compared LCS designs with participants from British military units. This allowed trials to be carried out in a realistic military setting including the carrying of loads over different terrain and in different load carriage configurations. Clothing layers (even when worn in multiple) were shown to have no impact on the pressure experienced (Jones & Hooper, 2005b), indicating strap design on the LCS was more important in terms of alleviating the high pressures experienced. This doctoral work by Jones also highlights the need for continued measurement of subjective data in order to distinguish between LCS designs.

2.5 Biomechanical response to load carriage

Of primary interest to this thesis is the change in biomechanics of an individual due to carrying military loads. In particular any alterations in posture and stability whilst carrying these loads could have implications for future equipment design. Although research has been predominantly centred on physiological factors in this field, progress has been made in the area of biomechanics. Studies have been concentrated on hikers/backpackers (Bloom & Woodhull-McNeal, 1987; Cook & Neumann, 1987; Ghori & Luckwill, 1985; Lloyd & Cooke, 2000a), military personnel (Harman et al., 1994; Harman et al., 2000a; Holewijn & Lotens, 1992a; Johnson et al., 1995; Knapik et al., 1991; Knapik et al., 1997; Martin & Nelson, 1985, 1986; Tilbury-Davis & Hooper, 1999), and school children (Chansirinukor et al., 2001; Merati et al., 2001; Pascoe et al., 1997; Wang et al., 2001; Whittfield et al., 2001). These investigations include the examination of muscle group activity using EMG analysis, kinematic (angular) analysis and kinetic analysis using force plate data.

2.5.1 Muscle group activity

Analysis of electromyography (EMG) data during load carriage has concentrated on musculature located on the trunk and close to the point of contact of backpack loads. Studies on the erector spinae muscle group show conflicting results which seem to suggest a critical load which, once reached, results in an increase in erector spinae activity, but prior to this there is little change or in fact a decrease in activity. Similar EMG values are found for loads of 6kg, 20kg and 33kg, but almost doubled for a load of 47kg (Harman et al., 1992). However, increases from 10% to 20% BW loads show a non-significant decrease in EMG activity (Cook & Neumann, 1987) as do comparisons between loads of 19.5kg when compared to a non loaded condition (Bobet & Norman, 1984).

Trapezius muscle activity is also important for the support of loads being carried on the body. Rather than being load dependant, the position of the load is more important here. Therefore, depending on the protocol of the experimental work, differing responses have been reported in the literature. Harman et al., (1992) noted no significant change when examining EMG of trapezius muscles with loads up to 47kg. Bobet & Norman (1984) however noted a slight decrease in muscle activity when the load was placed on the mid back region, but once the load was placed high on the back there was an increase in activity.

The main support to carrying loads is provided by the larger muscle groups of the lower limb. The quadriceps muscle group generates greater activation during load carriage in order to facilitate movement during marching (Quesada et al., 2000). Harman et al., (1992) supports these findings with a significant increase in both the quadriceps and the gastrocnemius muscle group activity during load carriage with no resulting significant change in the activity of other major leg muscle groups (including hamstrings and tibialis anterior).

2.5.2 Body posture

One mechanical aspect of load carriage that has been consistently observed in the scientific literature is an increased forward lean when carrying loads on the posterior aspect of the trunk. Differing methods of measuring trunk angle have always resulted in the same conclusion, with increases in load exacerbating these results (Filaire et al., 2001; Goh et al., 1998; Harman et al., 1994; Harman et al., 2000a; Kinoshita, 1985; Martin & Nelson, 1986; Pascoe et al., 1997). An example of these results is indicated in figure 2.3 below (decrease in trunk angle indicates greater forward lean). Studies that have examined the effect of loads on school children (Chansirinukor et al., 2001; Hong & Cheung, 2003; Pascoe et al., 1997) have also linked an increase in forward head tilt to the increase in forward lean, which is associated with significantly increased loads on C6 vertebrae and decrease in stature (Bonney & Corlett, 2002).

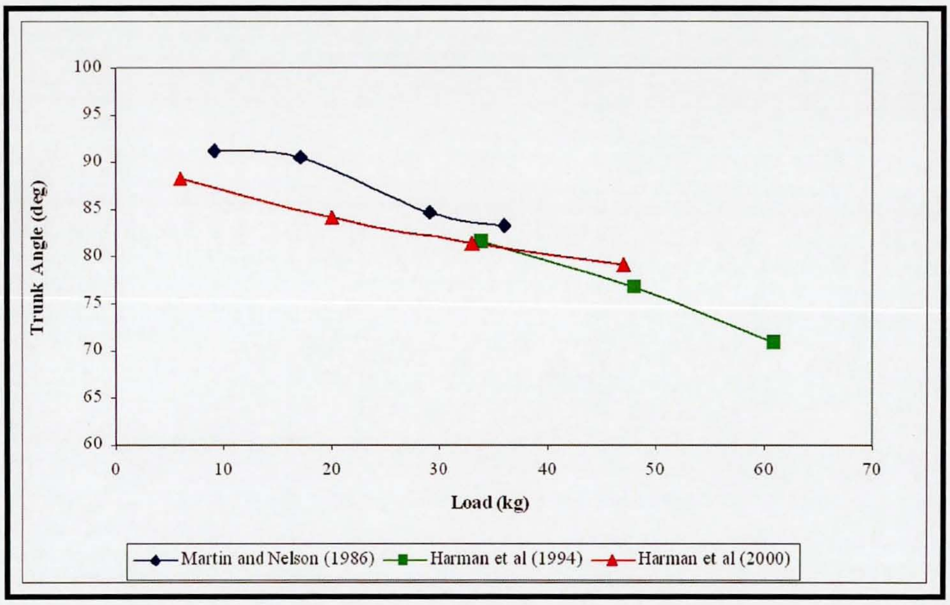


Figure 2.3: Trunk angle as a function of load (Harman et al., 1994; Harman et al., 2000a; Martin & Nelson, 1986)

The methodologies of the studies shown above (figure 2.3) fail to examine more than one walking trial, which has been deemed the "best" data for each participant. Whilst this method is effective in reducing the time required to collect experimental data, it is questionable as to whether a true representation of a participant's walking gait has been collected. Data from Kinoshita (1985) examines the mean of 3 trials of kinematic data, which improves on this US Army data, but may still not fully represent a true response due to the variability in walking gait. These methodological questions will be further addressed in Chapter 3.

Positioning of the load and the type of backpack also influence forward lean. Loads placed posteriorly result in the greatest change to forward lean. In contrast a double pack system results in positions that are more similar to those of normal (unladen) walking, suggesting this type of loading is more beneficial (Kinoshita, 1985). However, as mentioned previously there are several detrimental factors associated with having the front of the body covered by a load (section 2.3.1). External or internal frame backpacks also elicit different responses, although it is possible that these may be attributed to a change in the position of the COM of the load rather than the pack itself (Bloom & Woodhull-McNeal, 1987; Kirk & Schneider, 1992).

2.5.3 Load positioning

In terms of load position there has been a school of thought since 1869 that for the greatest stability and efficiency the load should be kept as close to the body's COM as possible and that it should not exceed 1/3 body weight (McCraig & Gooderson, 1986). Deviations from the body's COM may result in increased energy cost and changes to biomechanical response. When examining different letter carrying satchels in the US Postal system Joe Lin et al., (1996) concluded that load supported by two straps and using a waist belt that was symmetrically loaded placed the lowest compressive force on the lower spine, resulted in lower postural deviation and pressure on the shoulders, and led to a more even spread of force over the foot. Asymmetrical loads were not received as well and resulted in unfavourable changes in these parameters. Symmetrical loading is important for all types of load carriage systems, especially when the shoulders are being used as the primary load bearing structure.

Examination of external and internal frame backpacks has indicated similar energy cost for walking speeds of $1.3\text{-}1.7 m.s^{-1}$ (Harman et al., 2000b; Kirk & Schneider, 1992). An internal frame pack, used with its hip belt, results in the best load carriage economy and obstacle course time, whereas the external frame pack results in a faster time to move from prone to standing (Harman et al., 1997; Harman et al., 2000b), which may be an important consideration in the military context. When examining the biomechanical perspective trends indicated that wearing an internal frame pack tended to invoke a greater forward lean. The internal frame pack was also found to change the stance of participants more than the external pack (Bloom & Woodhull-McNeal, 1987). These results suggest that during a static situation an external frame pack would be more advantageous. However, the lower position of centre of gravity with the internal pack would be an advantage in a dynamic situation both in terms of stability and because it results in a lower moment of inertia.

Preference for pack type also follows no strict pattern. Female military personnel had no significant preferences for pack type (Kirk & Schneider, 1992). Differences in these preferences may have been due to subject population (hikers as opposed to military personnel) and tasks performed (standing still as opposed to walking on a treadmill). In contrast the study by Bloom & Woodhull-McNeal showed significant gender differences with 90% of males preferring an internal frame pack and 80% of women an external frame.

Placement of load in a backpack determines the COM of the pack and, as discussed above, this can have a significant effect on the physiological and biomechanical aspects of load carriage. When investigating task performance, situations where the body must be displaced are affected by load positioning. Loads high on the back produce a significantly better performance in an 80m dash when compared to loads low on the back. However this same high load results in the highest loss of performance on a mobility task (Holewijn & Lotens, 1992a). Individual body type also influences the response to load positioning. A taller individual with a load placed high on the back results in greater loss of stability than for someone shorter due to the already high centre of gravity of the taller person (Hellebrandt et al., 1944). Strain on the foot has also been shown to be greater when the pack is carried too low.

2.5.4 Spatiotemporal parameters of gait

Alterations in spatiotemporal parameters of gait (stride length (SL), stride frequency (SF), stance time and speed) are commonly reported in investigations examining load carriage. In order to provide the body with an improvement in stability as load is added SL is generally seen to decrease and stance time to increase, resulting in a longer double support phase of gait. Whether self selected or set pacing is used impacts such results. To maintain a set pace any decrease in SL will force an increase in SF, however when self selected pace is used this is not readily observed (Charteris, 1998; Harman et al., 1992; LaFiandra et al., 2003). Another explanation for the decrease in SL and increase in SF when carrying loads at a set speed is the resultant decreased pelvic rotation due to the position of the load (LaFiandra et al., 2003).

Ghori & Luckwill (1985) demonstrated that increases in load from 10% to 50% BW (by 10% increments) resulted in no significant change in stance duration (foot on ground), but a significant decrease in swing duration (foot in the air). It is thought that as the backpack load in this study was placed high on the back, it resulted in a greater shift in the body's centre of gravity, making the body more unstable. The body compensates for this by delaying toe off allowing a greater percent of the step cycle to be in double support. These results have been mirrored by several investigations under different load conditions (Kinoshita, 1985; Lloyd & Cooke, 2000a; Martin & Nelson, 1986; Wang et al., 2001).

Variation in speed whilst carrying load produces changes in spatiotemporal parameters as well. As speed increases, the stride time, percentage of double support time and percentage of stride at toe off all decrease significantly. Consequently a significant increase in SL and SF is seen when examining speeds of 1.1, 1.3, and 1.5 $m.s^{-1}$ (Harman et al., 2000b). Interestingly, when examining an unloaded treadmill walk between speeds of 3-8 $km.h^{-1}$ similar responses are seen (Charteris, 1998). These adaptations are detrimental to the individual as they reduce the period of greatest stability (i.e. when the whole plantar surface of the foot is in contact with the ground).

The experience of the individual in completing a load carriage task may also play a role in the change in stride rate with load (Vacheron et al., 1999a). When comparing experienced and novice hikers, those that were experienced increased stride rate nearly linearly as load increased (10kg, 15kg and 20kg), but novice hikers changed stride rate very little. The increase in stance phase per second indicates that expert hikers are more sensitive to load increases than their novice counterparts, an important result when considering participant selection for experimental work.

2.5.5 Ground reaction forces

Ground reaction forces (GRF) may be split into three components; F_x, F_y and F_z. F_x affects lateral sway, F_z vertical sway and F_y the propulsion of the body. It has been shown that as speed increases the variability of F_x and F_z increases. F_y however has variability that is speed dependent with what is associated with a "normal" walking speed being the speed at which this force has the lowest variability (Masani et al., 2002). Therefore there is an optimum speed for propulsion, but as speed increases the stability of the body decreases due to increased sway. One would only assume the system becomes even more unstable with the addition of an external load.

Several investigations have indicated that with an increase in load the force exerted by the feet on the ground increases in downward, forward, rearward and lateral directions (Harman et al., 2000a; Kinoshita, 1985; Knapik et al., 1992; Lloyd & Cooke, 2000a). Differing opinions exist as to whether this increase is relative to the weight of the load applied. Upon examining the difference between military backpack loads (20kg and 40kg), Tilbury-Davis & Hooper (1999) found that for trained subjects, increasing load raised GRFs in proportion to the total mass (body mass + mass of carried load). This work is further supported by that of Birrell & Hooper (2005a) who examined incremental loads (8kg) between 8kg and 40kg on experienced load carriers. For loads of 20% and 40% body weight, increases in maximum braking and propulsive forces and impulses were found to all nearly be proportional to increases in the system weight (Kinoshita & Bates, 1983). Contrary to these findings Harman et al., (1992) reported that vertical forces did not increase proportionately to total load for the heaviest load when examining loads of 6kg, 20kg, 33kg and 47kg. It was suggested this was some sort of protective adjustment by the body to prevent injury.

Changes in forces experienced by the body (not just underfoot) are affected by load carriage as well. Increases of load from 0% to 15% to 30% BW result in a significant increase in peak lumbosacral forces (Goh et al., 1998). The component breakdown of these forces suggested that shear forces were on average lower than compression forces. The increase in these forces is also not proportional to the increase in backpack load. It is thought that an increase in forward lean could also have an effect on the propulsive and braking forces that are experienced during load carriage. This is due to a change in the momentum of the upper body, however further study into the links between these factors is recommended (Lloyd & Cooke, 2000a).

2.6 Maximum load carrying capacity

The maximum load carrying capacity of a soldier is reliant on factors such as physical fitness, load carriage experience and body size. Attempting to determine a load limit has been a concentration of researchers for many years, and the problem of overloading the soldier continues to remain as an issue today. Military campaigns in the past have encountered problems with load weight due to environmental factors. In World War I it was not uncommon for a soldier's load to increase from 60% to 75% BW due to clothing and equipment becoming saturated and covered in mud (Cathcart et al., 1923). Development of materials over time has reduced this problem, most current military equipment being water resistant. However, due to increases in technology (e.g. firepower and communication), load is continuing to increase. Addition of this new technology is not compensated by removal of other items (such as essential food and water), resulting in new issues related to the maximum load that must be carried.

Instructions detailing loads to be carried on exercise/operations are specified prior to commencement. In comparison to the civilian paradigm (where requirements on load carriage are rarely imposed), military loads are mission specific. However, decisions regarding the inclusion of equipment in such loads by individual members of military personnel are often inconsistent with instructions given. Items of survival equipment, extra clothing etc. are habitually left behind in order to carry extra ammunition or communication tools.

Following the Falklands campaign in 1982 McCraig & Gooderson (1986) conducted group interviews with 800 soldiers. The main problem cited associated with load carriage was the total weight carried. During this campaign the average load (50kg) would have been the equivalent to 70% BW of a 50th percentile infantryman. Research into the ability to carry load has concentrated on the examination of aerobic capacity of individuals (i.e. $V0_2max$). From this work over the last century theoretical load maxima have been identified. Early work by Lothian (1922) and Cathcart et al., (1923) suggest desirable loads of 33% and 40% BW respectively. Lothian also suggests a desired maximum of 45% BW. Hughes & Goldman (1970) propose maximum efficiency is obtained when walking at a comfortable speed (~ $5km.h^{-1}$) carrying loads of 40%-50% BW (approx 30kg-40kg), whereas Schoenfeld et al., (1977) conclude loads of 25kg are desirable for sustained activity (20km march). Therefore a load between the range of 33%-50% BW is desirable depending on the characteristics of the mission being completed.

As mentioned above, putting load limits into practice presents difficulty. A trade off always exists between the load that may be physically carried as opposed to that which is operationally essential (Haisman, 1988). Knapik et al., (2004) suggests modifications to equipment should focus on redistributing weight around the COM of the body and commanders should make realistic decisions about the risks associated with load carriage, only taking necessary equipment on missions. Load reductions may also occur by making loads operation specific and utilising specific load handling devices. These load carriage devices include the development of LCSs which ease the burden of the load on the soldier. It must be remembered; "the fighting value of a soldier is in inverse proportion to the load he carries" (Cathcart et al., 1923).

2.7 Gender differences in response to load carriage

In 1997 an announcement was made by the then Secretary of State for Defence that there would be an extension of employment opportunities for women within the British Armed Forces. As a result since early 1998 women have been able to serve in 73% of Naval posts, 70% of Army posts and 96% of RAF posts. At the same time as this announcement a study was commissioned to examine the suitability of women in close combat roles for which the results were released in May 2002 (MOD, 2002). The current restrictions do not allow women to be members of the Royal Marines General Service, Household Cavalry and Royal Armoured Corps, Infantry and Royal Air Force Regiment. A number of reasons were reported for this decision including physiological and psychological issues that women must overcome. As a result the restriction on women performing in these roles was upheld. One of the issues at the forefront of performing these close combat roles was load carriage.

Current published literature examining the differences between males and females when carrying load is somewhat limited. Two review papers that consider load carriage as a whole refer only to a few examples of gender based load carriage studies that have been conducted (Haisman, 1988; Knapik et al., 1996). They note the main factors that influence load carriage in reference to gender are body weight, VO_2max, muscle strength and changes in stride length and frequency. In all cases females were placed at a disadvantage when compared to males.

2.7.1 Physiological response

The amount of physiological research conducted on females carrying loads is much less than that conducted on males and few comparisons of gender with relation to military loads are present in the literature. Pandorf et al., (2000) examined the effects of 3 different military loads on time to complete 3.2km. This research was bought about by reasoning that in the army a unit's speed is limited by the speed of its slowest member. Women were chosen for this study for two reasons:

1. During basic training, all female recruits currently participate in load carriage marches and other combat manoeuvres;
2. Women have been well integrated into combat support military occupational specialities (jobs) and could easily become involved in combat if front lines shift or the enemy infiltrates behind enemy lines.

Twelve female soldiers (predominantly military police) were tested under 3 load conditions: fighting load (14.2kg), approach load (27.2kg) and sustainment load (40.6kg), all using external frame army backpacks as supplied by U.S. Army. Participants completed at maximal speed a 3.2km course 6 times, 2 times at each load. Performance was highly correlated with absolute VO_2max and the 3.2km run time in the Army fitness test. With the 41kg load greater body size was associated with faster course time and suggests that larger subjects with greater muscle mass were able to carry the heavier load faster (related to % BW). No correlation between males and females was examined here, although considering body size differences between males and females it would be assumed that males who were larger would have faster course times.

A similar study comparing genders during load carriage was commissioned in South Africa due to a dramatic shift in the demographics of military personnel (Scott & Ramabhai, 2000). Participants (10 male and 10 female) completed a 3-hour march over 12km at $4km.h^{-1}$ carrying a fully loaded backpack with either absolute load of 40kg or a relative load of 37% BW. Results indicated that females had a body fat percentage almost double that of males (26% compared to 12.4%), experienced higher heart rates under both loads than males (27% greater when carrying absolute load, 24% when carrying relative load) and had RPE (rating of perceived exertion) ratings closely following cardiac responses for the first two hours. Although heart rate responses dropped in the third hour RPE values continued to rise, with females experiencing more stress. The study concluded that soldiers should carry loads relative to their body weight, taking into account the fat mass being carried by the individual. In the military situation however it would be impractical to determine soldiers' loads based on their bodyweight. Rather this determination is based on the requirements of the training or operation.

Bhambhani & Maikala (2000) examined the effect of bilateral load carriage on physiological determinants of load carriage. Absolute oxygen uptake during both load carriage tasks (15kg and 20kg) was higher in males, although when body size was taken into account this response due to gender was no longer seen. When oxygen uptake was expressed as a percentage of VO_2max however it was shown that women were working at a significantly higher percentage during both load carriage tasks. There was also a tendency for women to have higher RPE values during this time.

2.7.2 Biomechanical response

The consideration of kinematic variables is important in examining the gender divide whilst load carrying. There have been a limited number of studies comparing gender with the response to military load carriage, others concentrating on general backpack loads. There are however differences noted between genders during normal walking without the addition of load.

In the case of the military, Martin & Nelson (1986) examined the effect of five different load conditions on a participant base of 11 males and 11 females (Army Reserve Officers). Women in this investigation had a significantly smaller stride length at all loads than men, and also showed a small but consistent decrease as load was increased (not observed for the male counterparts). Factors contributing to this included anthropometrical measures such as leg length and stature. As a set pace was used in this investigation the stride frequency for the females was required to be higher to maintain the same pace (due to anthropometric differences). Females also had a greater double support phase as load increased and as a consequence a smaller single leg contact time. No significant gender effect was found for trunk angle.

Martin & Nelson (1982a) also found differences in the walking and running kinematics between genders during 26kg load carriage. Whilst walking on a treadmill at 4.8km.h^{-1} females exhibited smaller stride lengths and consequently greater stride rates, suggesting females have to generate a greater number of step cycles over a given distance, resulting in higher energy expenditure. This may also have implications for injury due to the high forces being experienced by the lower limb. There was no difference seen in running kinematics, although as a large number of females in this study were unable to complete the five-minute run on the treadmill (8km.h^{-1}) a three minute run was completed instead, highlighting the lower physical capabilities of the female participants.

Many other studies have examined gender differences in the biomechanics of walking and/or running without external load being added to the body. Kerrigan et al., (1998) investigated gender differences in walking between 50 males and 49 females. Women were generally noted to walk with higher cadences and have slightly smaller stride lengths, although when normalised for height tend to have the same or slightly longer stride lengths. No significant gender differences in standing values were noted about the hip, knee or ankle in the study by Kerrigan. With the exception of some differences in peak values, similar basic patterns were seen between males and females when walking. Females exhibited greater peak hip flexion and less knee extension before initial contact. Kinetically females exhibited greater knee flexion moment in pre swing and greater peak knee absorption, and had a trend towards greater peak knee flexion, ankle plantar flexion, hip power generation in loading response, knee extension moment at initial contact and greater ankle power generation in pre-swing. Overall it was concluded by Kerrigan and colleagues that there are more similarities than differences between genders when walking.

Bhambhani & Singh (1985) found no significant difference between selected walking speeds between genders, however females had a significantly higher stride frequency and shorter stride length, presumably due to leg length differences. No differences were seen in vertical body displacement between sexes and no differences were seen in gross energy expenditure at walking speed, which is in agreement with other findings at self-selected speed but not with findings when speed is controlled. Nigg et al., (1994) also found no differences between males (n = 60) and females (n = 58) when walking barefoot at a controlled speed of $1.25 m.s^{-1}$.

Whilst running women tend to be in slightly greater hip flexion and produce a greater extensor moment throughout most of stance but exhibit similar knee joint moment, power and angular patterns to men (Ferber et al., 2003). They also demonstrate significantly greater peak hip adduction, greater hip adduction throughout stance and internal rotation of the hip. The information in this study is backed up by another study of running (and other athletic tasks) by Malinzak et al., (2001). Females were shown to have decreased knee flexion angles, increased knee valgus angles and a differing EMG response to running than males with the quadriceps muscles being more activated and the hamstring muscles less activated. These differences may be attributed to anatomical, physiological and motor control differences between males and females including differences in lower limb alignment, quadriceps muscle angle (Q-angle) and muscle flexibility.

When considering all of these studies there are a number of similarities in the results. In general stride length in females is shorter and this is mainly due to leg length differences. Coupled with this is an increased stride frequency during set paced activities in order for females to keep up. This has implications for injury, particularly when considering stress fractures. Differences are also seen in a number of kinetic variables, particularly around the hip and knee. What implications this has for the ability to carry military loads is yet to be investigated.

2.7.3 Body postural response

As mentioned in section 2.5.2 in order to compensate for carrying a load externally on the body, changes in posture are often observed. There is a lack of information on dynamic posture, the effect of military loads and differences between the sexes. When considering women independently, Ling et al. (2000) state that appropriate leg and trunk muscle strength appear to be critical for women to function on jobs that require carrying loads and walking. Carrying loads of 10kg in different configurations resulted in the most trunk flexion when carrying loads on the back, whereas when loads were around the waist, angles were similar to those in a baseline condition. Shoulder girdle muscle strength was positively correlated with trunk angle when load was carried over the shoulder and on the back. Given the anatomical differences between men and women in particular with reference to muscle mass this finding would suggest that men are more suitably built to carry loads over the shoulder and on the back. In military terms greater loads must be carried and therefore are predominantly placed on the back. Martin et al., (1982a) examined static posture whilst carrying 4 different frame length packs. No differences between males or females when carrying a 26kg load were seen in any condition. The time for testing however was only 4 minutes and it is possible that this could change over time due to factors such as fatigue.

At present there is a dearth of information surrounding dynamic measurement of such postures and also what occurs when loads are being carried. Raine & Twomey (1997) have conducted static posture measurements, although in this case no load was carried on the body. Poor posture and alignment is considered when the head is held forward in relation to the trunk or when the shoulders are slouched forward. A forward head position has also been linked to musculoskeletal dysfunction and pain as well as headache and neck ache. When studying the saggital head position of 160 males and females no change as a result of gender was seen. Age however did play a factor with increasing age resulting in greater forward head positioning. A similar study looking at the same saggital angles on school children examined the effect of 15% body weight loads on static and dynamic postural measurements (Chansirinukor et al., 2001). This is the first known study that has examined these angles whilst carrying load and including dynamic postures. Load was seen to cause an increased forward head position when compared to no load although the effect of gender was not examined here.

2.8 Military task performance

When a member of military personnel embarks on training and/or battle missions there are a number of other tasks besides load carriage that they must be able to perform. The ability to perform these tasks sometimes occurs in life and death situations and therefore any impedance that load causes may be crucial. A number of studies have examined the effect of load carriage on key tasks during military action – those referenced here were conducted in the United States.

Performance tests of a 25-yard sprint, a simple agility run, standing long jump, reaction movement over 4.6m and a ladder climb were examined over 5 military loads with increases in load found to consistently decrease performance in all tasks in almost a linear fashion (Martin & Nelson, 1985). Other military activities that have been examined include marksmanship, vertical jumping ability and grenade throw distance (Knapik et al., 1991). Following a 20km march, carrying a 46kg load, both marksmanship and grenade throw showed a marked decline; however vertical jump did not change. As there was no control condition (i.e. zero load) in this experiment it is difficult to ascertain whether this decrement in performance was due to the load, the fatigue from the march, or a combination of both. In order to answer this question the same authors completed a further study examining 3 loads of 34kg, 48kg or 61kg over a 20km march using both a backpack and double pack (Knapik et al., 1997). Following this march there was a slight decline in the quality of the first shot during the marksmanship task, but not for subsequent shots; grenade throw performance did not change. For these parameters, then, no effect of load was seen. However, an effect of load has been seen on performance of vertical jump, obstacle course completion and other mobility tasks when carrying a 16kg load (Holewijn & Lotens, 1992a). Therefore performance scores may be test specific and could be related to physical condition of the recruits, the tasks performed and training in these tasks.

Work has also been completed in this area investigating gender differences in military task performance. Frykman et al., (2000) examined obstacle course performance carrying 2 different loads (14kg and 27kg) as soldiers not only need to carry loads on a battlefield but also need to traverse a battlefield quickly, important for individual survival and effectiveness of the unit. Eleven women were examined, of which none were combat soldiers (prohibited in the US army) but most had physically demanding jobs such as Military Police. It took participants longer to traverse hurdles, zigzag and straight sprint with the 27kg load, with the biggest difference seen in low crawl (twice as long). This load also heavily affected the horizontal pipe and wall climb performances. In previous studies by the same authors (Harman et al., 1999b) men had no trouble clearing the wall which was associated with the height of their COM and the corresponding height that they must raise it to get over the wall when compared to females. Also, the 27kg load represents a higher percentage of women's body mass (44%) than men (31%) placing the women at a considerable disadvantage. One must also consider in the military context the likelihood that backpacks may be discarded before performing such tasks.

A study was conducted comparing male and female performance of 6 field tests with 6 differing loads ranging from 1kg to 43.5kg (Martin et al., 1982a; Martin & Nelson, 1985). These tests included reaction movement, standing long jump, agility run, 10-yard and 25-yard sprints and a ladder climb. The highest load carried by females was 36.5kg and for males was 43.5kg, which were of military configuration. Results showed consistently better performance on all tasks for males ($p < 0.05$) and as load increased significant decreases in performance were also seen. Height, weight and percent body fat were determined not to be major factors in task performance. In all cases females were under a load that was a greater percentage of body weight than their male counterparts, thus explaining the performance decrement. It was interesting to note that in tasks where females were required to move the load against gravity there was a greater difference in performance between genders than in those tasks where horizontal movement of the centre of gravity was involved. This result was also seen in a study in the same year looking at backpacks with different frame lengths (Martin et al., 1982a).

Continuing with research conducted by Harman, performance variables such as shooting and grenade throwing ability have also been studied (Harman et al., 1999a). As mentioned previously clearance of high walls and walking along pipes was a significant problem for females. Wall climbing could become crucial for example in urban environments when needed to get into ground floor windows or having to clear walls and fences while either on attack or retreat. Grenade throwing ability also sees females placed at a great disadvantage. In this study women averaged approximately 50 feet shorter than males during grenade throwing tasks. In turn this would diminish the ability to harm the enemy in a combat situation but also to place the thrower in danger as they could be subject to a shrapnel injury.

2.9 Medical considerations associated with military load carriage

Medical problems experienced as a result of load carriage, although usually minor, can impact the mobility and effectiveness of the individual, and in a military situation possibly the entire unit. These injuries have high costs in terms of monetary value, treatment time and loss of associated man hours and are of concern to military establishments worldwide. Once again a gender divide is evident with females experiencing a much greater injury rate. A similar divide is seen when comparing trained military personnel as opposed to new military recruits.

2.9.1 Injury incidence and risk factors

It had been suggested previously that female basic trainees are less physically fit than males entering basic training. Bell et al., (2000) conducted a study on the relative injury risk for male and female Army trainees in which they controlled for physical fitness with baseline screening undertaken as well as body composition (percent body fat) and fitness measures. Injury occurrence was defined as any condition causing a trainee to seek medical care that also resulted in an injury diagnosis. Males exhibited significantly higher measures of physical fitness on all measures with the exception of flexibility as would be expected. Results indicated that females experienced about twice as many injuries as males and their risk for serious injuries was even greater at 2.5 times. In both sexes most injuries were to the lower limb. When matched for fitness levels (run time) the injury risk for females was the same as that for males, suggesting aerobic fitness explains much of the injury potential. Therefore although crude injury rates suggest that women are at more risk, when matched for fitness level there are no significant injury risk differences seen.

In a similar study by Knapik et al., (2001) injury levels during basic combat training were found to be almost 2 times greater in females than in males, attributed to the relative workload intensity. The nature of these injuries for both sexes were predominantly overuse injuries and once again were concentrated in the lower limb and lower back with risk factors including slow 3.2km run time, fewer push-ups in 2 minute time frame, lower aerobic capacity and cigarette smoking. Lower previous fitness levels and low or high flexibility levels were also risks for males.

A review paper on the patterns and risk factors for injuries states physical fitness (i.e. aerobic fitness) is the critical element in determining risk for injury (Deuster et al., 1997). Injury rates of greater than 50% have been reported for women attending 8 weeks of Army basic training, 22% for Navy training and almost 50% for Marine basic training. Stress fracture rates are higher in females and constitute a high proportion of the musculoskeletal injuries that women suffer. Overall time lost due to injury is also higher in females than in males, expected given the higher injury rate. The primary risk factor for females, aerobic capacity, is also the primary risk factor for males, those with the same aerobic fitness level having the same injury risk. Other components of physical fitness, muscular strength/endurance and flexibility, show similar patterns of risk and smoking and alcohol are identified as risk factors for both genders. Pelvic width, knee flexor/extensor strength and flexibility imbalances are other biomechanical factors that must be addressed in females.

Epidemiology of illness and injury in the US forces reported from 3 separate training centres showed medical encounter rates for females ranging from 72%-86%, correlated with training intensity (Shaffer et al., 1999). The majority of medical encounters were for musculoskeletal injuries, in particular overuse injuries. Comparison to males in an equivalent study showed similar results, although initial injury rates were lower at 61%. Other key reasons for medical visits included respiratory infections and dermatological disorders such as blisters.

2.9.2 Stress fractures

As overuse injuries are the predominant injuries experienced, investigations have been conducted on stress fracture incidence to examine this trend. Friedl et al., (1992) examined risk factors associated with stress fractures in female army personnel, due to females having substantially higher risk than men in military training (10%-12% incidence versus 1%-3% incidence). A questionnaire given to 1630 female soldiers at Fort Lewis reported five factors independently associated with self-reported stress fractures: history of amenorrhoea, current cigarette smoking, non-black ethnic origin, known family history of osteoporosis and young age.

As pelvic stress fractures are specifically linked to females, Kelly et al., (2000) examined 86 female Navy recruits with risk factors being associated to those participants who were on average, shorter, lighter and more often Asian or Hispanic. In addition those experiencing stress fractures usually marched in the rear of their training divisions (placed by height with tallest at front), served as road guards (march at rear of division) and felt that their stride was too long while marching. Shorter individuals, having to take larger steps, experience an accumulation of large shear and/or tensile stresses on the pubic rami by the adductors and hamstrings, this serving to contribute to pelvic stress fractures.

The Australian Army also commissioned a study to examine pelvic stress fracture incidence and the effect of a training intervention (Pope, 1999). Comparisons were made between female recruits training in two separate groups, one with an altered training regimen, both groups being compared to male injury incidence data collected at other bases in the same year (n = 1093). Normal training conditions involved route marches at 7.5km.h^{-1}, requirement to march in step and close formation and runs on bitumen surfaces, the only difference between males and females being that occasionally males carried backpacks weighing up to 20kg. Males and females trained separately on all occasions. The altered training regimen included route marches at 5km.h^{-1}, marching at own comfortable step length, running and marching in more widely spaced formation, running on soft grass and in interval training sessions of 800m rather than middle distances. Incidence of pelvic stress fractures in females showed a 20-fold decrease from 11.2% to 0.6% with training intervention. Training efficiency was also reported to increase because of reduction in fatigue and injury, both seen as barriers to achieving objectives. Therefore this type of intervention could be a successful method for decreasing such injuries.

2.9.3 Blisters, lower back pain and other load carriage associated injuries

The most common injury associated with load carriage is due to frictional forces between socks/shoes and the skin. Blisters can cause extreme discomfort and result in the most number of limited duty days following military marches (Knapik et al., 1992). Heavy loads may be a risk factor for blisters and a possible source of these frictional forces in the increased maximal braking and propulsive forces that act on the foot as backpack load increases (Kinoshita, 1985). If left untreated or not properly managed blisters may develop into more serious problems such as cellulites or sepsis (Hoeffler, 1975).

Following a 161 km march blisters were reported by 47 of the 218 soldiers (22%) and accounted for 48% of the total injuries observed (Reynolds et al., 1999). This resulted in the second greatest number of limited duty days (29% of total), only beaten by foot pain in general (32% of total). Younger age, cigarette smoking, lower body mass, lower fat-free mass and white ethnicity were all factors associated with increased risk of blisters. Of interest in this study by Reynolds was the use of active surveillance, which may result in higher injury incidence recorded. Soldiers often do not seek medical care or are reluctant to disclose they are suffering from injury due to peer pressure or fear of prejudice from senior officers. They may also have experience with such injuries and feel self treatment is adequate. When passive surveillance was used over a 20km march only 10% of soldiers reporter blister incidence (Knapik et al., 1992).

Although blisters are the highest reported specific injury, the lower limb in general accounts for the most reported injuries during/following load carriage. Australian Army figures from 1987-1991 report the lower limb accounts for 40% of all reported injuries which were responsible for 50% of bed days, 47% of sick leave and 51% of restricted duty. During 1992 leg/knee injuries were the single most important cause of reduced operational readiness (Rudzki, 2000). In US data collected by Reynolds et al., (1999) other than blisters 43% of injuries recorded were also associated with the lower limb in some respect. These included metatarsal stress fractures, knee pain and ankle and knee sprains.

Lower back pain, caused by rubbing from the load carriage system or excessive stress on the musculoskeletal system is also associated with load carriage. Back problems can pose an immediate problem whilst load carrying; (Knapik et al., 1992) reporting half of the participants who were unable to complete a 20km march not being able to do so due to back strain. This was the leading cause for non completion of the march. It has been suggested that as loads become heavier the risk of back pain increases as more stress is placed on the supporting musculature and on the spine. Also, heavier loads induce greater forward lean and eccentric contraction of back musculature is required to support such lean. Interestingly, when carrying loads of 61kg in the form of a double pack rather than backpack alone, less discomfort was reported in the lower back region (Knapik et al., 1997). This may be associated with the return to a more normal unloaded posture.

Moving away from the lower body, one of the most debilitating injuries associated with load carriage is brachial plexus syndrome, otherwise known as rucksack paralysis/palsy. The proposed aetiology is compression of the nerves of the brachial plexus resulting in traction injury of the C5 and C6 nerve roots. This is caused by the backpack exerting heavy pressure in the region of the upper trunk of the brachial plexus. Symptoms include cramping, pain in the shoulder, elbow and wrist musculature, numbness and even paralysis. Periods of dizziness have also been reported associated with exertion (Daube, 1969). Of the 17 cases reported by Daube (1969) all patients agreed that the weight of the backpack was the major factor in determining the severity and duration of the symptoms. The duration for which the backpack was carried and the terrain over which one must travel also played a significant role. Nerve injury as a consequence of rucksack palsy is usually only temporary although there are some instances where it may become chronic. It is suggested that decreasing the pressure on the shoulders by use of a hip belt or frame may alleviate some of the pain and reduce this injury incidence (Bessen et al., 1987). This injury may influence the ability to perform certain military tasks such as grenade throwing and marksmanship due to the damage it inflicts on the shoulder.

2.9.4 Injury risk during career specific training

It is well documented that there are a large number of injuries experienced by both males and females during initial basic combat training. Henderson et al., (2000) examined injury risk during a second stage of career specific training, in this case combat medic, which has a large physical training component. Males (n = 439) and females (n = 287) participated with results indicating injury incidence decreased when comparing basic training to career specific training, although females still had a higher injury rate than males. The lower extremity accounted for 80% and 87% of injuries in males and females respectively with the foot having the highest injury incidence in both sexes. Overuse injuries represented the largest proportion of this total, with risk factors associated with injury including older age, higher body mass and period between basic training and job specific training. A possible explanation for the decrease in injury incidence during job specific training may be due to the greater physical fitness in this period when compared to entering basic training.

2.9.5 Discharge rates from British Tri Service

Geary et al., (2002) examined the discharge rates due to injury of males and females in the British armed forces over the period 1985-2000. Previous studies indicate female discharge rates to be greater than males; by 2-3 times in the UK and 1.5-2.0 times in the USA and Australia. Increased injury rates in females are associated with decreased stride length and mixed marching, with male marching speed placing women at a disadvantage and at increased risk of pelvic stress fractures. Data showed clear excess in discharge rates of females in musculoskeletal disease and all injuries (Figure 2.4).

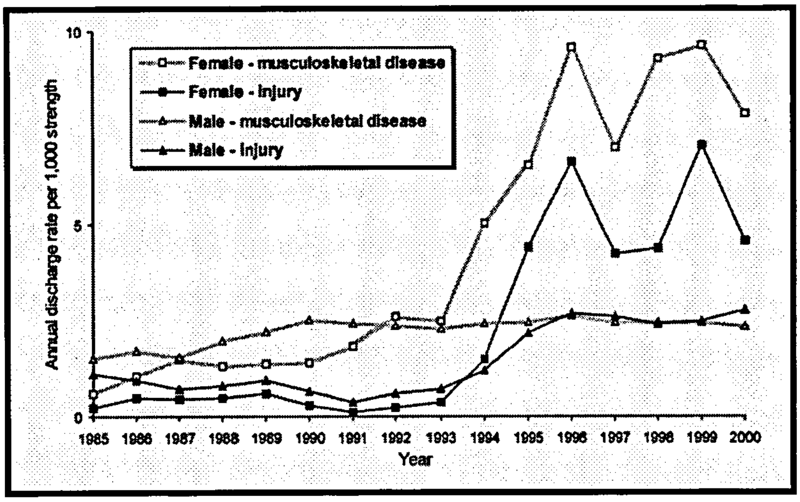


Figure 2.4: Medical discharge rates for musculoskeletal disease and injury by gender, 1985-2000 (Geary et al., 2002)

Changes occurred dramatically after 1993 with a sharp increase for females and moderate increase for males (only in total injury, not musculoskeletal disease) which, when split up by service, was due to Army related injuries. An increasing trend in the Royal Navy and no real change in the RAF were also seen. The Royal Navy showed no gender difference in musculoskeletal disease but there was a 2 to 4 fold increase in risk for females over males in the RAF and Army respectively (Figure 2.5).

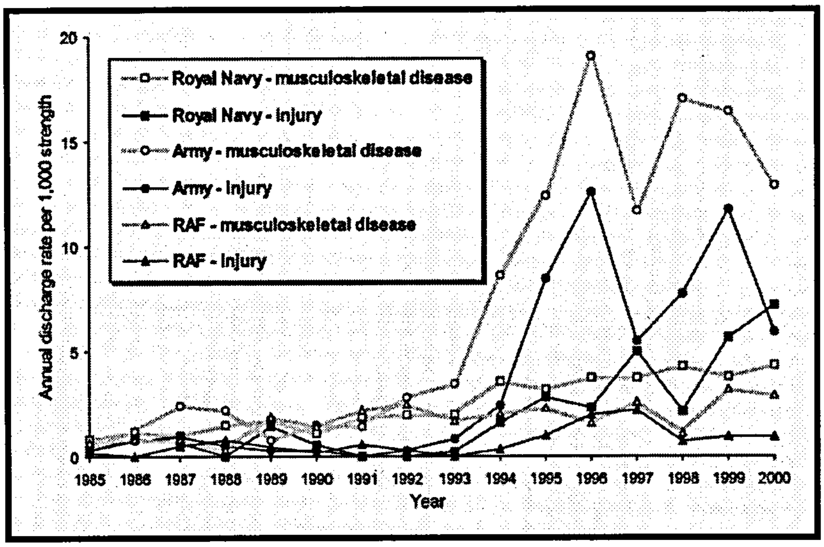


Figure 2.5: Medical discharge rates for musculoskeletal disease and injury in female personnel by service, 1985-2000 (Geary et al., 2002)

The observed rise in injuries in females after 1993 (mainly in Army) was a direct consequence of the pressures to increase employment opportunities for females at that time. The change in trend for the Royal Navy however has no obvious explanation.

Linked to these discharge rates is the change in female roles in the British military. Gemmell (2002) reports over the last 15 years it has been acknowledged there was a need to increase the proportion of women in the British Army. Widening of career choice was identified as one means and a system was introduced in 1998 to allow standard physical tests for careers. When comparing gender-fair (i.e. different training regimes for each sex) versus gender-free (i.e. males and females train exactly the same) training males showed little change in overuse injury patterns but females medically discharged due to overuse injury rose from 4.6% to 11.1%. There are clear differences in the bone architecture, muscle physiology and body composition between genders that serve to place women at a disadvantage when working (or training) at the same level as males. Therefore health and safety guidelines should ensure that allowances are made for gender differences.

Carrying heavy loads (61kg) over a 20km march using a double pack system was shown to result in the most intense reports of distress and levels of heat illness index (Johnson et al., 1995). It is probable that the double pack's front compartment served as a barrier to heat loss by impeding evaporation of sweat in the chest area, which in turn could impair thermoregulation.

Investigation of injury incidence during a 20km march carrying 46kg resulted in 79 injuries reported from 335 (24%) experienced soldiers (Knapik et al., 1992). All injuries involved either the lower extremities or the back, with foot blisters, back pain and back strain accounting for over 50% of the problems. Foot blisters were by far the most commonly reported injury and resulted in the most number of limited duty days following the march. Heavy loads may be a risk factor for blisters. Frictional shearing forces on the skin can cause blisters, and a possible source of these forces is the increased maximal braking and propulsive forces of the foot as backpack load increases (Kinoshita, 1985).

2.10 Summary

Load carriage tasks are part of many daily work and leisure activities, including those serving as members of the military. A great deal of work has been conducted examining the effects of such loads in relation to the human body, with suggestions as to ways to manage these loads in order to reduce any undesirable response that occurs. These include proposals to increase comfort and reduce the large number of injuries that occur as a result of load carriage – especially in the military.

Key factors in the body's response to external load are load positioning – which should be as close as possible to the body's COM, load weight – suggestions this should not exceed greater than 45% BW, and the duration for which load is carried. Whilst the position in which the load is carried may be altered by the design of LCSs, load weight and carriage duration recommendations present a much more difficult question for the military and more often than not these recommendations are unable to be applied. This is due to the specific requirements of military operations. Therefore design of military equipment must be the factor that is concentrated on as this is most easily altered.

The main gap in current biomechanical research is the lack of consideration of the military LCS as a whole. Work examining the effect of backpacks alone does not consider the integration of the elements of a LCS (webbing + backpack) and the possible alterations to load positioning and stresses placed on the body as a result of this. Also, LCS design is different for each military outfit throughout the world. Therefore the main military research that has been conducted – in the United States, Canada and Australia - may not apply to the current issue British military equipment.

The measurement of gait variables and trunk movement response to load carriage has been investigated with some of this foreign equipment. However consideration of the movement of the neck and head has received little attention. Considering the heavy loads members of the military must carry and the position of these loads, there is a considerable amount of stress placed on the small musculature supporting the head and neck. Therefore it is important to examine the response such loads place on this area of the body and whether there is a progressive effect across the body.

Another important consideration is the effect of gender. Whilst women are currently not permitted to serve in close combat roles in the UK Armed Forces, there are still roles which require load carriage, and the possibility that changes in role definitions may occur in the future. The examination of differences in body size and response may indicate design alterations that must be applied in order to produce a more effective military unit.

The work discussed in this literature review concentrates on the carriage of loads in relation to specific biomechanical and physiological variables. It presents an overall view of the response to carrying loads, with work completed in the laboratory and in the field examined and injury incidence and implications on task performance commented on. A second concentration of this thesis is the examination of the effect of longer term load carriage. A thorough review of literature related to such load carriage is presented in Chapter 7 along with consideration of subjective responses to load carriage.

Chapter 3 – Experimental Equipment and Protocol

3.1 Introduction

One of the main aims of this thesis work was to develop a protocol which allowed measurement of gait and posture variables whilst carrying load. The equipment used to measure these variables is ideally such that no impediment of movement occurs, allowing the load carrier to move freely. Sensors used should be able to be placed both on the individual and on the LCS to allow accurate measurement of movement of body segments and equipment. This chapter describes the equipment chosen for this work and outlines the protocol used in subsequent experimental work in terms of marker placement and angular data collected.

3.2 Motion analysis equipment

Motion analysis equipment is used worldwide for a variety of applications including analysis of sporting movements and clinical gait. The reasons for studying human movement has changed over the centuries; the Greeks (500-300BC) examined movement in order to place harmony in the universe (Leardini et al (1992) quoted in (Andriacchi & Alexander, 2000)); these days movement analysis is used to answer questions posed by science in order to advance and assist the human race.

As expected, with these changes in reasoning for studying human locomotion, the development of more sophisticated measurement equipment has come about.

Initial measurements were made by taking a series of photographs in rapid succession (during late 1870's – Etienne Jules Marey and Eadweard Muybridge (http://www.univie.ac.at/cga/history/enlightenment.html)). In the current age there are a myriad of systems that allow in-depth analysis of human movement which can be provided in "real-time" as the individual moves within the analysis area. Two types of systems are currently used; those that use a visual record of body segment positions and those that use magnetic sensors to provide information on the orientation and position of body segments in space (Richards, 1999). Within those systems that use image-based recordings they may then be split to those that use passive and those that use active marker systems. A passive marker is one which reflects light back to the sensor on the camera. These are the most commonly used variety of motion analysis equipment, with Vicon 370 ™, Motion Analysis ™, Peak Performance Motus™ and Proreflex ™ (Qualisys) being examples of such systems. On the other hand, an active marker system contains a source of light which the camera sensor detects and is usually powered by batteries. Charnwood Dynamic's CODA ™ motion analysis system is an example of an active measurement system.

3.3 CODA™ Motion Analysis

The CODA™ motion analysis system allows measurement of movement data in real time via the use of infrared sensor units and small LED markers which are placed on the body in key positions. CODA (Cartesian Optoelectronic Dynamic Anthropometer) was initially designed in the 1970's at Loughborough University (www.charndyn.com). In the 1980's a commercial version of the product was produced, followed in the 1990's by the mpx30 (Figure 3.1). The mpx30 contains 3 hi-resolution uniaxial cameras mounted on a single rigid frame. By the use of polygonal mirrors as scanning devices and LED markers the system can track up to 56 markers simultaneously. The Cx1 is the latest development in terms of CODA measurement units (Figure 3.1) which allows complete portability of the system. Much of the processing that used to occur in the main computer (with the mpx30) now occurs within the camera, allowing this system to be attached only to a standard laptop or PC. It also has the capability to be deployed in the field – with an inbuilt 12 volt battery. Each marker is attached to a battery cell (Figure 3.1), which allows a light pulse to be fired, detected by photodiodes in the scanner unit. A multiplexed timing sequence allows immediate identification of each marker and its global position in space.

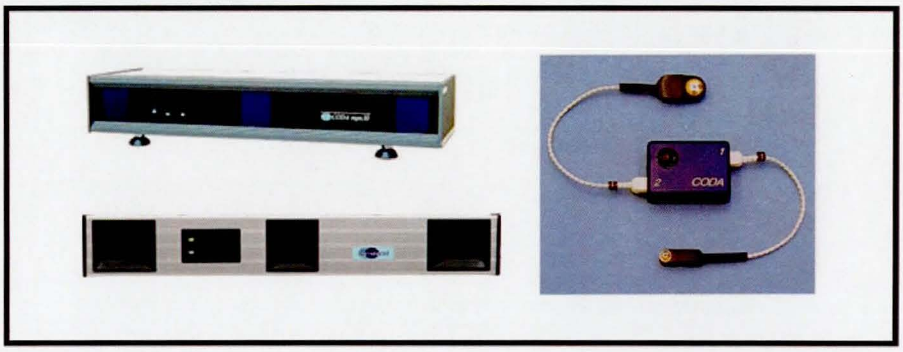


Figure 3.1: CODA motion analysis system. The MPx30 (top left), the Cx1 (bottom left) and two markers attached to a battery cell (right)

One main advantage of the CODA system is the pre-alignment of the system, allowing setup in a manner of minutes and no need to recalibrate the space in which one is working. Also, due to the process by which markers are detected the system does not suffer from parallax error – which is a problem sometimes experienced with active marker systems as they rely on a lens to form an image of the whole field of view. Another main advantage of this system is the automatic identification of markers. This means that tracking is not required which is a time consuming process for all passive marker based systems. Although the time to track such markers is reducing more and more as technology of the passive systems increases, there are still some systems in which it becomes a major part of the trial processing.

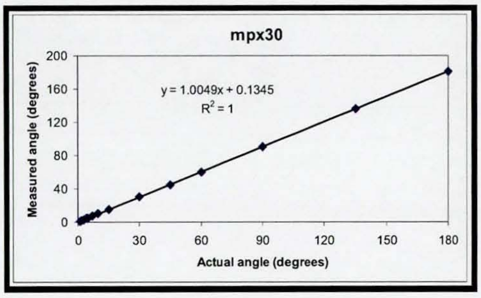
A possible advantage of the passive marker systems however is that they do not need to be attached to a battery, therefore cable connections are not placed all over the body segments being measured. The cables used with CODA™ motion analysis are extremely thin and of a variety of lengths, which can be easily attached to the skin with tape to prevent any restriction of movement or possible entanglement. Sensors also come in 2 different sizes, allowing placement on areas such as the face as well as larger areas on the leg. The availability of an mpx30 and Cx1 (for fatigue related work), along with the ease of use and the ability to measure the required biomechanical information, resulted in this motion analysis equipment being chosen for this experimental work.

3.3.1 Measurement of marker positions

A number of studies have taken place examining the ability of motion analysis systems to correctly measure specific positions in space (Ehara et al., 1995; Ehara et al., 1997; Richards, 1999). Comparisons are made between passive marker systems in the form of Ehara and colleagues' work; whilst the work by Richards includes comparison with the active marker system CODA™ and an electromagnetic device. Two markers were placed on a rigid aluminium bar, 50cm apart, rotating at a rate of ~60rpm, with 3 markers in a triangular pattern on a plate mounted vertically (facing outwards) at the end of this bar. Several other markers to determine the height of the bar were also examined. Performance of CODA™ in comparison to Vicon™, Ariel™, Motion Analysis™, Peak Motus™, Qualysis™ and Elite™ systems was mixed. It showed the second to highest variability at measuring the set distance of 50cm with a root mean squared (RMS) error of 5mm. When measuring those markers rotating on the end plate this error reduced to 3mm. When asked to measure the specific angles between the markers on the rotating plate only Ariel, Vicon and Motion Analysis performed better than CODA™ (Richards, 1999). All in all however it was felt that the camera systems all performed well in regards to the measurement of position in space.

As mentioned previously the CODA™ motion analysis system is factory aligned and does not require realignment within the laboratory space. The configuration of the polygonal mirrors results in automatic 3-D positioning of markers to be examined. In order to confirm that the alignment of the systems within the Load Carriage laboratory at Loughborough University had been maintained, a straightforward experiment was conducted. Markers were placed on a simple goniometer (Figure 3.2) and a series of angular measurements were taken using both the mpx30 and the Cx1. Angular measurements chosen were over the range of 180° with 5 repeats of 5 second data collection made at angles of 1,2,3,4,5,7,10,15,30,45,60,90,135 and 180°. The goniometer was placed on the floor in the middle of the laboratory. Mean values were obtained for each angle and both systems (mpx30 and Cx1) reported an average RMS error value of 2.9% for the mpx30 and 0.34% for the Cx1 over the entire angular range (Figure 3.3). It is possible the larger error seen in the mpx30 could be due to the system being several years older than the Cx1, but also that at the lower angles measured there was consistent greater RMS error of approximately 7%. This could have also been due to the experimental setup i.e. human error as these values were constantly above the angle being measured (see Table 3.1), or also due to error of the system, which would explain why they are larger at smaller angular values. It was therefore concluded that the pre-aligned state of the cameras was still intact.

Figure 3.2: Markers placed on a simple goniometer to measure reliability of camera system



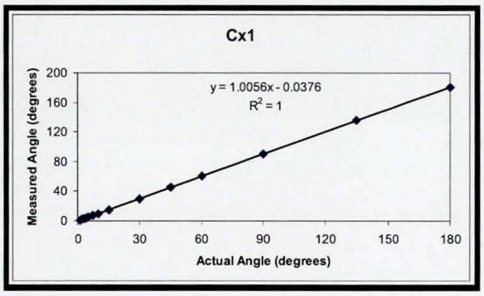


Figure 3.3: Comparison of actual angles with measured angles for the mpx30 (left) and Cx1 (right) camera systems

Table 3.1: Absolute error of mpx30 camera system

	Absolute error					% diff
Angle (°)	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	
1	0.05	0.12	0.08	0.06	0.01	7.3%
2	0.07	0.09	0.07	0.07	0.12	4.3%
3	0.22	0.25	0.20	0.23	0.19	7.3%
4	0.29	0.29	0.23	0.29	0.38	7.5%
5	0.23	0.16	0.17	0.13	0.19	3.6%
7	0.10	0.17	0.20	0.19	0.17	2.4%
10	0.33	0.36	0.42	0.33	0.35	3.6%
15	0.26	0.21	0.32	0.17	0.22	1.6%
30	0.19	0.22	0.24	0.23	0.19	0.7%
45	0.17	0.15	-0.06	0.15	0.18	0.3%
60	0.17	0.19	0.30	0.28	0.23	0.4%
90	0.31	0.59	0.62	0.61	0.57	0.6%
135	1.17	1.20	1.12	1.22	1.26	0.9%
180	0.83	0.68	0.87	0.94	0.91	0.5%

3.4 Gait analysis

A gait cycle is defined as the period from initial contact of one foot until initial contact of that same foot again. During each cycle each leg undergoes a stance and a swing phase and there are periods of single and double support (Figure 3.4). For the purposes of a large amount of gait analysis it is the stance phase (measured on a force plate) that is considered, as this allows the most comprehensive analysis of the movement of the lower limb. This phase constitutes approximately 60% of the total gait cycle (Norkin & Levangie, 1992; Rodgers, 1988).

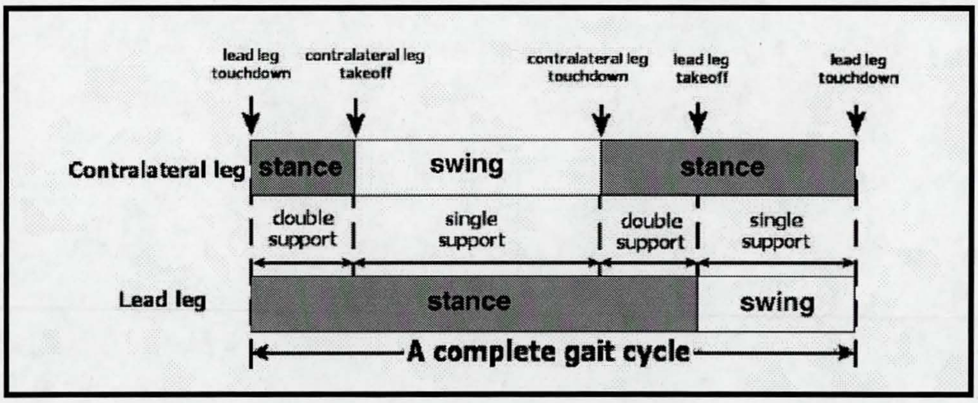


Figure 3.4: Phases of the gait cycle (Hong & Li, 2005)

Walking is defined as "a method of locomotion involving the use of two legs, alternately, to provide both support and propulsion" and in order to exclude running, "with at least one foot in contact with the ground at all times" (Whittle, 2002). Gait on the other hand is the type/style of walking that an individual has rather than the action of walking itself. Therefore it is gait that is analysed and not changes in walking. The positions of the leg during a typical gait cycle are shown in Figure 3.5.

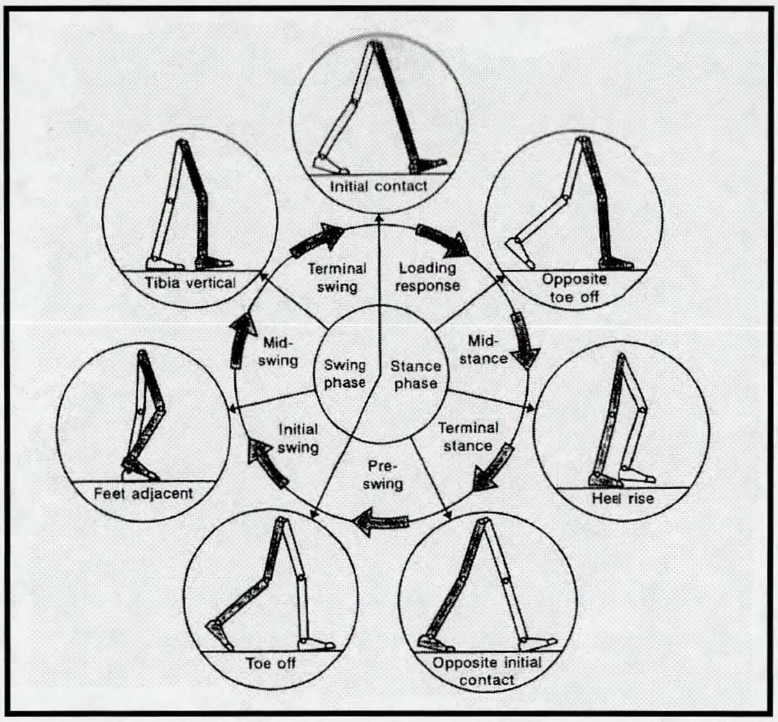


Figure 3.5: Positions of the leg during the gait cycle (Whittle, 2002)

3.4.1 Reliability of marker placement

As mentioned in the description of gait analysis systems (section 3.3), the process of gait analysis usually entails the placement of markers or sensors upon the body of the individual that requires examination. The placement of these markers introduces a source of experimental error, both due to the experimenter and movement of the skin over the bony landmark one wishes to locate (i.e. skin movement artefact). Skin movement artefact has been described as "by far the greatest source of noise in the measurement" (Macleod & Morris, 1987), but is inevitable for non-invasive methods of gait analysis. The significance of such errors depends on the body segment being measured and the amount of tissue over the site for the individual being measured. For example the muscle and fat tissue that exists over the greater trochanter is much greater than that over the lateral malleolus of the ankle.

A solution to the use of skin markers is to use bone pins to place sensors directly on the bones one is trying to measure (Reinschmidt et al., 1997). However, this invasive procedure is rarely granted ethical clearance for human based trials and the technical considerations in terms of participant wellbeing must also be taken into consideration. Another method to reduce the error associated with marker placement on the skin is to use the same experimenter to locate sensor positions for all experimental work. For the purpose of this thesis, a single trained experimenter (Renée Attwells) placed markers on the body at all times.

In order to quantify using a single experimenter a study was conducted in the laboratory on 3 individuals (female) to indicate the reliability of marker placement in the same anatomical position over 3 experimental trials. These participants (age: 25.7±4.2 years, height 168.3±3.8cm, and body mass 63.0±4.2kg) attended the laboratory on 3 occasions and markers were placed on the right hand side of the body with 10 gait trials obtained. Figure 3.6 indicates lower limb results from these trials and Figure 3.7 upper body results for all three participants. These figures demonstrate a small variability in each individual's data over the 3 measurement days by the narrow ± 95% confidence intervals (CI) that are presented on the graphs, this supporting the use of this experimental technique.

A similar trial was conducted by Maynard et al., (2003), the first known reliability study using the CODA mpx30. Ten participants (5 male and 5 female; mean age 39.2 years) had gait analysis carried out 3 times; twice on the same day (morning and afternoon) and then again 1 week later, with only saggital plane kinematics analysed. Results indicated that test retest reproducibility for the same examiner was poorest for angles around the hip and best for knee angles, with ease of identification of bony landmarks being suggested as the main influencing factor. This study did use 10 individuals for gait analysis, but only examined one "best gait cycle" per individual. This should be viewed with caution as a single gait cycle may not be representative of an individual's usual walking gait. Repeatability of kinematic measurements has also been examined by Kadaba et al.,(1989) who evaluated 40 normal subjects 3 times in one day and over 3 different days using a VICON™ system. In this case 3 gait cycles were used with results indicating that the saggital plane is the most reliable both within a test day and between test days when considering intra-subject data, and that gait patterns are quite repeatable.

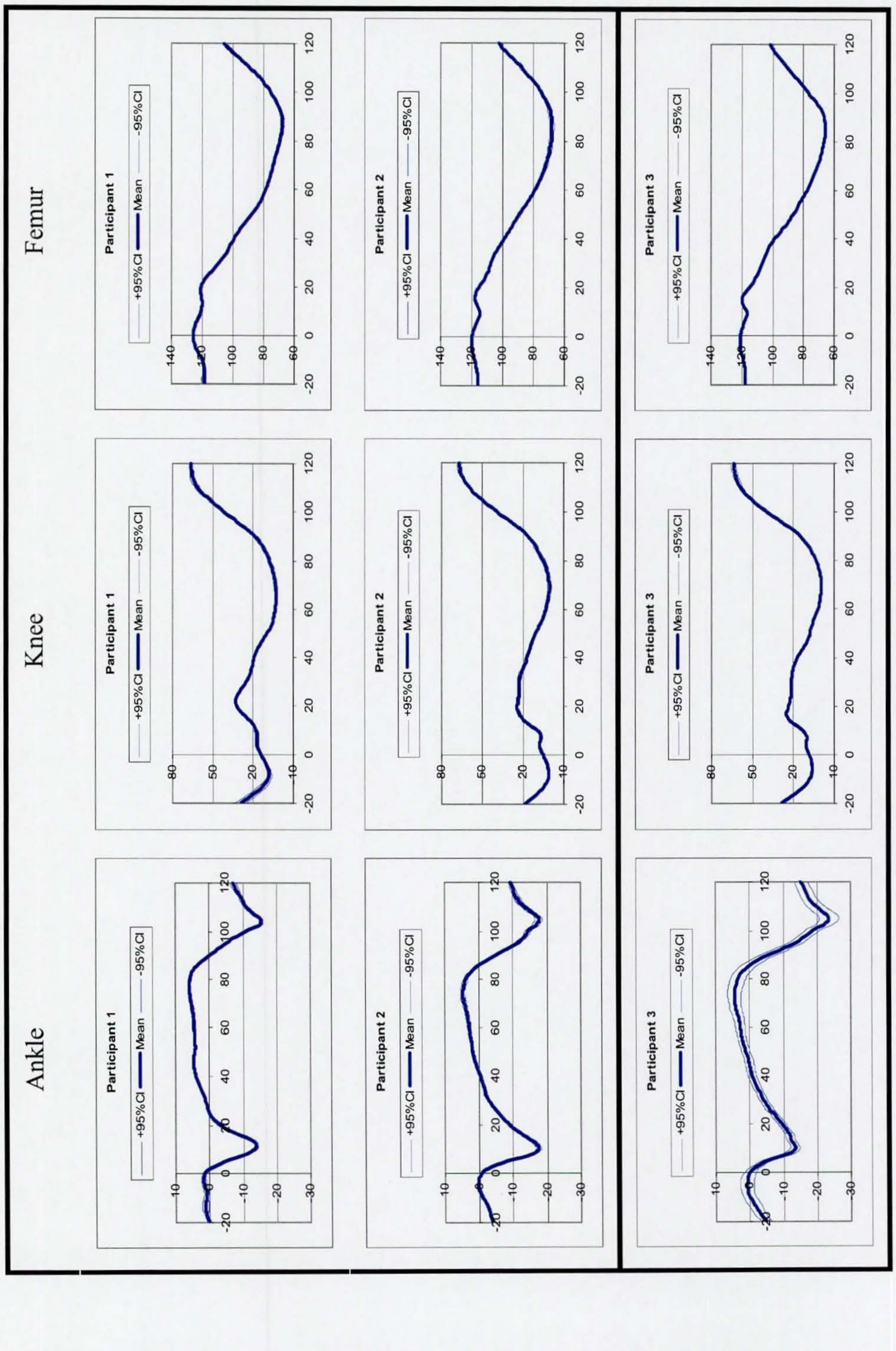


Figure 3.6: Lower limb day to day variability

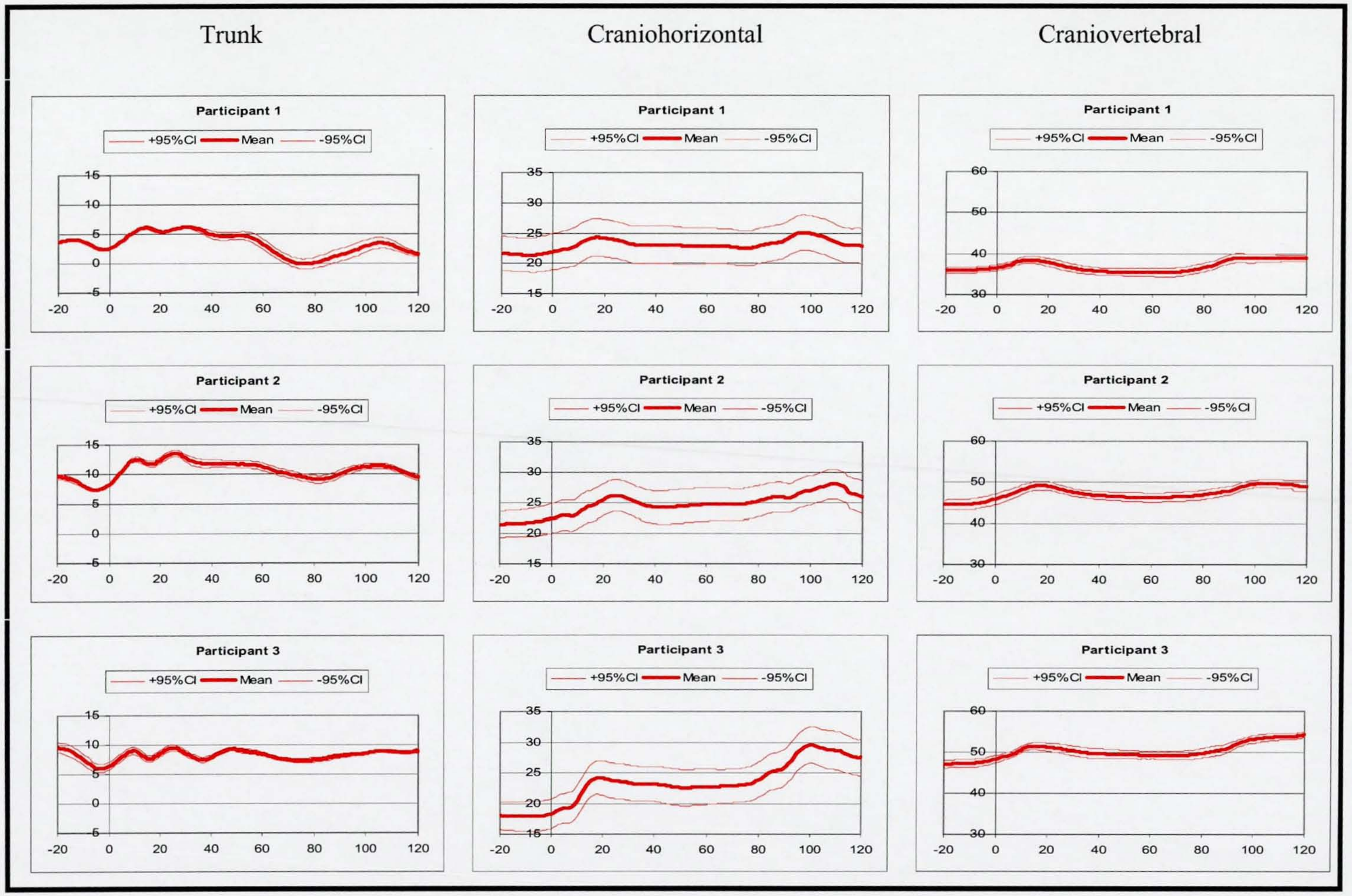


Figure 3.7: Upper body day to day variability

3.4.2 Trials required to obtain representative gait

The number of trials considered adequate to represent the true gait of a participant is of question. As yet, a definitive number of trials required to achieve repreatable data has not been stated in the literature. Rather the number of trials collected is dependent on the experimental conditions, the availability of participants, and the post processing time required. Many studies report using only one gait cycle as with the work by Maynard et al., (2003), or choose the "best" walking trial for each participant as in the case of some military studies (Harman et al., 1994; Harman et al., 2000a; Martin & Nelson, 1986). These data must be treated with caution as it is important to record enough gait trials to have a true representation of an individual's gait, without obtaining too many so that possible effects of fatigue may come into play. Work done by Diss (2001) suggests that for running at least 5 gait cycles should be recorded for kinematics (and 10 for kinetics). Other studies examining walking have suggested 10 repetitions of data within one day is repeatable (Kim et al., 1996), or a minimum of 3 trials in paediatric data (Gorton et al., 1997).

In addition to the laboratory study mentioned in section 3.4.1, the same 3 participants also completed a study to determine the number of gait trials required. A series of 50 walks was completed by each participant in one gait analysis session. The same marker setup and angular definitions were used (explained in detail in the next section). Whilst a study of this size is too small to determine the criteria for the number of trials required for gait analysis, it does serve to indicate the possible behaviour of the data when using this particular experimental protocol.

An example of the data for the 50 walking trials for one participant is indicated in Figure 3.8. Variability of the knee data is relatively small as a percentage of the entire movement, whereas trunk data indicates more variability over time. When examining variables investigated in experimental work reported later in this thesis (i.e. maxima, minima, mean and range of motion), the location of the variability may be examined closer (Figure 3.9). Each gridline represents an angle of 0.5°, with the number of trials represented on the x axis. Once again this is data for Participant 1. In terms of the knee angle, there are several degrees of variability in terms of the maxima values in the initial trials, eventually reaching within a range

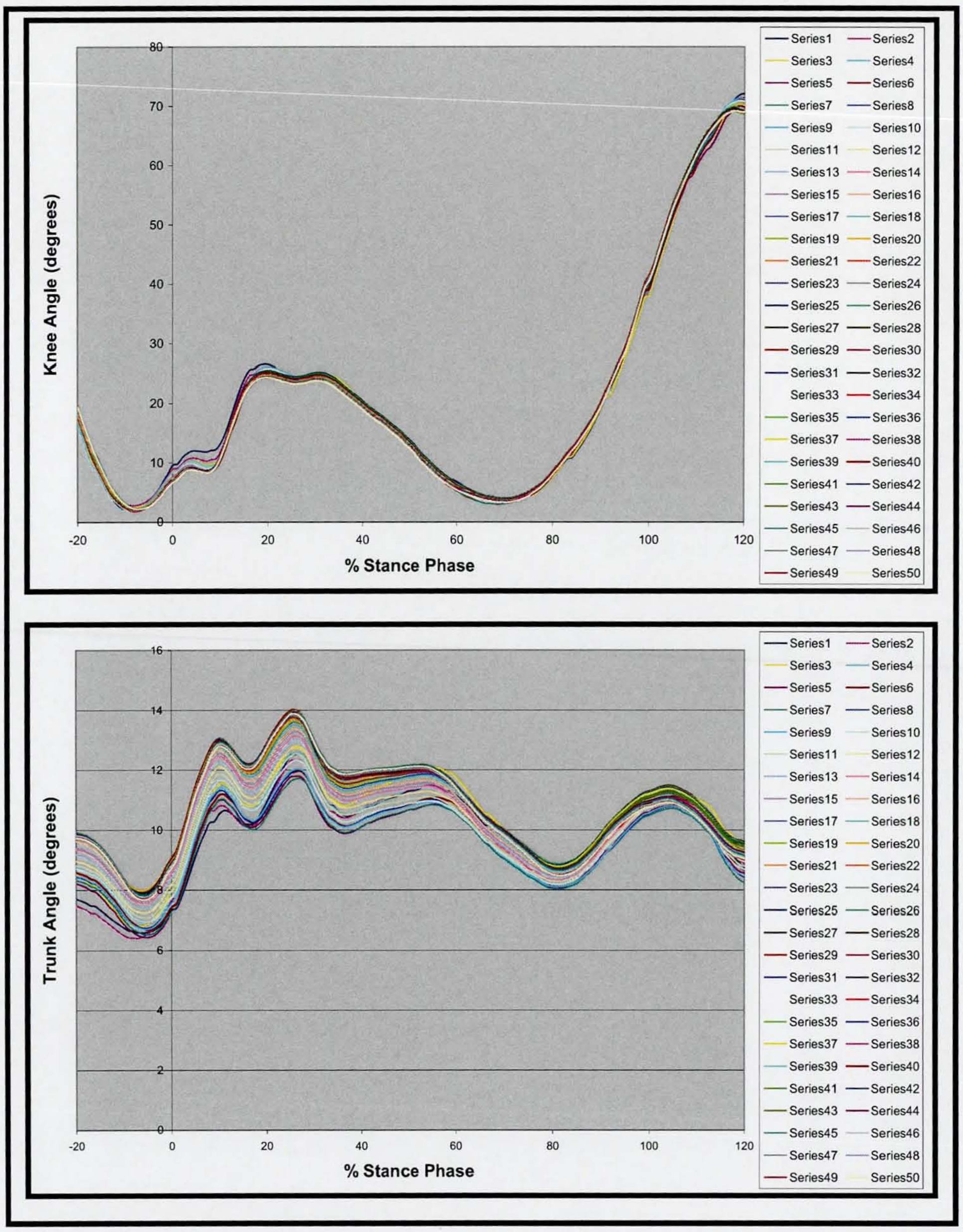


Figure 3.8: Knee (top) and trunk (bottom) angles for 50 walking trials for participant 1

of 1° by trial 10. On the other hand the minima values remain within a 1° range throughout the entire period. In terms of the trunk, variability is greater, although once again more so in the initial trials. The context of these changes must also be considered, as knee movement occurs over a total range of approximately 40°. However, throughout this thesis the statistical significance of the maxima and minima values is examined, so alterations in these data may influence experimental results. Also noted from these graphs in Figure 3.9 is the effect as number of trials increases. This suggests too many trials may not be representative of an individual's movement, but also adds justification for measuring longer duration trials (as is the case with the military where loads are carried for extended time periods, see work in Chapters 7-9).

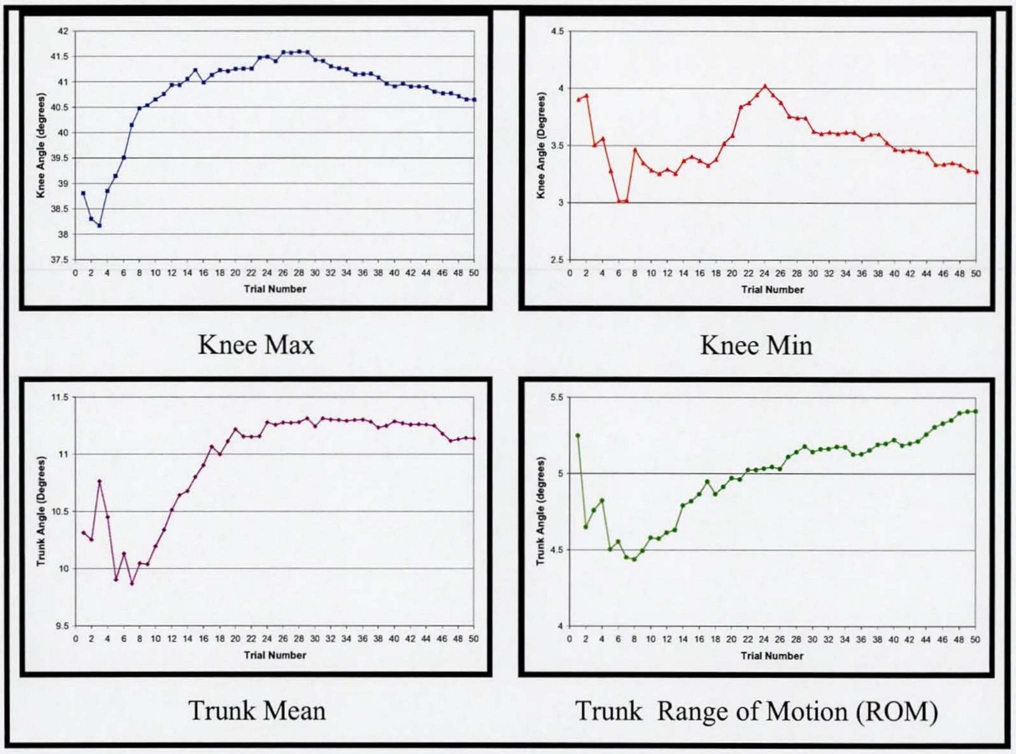


Figure 3.9: Knee (top) and trunk (bottom) variables across 50 walking trials. Each value represents the average for that number of walking trials; i.e. 24 is the average of the first 24 trials

Similar trends to the presented data were seen when examining the other two participants, with the lower limb remaining less variable than the upper body measures over the 50 trials. This data does serve to demonstrate that a choice of using 1 walking trial may not be representative of the individual's movement. Whilst trying to avoid using too small a number of trials, time constraints of experimental work and number of conditions to be examined also had to be taken into account. Considering these variables, and using previous research experience (Attwells & Smith, 2000, 2001), the number of trials examined was chosen to be of a minimum of 5 with an optimum of 7. If 5 experimental trials were not available for a participant their data would be excluded from that particular piece of experimental work.

3.5 Marker placement for experimental trials

All biomechanical experimental trials conducted in this thesis place importance on measurement of both the lower limb and the upper body. Therefore markers (sensors) were placed over specific and identifiable bony landmarks over the entire height of the body. The positions of these sensors were as follows;

1. Toe – head of 5th metatarsal (on outside of boot when boots worn).
2. Heel – outer edge of lateral calcaneus (on outside of boot when boots worn).
3. Ankle – lateral malleolus (on outside of boot when boots worn).
4. Shank – a mark 2/3 of the distance from the ankle to the knee in a straight line.
5. Knee – head of lateral epicondyle of femur.
6. Mid Thigh – a mark 2/3 of the distance from the knee to the greater trochanter in a straight line.
7. Greater trochanter – a virtual marker created from the position of the knee and mid thigh markers. (Virtual markers are points in 3D space constructed, by means of a fixed geometric relationship, from two or more other points which are real sensors actually seen by the camera

system. Validity of the virtual greater trochanter marker is explained in section 3.5.1)

8. C7 – bony prominence palpated with head forward.
9. Ear – tragus of the ear (projection of cartilage that extends back over the opening of the ear canal).
10. Eye – canthus of the eye (between lower and upper eyelids on lateral portion).

When pack worn

11. Upper Pack – secured near shoulder strap
12. Lower Pack – secured near shoulder strap connection to base of pack
13. Mid Pack – secured at centre of pack at furthermost point from the body.

In all situations these markers were placed on the right hand side of the body. As all angles are reported in the saggital plane only (i.e. plane of progression) no markers were placed on the left hand side of the body. Unipedal gait analysis was used in this thesis due to restriction of availability of motion analysis equipment. For the experimental trials only one CODA™ motion analysis system was available. Therefore marker positioning was determined to gain the best representation of body segment movement over the greatest distance within the laboratory confines. This type of gait analysis (unipedal) has been used many times in the past, with the value placed on simplification of the research methodology and data processing (Sadeghi et al., 2000). There is debate over whether there is symmetry of gait between the left and right sides of the body. A number of studies indicate that symmetry does exist whilst others suggest that asymmetry is present – although this is mainly seen when examining pathological gait (Sadeghi et al., 2000). For the purposes of this thesis symmetry is assumed. A repeated measures design was also incorporated to ensure that trends seen fully represent the gait being examined.

In all situations marker locations data was collected at 200Hz. All angles were calculated and exported from the CODA motion analysis software. Subsequently the time was converted to a percentage of stance time, angles being interpolated as necessary. Stance time was determined as the time from initial contact of the heel until final contact of the toe markers within one stride.

3.5.1 Validity of the virtual greater trochanter marker

As mentioned in the previous section (greater trochanter marker placement position) a virtual marker was used to indicate the movement of the greater trochanter. A virtual marker is a point in 3D space that is constructed, by means of a fixed geometric relationship, from two or more other points which are real markers (sensors) seen by the camera system. This type of marker was used due to the positioning of webbing around the participant's waist during all load carriage conditions. The webbing obscured the greater trochanter as shown on the left hand panel of Figure 3.10. This anatomical landmark however is crucial for the definition of 2 angles used throughout this thesis – the trunk angle and the femur angle (section 3.6).

The virtual greater marker was therefore constructed from a fixed geometric relationship between the knee and mid thigh markers. Position of the knee marker was obtained by palpating the lateral epicondyle of the femur. A mark was made with a water soluble pen. The greater trochanter was then palpated and a similar mark made. The distance between these two marks was obtained with a anthropometric tape and the position of the mid thigh marker was then calculated as 2/3rd's of the distance from the knee to the greater trochanter (right side of Figure 3.10), this mark also drawn on the participants and then the appropriate sensors put into place (also indicated in the left panel of Figure 3.10).

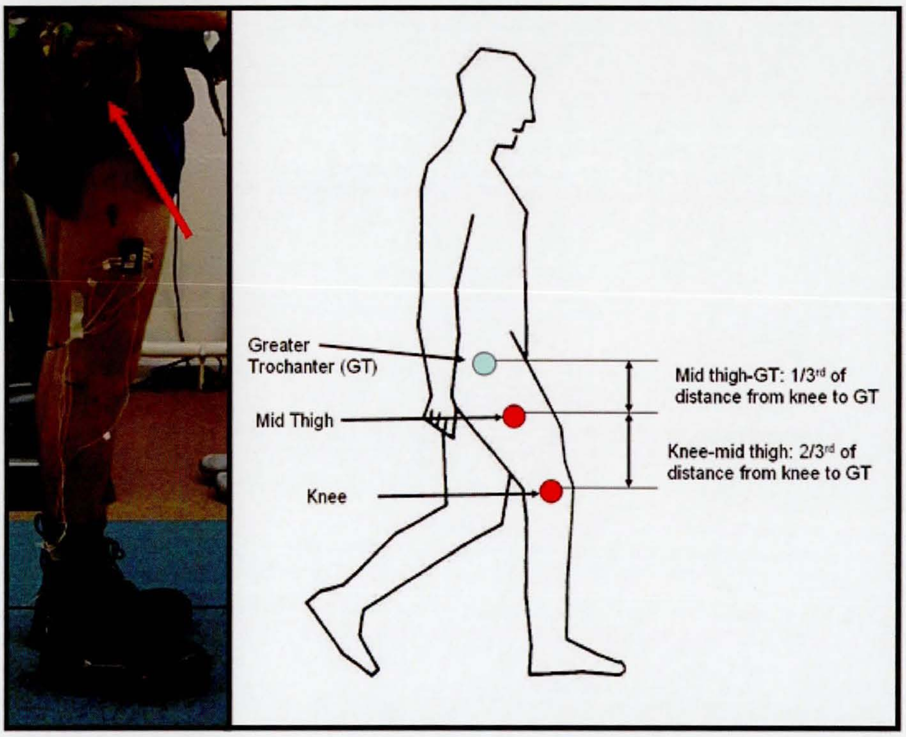


Figure 3.10: Positioning of the virtual greater trochanter marker. Indication of why a virtual marker is required (webbing in left panel) and the markers and geometric relationship used to determine the marker position (right panel)

In order to validate the use of this virtual marker, an experimental trial was conducted. Twenty participants (10 male and 10 female - participant statistics (mean ± SD): age 24.35 ± 5.96 years, height 173.85 ± 9.78 cm and body mass 73.69 ± 8.79 kg) completed a series of barefoot walking trials. Markers were placed on the knee, mid thigh and the greater trochanter. The virtual greater trochanter marker was also constructed within the CODA™ motion analysis programme. All participants completed 7 walks throughout the testing area with data extracted for the X, and Z positions of the greater trochanter and the virtual greater trochanter markers in space. As all angles calculated in this work are done in the saggital plane, through the definition of the lab coordinate system all angles are defined in the X-Z plane. Therefore the positional differences for the virtual marker are important in this plane, with the position in the Y-direction discarded. Following obtaining the positional information, the absolute error of the virtual marker was calculated using the method outlined in Figure 3.11. The root mean squared (RMS) error was calculated for the X and Z components of the virtual marker, then the absolute error calculated using Pythagoras theorem.

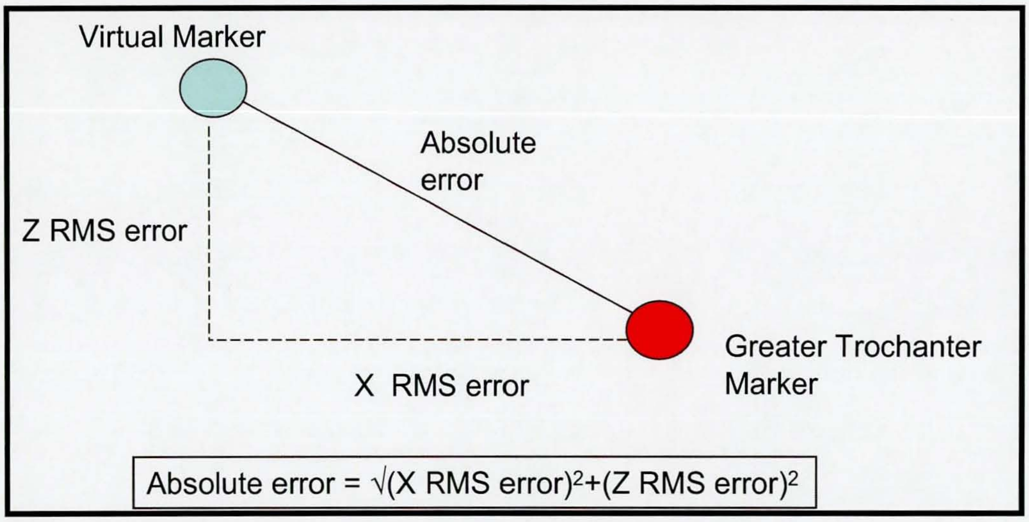


Figure 3.11: Calculation of absolute error of virtual marker

Data from the 7 walking trials for each participant was calculated, followed by an average for each participant, then finally an overall average from all individuals. The overall absolute error calculated was 14.69 ± 4.7 mm (mean ± S.D). When broken down into components the predominant contributor to the error was that in the Z plane. There was a slight deviation between the two markers around heel strike in the X plane, whereas in the Z plane there was a consistent deviation across the entire stance phase. This is further illustrated in Figure 3.12, which compares the X and Z positions of both markers as a percentage of stance. It is thought this error in the Z plane is due to the calculation within the software and the placement of the mid-thigh marker. The mid thigh marker was placed on a straight line between the knee and greater trochanter. Achieving a position on that line in the X plane is considerably easier than determining the exact position in the Z plane. The impact of a slight deviation in this marker position in the vertical may explain these results seen in Figure 3.12 as the main component of the positional calculation occurs in this plane. The size of the markers themselves (in the order of 10mm) must also be taken into account.

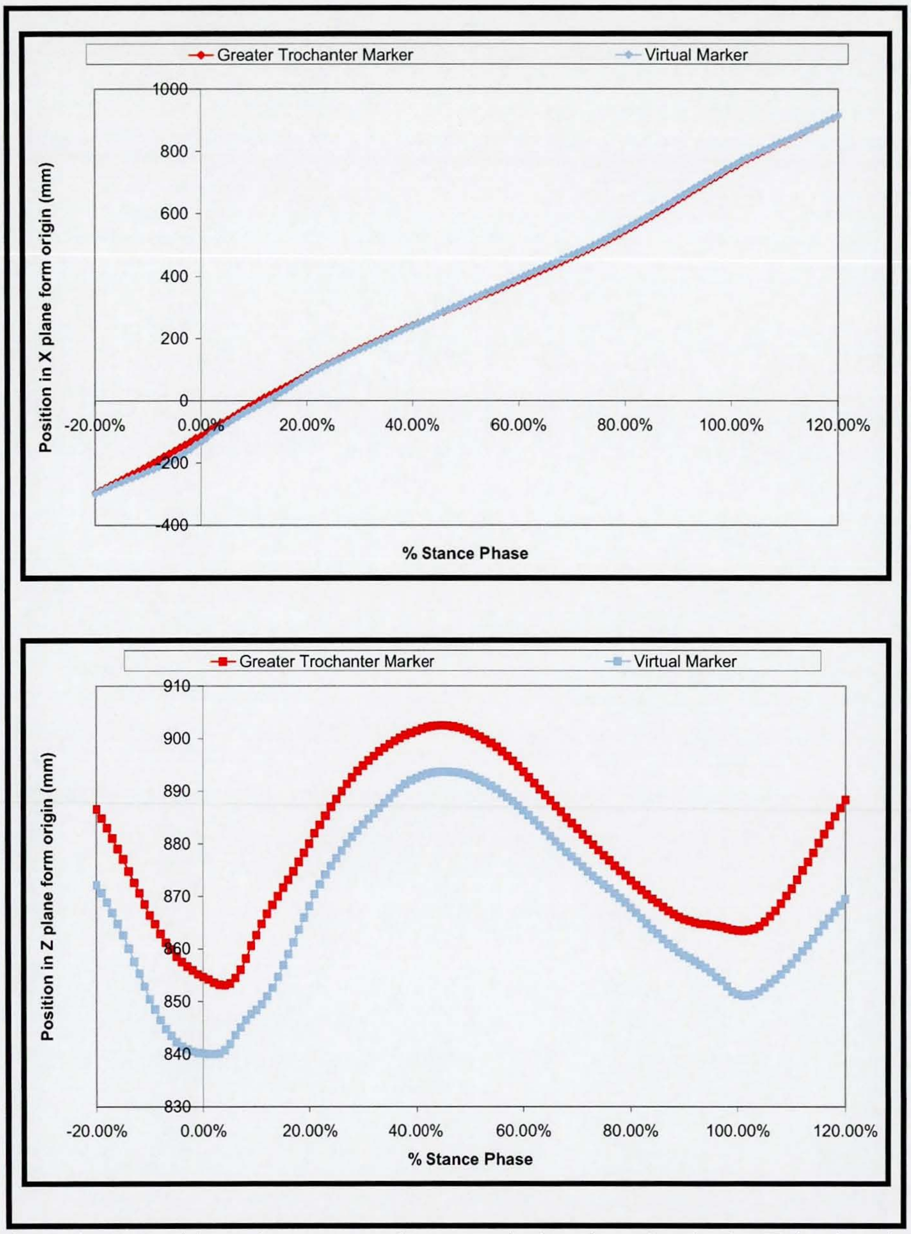


Figure 3.12: Position of greater trochanter and virtual marker in the X (top) and Z (bottom) planes as a percentage of stance phase (mean data for all 20 participants shown)

As with any biomechanical data there is the possibility for error with position of experimental markers as discussed previously (section 3.4.1). It was concluded by the author that this experimental error involved with using the virtual marker was less than that which would be experienced if a marker was to be placed on the webbing which the individual carried – as this marker would be at least 10cm from the individual's body and would include any movement of the webbing as well as the body. Also, in order to make all experimental conditions the equivalent (some conditions of experimental work throughout this thesis do not involve wearing webbing) a standard marker setup needed to be determined.

3.6 Angles examined in experimental work

In order to examine the movement of the entire body a series of angles were defined for movements in the saggital plane i.e. flexion and extension. As mentioned all markers were placed on the right hand side of the body. Lower limb and body angles measured were the ankle, knee, femur and trunk. Head posture angles were the craniovertebral and craniohorizontal angles (Chansirinukor et al., 2001; Raine & Twomey, 1997).

Definitions of the angles used for all kinematic experimental trials are as follows and are represented in the Figures 3.13 and 3.14 below.

- Ankle Angle – formed by two lines; knee to ankle and heel to toe; offset by 90°. Flexion (dorsiflexion) is indicated by a positive angular position and extension (plantarflexion) by a negative position.
- Knee Angle – formed by two lines between the lower leg (knee to ankle) and the thigh (knee to mid thigh marker). Once again flexion is indicated by a positive angular position.
- Femur Angle – angle to the horizontal from a line joining the knee to the virtual greater trochanter marker.
- Trunk Angle - angle to the vertical from the line joining C7 and the virtual greater trochanter marker. A positive angle was indicated when an individual was to the left of the vertical axis, i.e. upright, and as one lent further forward this angle became increasingly more negative

- Craniohorizontal (CH) Angle – angle to the horizontal from a line joining the tragus of the ear to external canthus (border) of the eye (providing an estimation of head on neck angle or position of upper cervical spine).
- Craniovertebral (CV) Angle – angle to the horizontal from a line joining spinous process of C7 to the tragus of the ear (provides an estimation of neck on upper trunk positioning with a smaller angle indicating a more forward head posture).

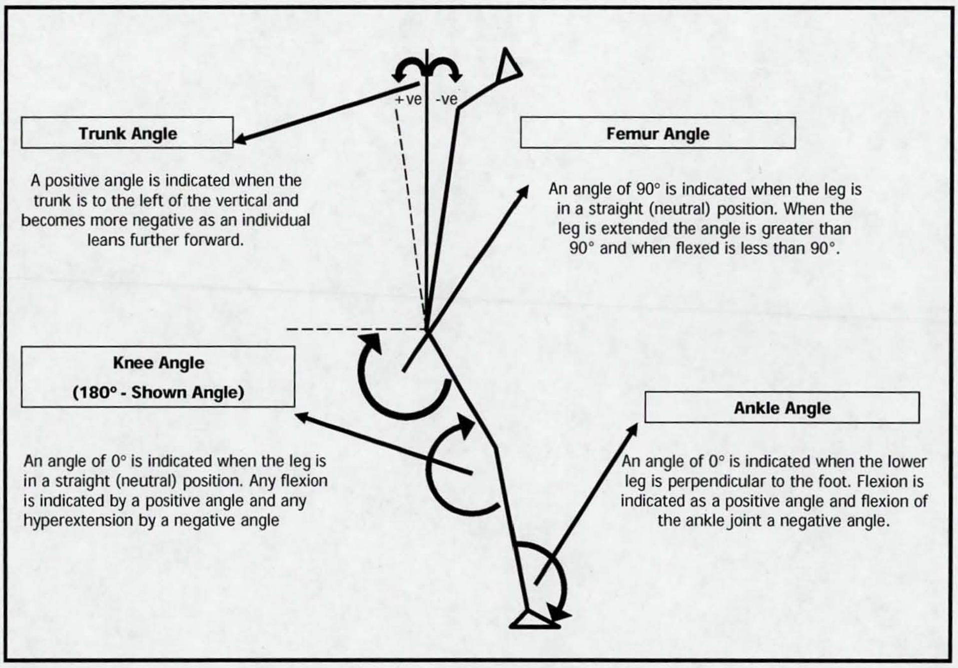
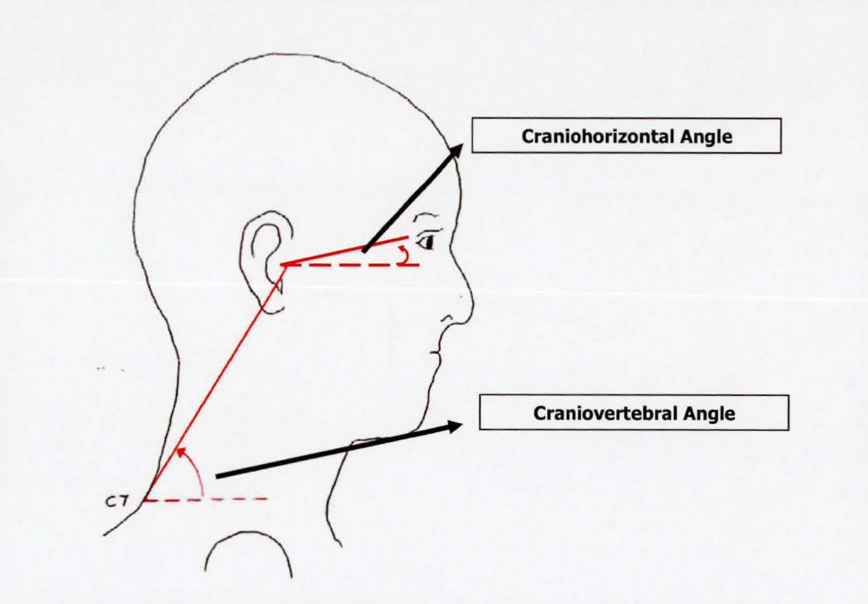


Figure 3.13: Angular measurements of the lower limb and trunk



Adapted from the work of Raine and Twomey (1997) and Chansirinukor et al., (2001).

Figure 3.14: Head posture angular measurements

3.7 Components of a military LCS

In addition to the equipment used to report kinematic information (i.e. CODA™ and associated markers/sensors), the load carriage equipment which is carried by members of the military was also of importance. As mentioned in the literature review (section 2.1) a LCS comprises of two pieces of equipment; webbing (housing all items essential for survival and always worn), and a Bergen or backpack (housing those larger non-essential items). In addition, military boots, a rifle (also always carried) and in some cases other weapons such as a light anti tank weapon (LAW) are carried/worn (Figure 3.15). Throughout the course of this thesis a variety of combinations were utilised in order to examine the true effect of current use military loads. Two different designs of LCSs were also examined. These were the current standard issue personal load carriage equipment (PLCE) LCS (Figure 3.16) and the prototype Airmesh Phase II LCS (Figure 3.17).

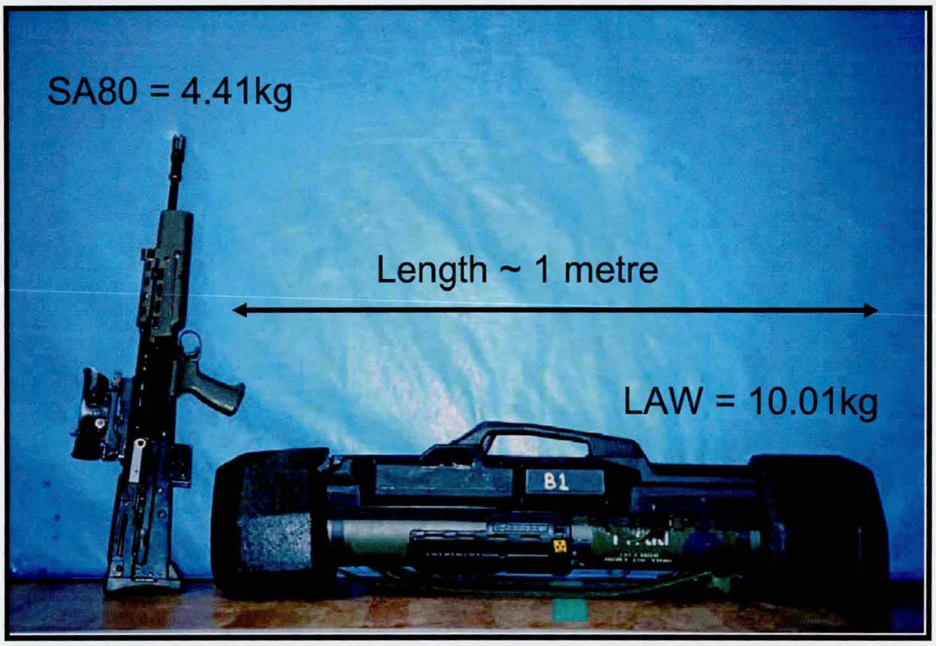


Figure 3.15: Military weapons. The SA80 rifle (left) and the Light Antitank Weapon (LAW-right)

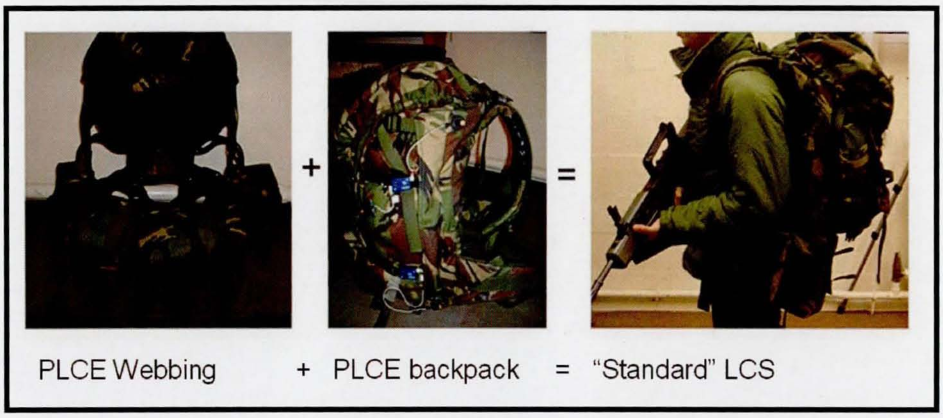


Figure 3.16: Components of the Standard LCS; PLCE webbing and backpack

The standard issue LCS has been in use within the UK armed forces since 1990. The webbing is worn around the waist and is supported by a shoulder harness. When the backpack (bergen) is added, most of the support is taken on the shoulders. Depending on the individual wearing the equipment and the way in which they have set the tension on the shoulder straps some weight may also be transferred to the hips by resting the Bergen on top of the webbing as shown in the Figure 3.16. This however places further stress on the shoulders as it pulls down on the shoulder harness of the webbing. The hip belt shown in the figure is rarely used as the position of the webbing on the waist results in the strap being fastened in the mid stomach area if at all. A more detailed description of this equipment is given in the work of Jones (2005a).

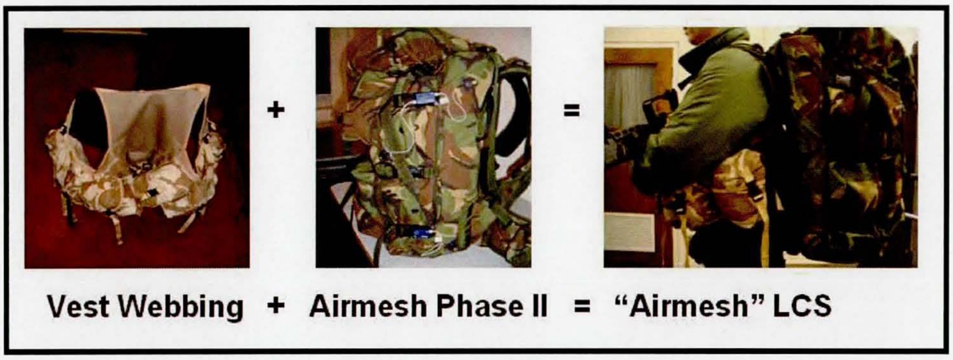


Figure 3.17: Components of the Airmesh Phase II LCS; Vest webbing and Airmesh Bergen

In contrast to the Standard LCS, the Airmesh Phase II LCS prototype is presently not in issue to any UK troops. The vest webbing is issued to Special Forces, Royal Marines and mechanised Army units (and may be purchased commercially), but a backpack that integrates with this webbing is not issued. Rather, the Standard PLCE backpack must be carried. A previous backpack prototype was distributed to some members of the special forces in 2003/04 for comment and also used in the military field trials of the work conducted by Jones (2005a). The capacity of the vest webbing is similar to that of the PLCE webbing, however the location of the load is shifted and worn on the front of the body – hence the name "vest webbing". The major difference between the two backpacks is the addition of a rigid waist belt with the Airmesh Phase II design. This waist belt can be fastened underneath the chest webbing to redistribute some of the weight onto the hips.

Again the importance of a LCS is highlighted here. The components of the two different systems do not integrate together. If the Standard bergen was to be worn with the vest webbing then the entire weight would be placed on the shoulders. On the other hand, it is not possible for the Airmesh Phase II bergen to be worn with the PLCE webbing as the addition of the hip belt does not allow it. The design and evaluation of these pieces of equipment must not be undertaken one piece at a time - the whole system is the most important factor to consider.

3.8 Loading a military LCS

The experimental work examining the effect of addition of load to the human body conducted in Chapter 5 used specific military loads as per packing for a 3 day military exercise. Details of this loading are further described in that chapter. For all other load carriage experiments it was important for the LCSs to be loaded in an identical manner. This allowed comparisons between LCSs and presented a consistent loading for participants. In order to achieve this a weight block was constructed (Figure 3.18). This consisted of a custom made bag which housed a series of foam blocks cut to measure. Steel rods of predetermined weight were then placed within the foam blocks as shown. Should any additional weight need to be added (in order to obtain exact weights) bags of sand were placed either inside the foam blocks or on top of the bag.

In terms of load distribution, the largest steel rods were always placed closest to the back of the individual carrying the load, and the smallest furthest away. This is in line with packing instructions distributed to military personnel and the ideology that load should be carried as close to the body as possible.

Figure 3.18: Weight block (left) and steel rods (right) used to load LCSs

When loading the webbing, placing sand weights in the bottom of the pouches was not an option, as this was not considered representative of how the weight would be distributed; i.e. would act as a dead weight. Therefore webbing pouches were filled with foam with slits cut in the middle into which 1kg steel rounds were added (Figure 3.18 right). Smaller pouches were filled entirely with accurately measured sand bag weights. All load carriage equipment was measured on scales accurate to 0.001 of a kilogram before testing sessions commenced (Figure 3.19).

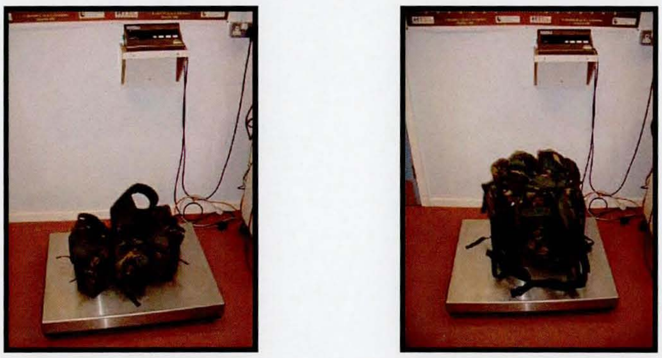


Figure 3.19: Weighing of load carriage equipment; webbing (left) and Bergen (right)

3.9 Military participants

As with any experimental work, it is important to select participants that are representative of the field into which the knowledge gained will be applied. With this in mind, during all experimental work in this thesis, the desired participants were the end users of the equipment, i.e. military personnel (in particular the infantry). This is because the infantry are the only regiments who are specifically specialised in the carriage of military loads. Every effort was made to obtain such personnel both through the working with the Ministry of Defence channels and through personal contacts. However, should military personnel not be available, members of the public with load carriage experience were recruited. Experience of carrying loads is important in terms of response of the individual and predisposition to injury. As outlined in section 2.9 a large number of injuries associated with load carriage occur during the initial stages of military training as the body adapts to carrying the loads required. In each chapter of experimental work those participants selected and their experience is outlined.

3.10 Summary

This chapter summarises the equipment and marker protocol used throughout the laboratory based experimental trials within this thesis. Specific protocol to each experiment is detailed within the specified chapters. The load carriage equipment carried during all load carriage situations is also described. CODA™ motion analysis provides a valid method with which to measure and individual's gait and changes in movement of body segments. As with all motion analysis studies possible sources of error are present. These have been identified within this chapter and are taken into account when interpreting the data collected. The positioning of markers as outlined enables a saggital view of the whole body to be represented with minimal impediment from load carriage equipment. Thus the experimental protocol presented here is deemed valid and reliable and is used in subsequent chapters where motion analysis trials take place.

Chapter 4 – Effect of Military Boots on Lower Limb Movement

4.1 Introduction

Military boots are worn in all training and combat situations by all members of the military. These are of a standard design regardless of the age, experience, training or gender of the individual they are being issued to. Personnel are allowed to purchase their own boots if they so choose, but the predominant number of military personnel in the UK wear the standard issue assault boot (Figure 4.1).

Figure 4.1: UK standard issue assault boots

As standard issue boots are worn by almost all military personnel, and one of the main themes in this thesis was to replicate as close as possible military load carriage, it was important that in all cases military boots were worn. However, as most data presented in the literature do not include the wearing of military boots, an examination of the effect that they may have on the kinematics of the lower limb is important.

As mentioned in section 2.9, injuries to the lower limb are the main contributor to sick or leave days, and monetary cost than any other type of injury experienced by military personnel. This is particularly evident during initial recruit training, but does continue into all levels of military service. The level of discomfort experienced in the feet is high (see Chapters 8 and 9), due to the alteration of foot mechanics and the rubbing between the boot and the sock, causing blisters.

In a study of 2000 soldiers on return from a mission in the Falklands in 1982, the most common source of dissatisfaction within the group in regards to their equipment was the performance of their boots (McCraig & Gooderson, 1986). The second most common complaint was cold and wet feet due to the inability of the boots to keep the feet dry. All infantry complete missions predominantly on foot, making the comfort of this area one of critical performance. If a soldier's movement is impeded this may lead to more serious consequences, including risking their lives.

The design of military boots should also take into account the gender of the person wearing them. The boots which women wear should not just be small size versions of the men's boots as there are distinct differences in feet dimensions (Wunderlich & Cavanagh, 2001). For the same size foot length, women have a higher arch, smaller instep, shorter length of the outside ball of the foot and a shallower first toe than men. Differences are also noted around the malleoli level with women having larger calf circumferences and lower malleoli heights, which are important factors to consider when designing boots.

Some non-military occupations are put under similar footwear restrictions (e.g. fire fighters). The reason for these restrictions is mainly for the safety of the individual when carrying out their daily duties. However boots change the movement and behaviour of the foot. When wearing fireman boots the accelerating impulse experienced by the foot is lower and the braking impulse is higher – presumably due to the increased weight of the boot being carried by the lower limb (Camara & Gavilanes, 2005).

These studies demonstrate the need to further research the boots that are worn by military personnel and the effect they may have on injury incidence. This is not the focus of this thesis; however, in order to quantify the difference boots make when using the protocols followed in this thesis, the following experimental trial was undertaken.

4.2 Method

Twenty civilian participants (10 male and 10 female) were recruited for this study under ethical conditions approved by Loughborough University Ethical Advisory Committee (LUEAC) protocol G03-18. These participants were members of Loughborough University student and staff population. Participant statistics (mean ± SD) were; age 24.35 ± 5.96 years, height 173.85 ± 9.78 cm and body mass 73.69 ± 8.79 kg. All participants completed a health questionnaire prior to commencement of testing sessions and gave informed consent ensuring knowledge of procedures involved (see Appendices A4-A6).

Participants were required to attend the laboratory on one occasion. They were asked their normal shoe size and then given a pair of standard issue assault boots that size, one size below and one size above. They were asked to try them on, walk around and once they had selected those with the best fit the experimental trial began. Boot sizes ranged from 4-11. Two experimental conditions were considered in these trials; barefoot and boots (Figure 4.2). As per the protocol for sensor positioning outlined in chapter 3 markers were placed on the lower limb – on the outside of the boot when boots were worn. In order to obtain kinematic data the CODA™ mpx30 was used and kinematic data for timing of foot contact events was collected using a Kistler force plate embedded in a specifically designed 7m walkway as shown in Figure 4.3.

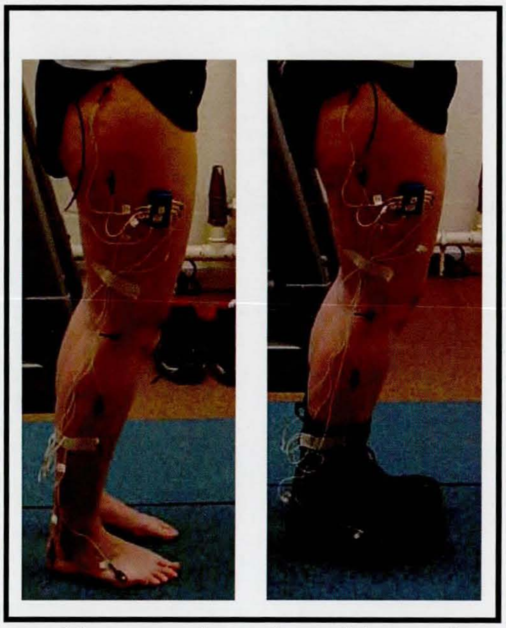


Figure 4.2: Barefoot and boot experimental conditions with marker placement on lower limbs

Figure 4.3: Laboratory walkway with embedded force plate as circled

During all conditions participants walked at a self selected pace along the walkway. A successful trial was determined by placement of the right foot fully within the boundaries of the force plate with all markers being successfully acquired prior to and for a full stride following the foot strike on the force plate. Following the completion of 7 successful trials within a condition the participant moved onto the next experimental condition. All trials were collected in the order of barefoot then boots.

In order for comparisons to be made between participants all data were calculated from –20% stance phase to 120% stance phase, making them independent of time and walking speed (as this was self selected). Observing data from –20% to 120% ensures that any anomalies around heel strike (0%) and toe off (100%) can be observed and taken into account. Despite action being taken during experimental trials to minimise marker dropout, trials were removed if equipment failure or marker dropout distorted results. The means for the 7 repeats for each participant were calculated. To obtain a single representation of each experimental condition the mean and 95% confidence intervals were calculated for all 20 participants. A paired t-test was conducted on all spatiotemporal data and maximum, minimum, and ROM values for all angles (significance level set at $p=0.05$). Spatiotemporal parameters of SL, SF, stance time and speed were also examined using this t-test.

4.3 Results

Analysis of mean values for each individual indicated significant differences in all lower limb angles between the barefoot and boot conditions. Ankle movement was significantly restricted by the boot, resulting in lower maxima ($p<0.05$), minima ($p<0.01$) and ROM ($p<0.01$) than when walking barefoot (Figure 4.4). This information is further illustrated in Figure 4.5 showing the movement throughout stance of the ankle. The progression of the foot occurs later when wearing the boot and the movement is restricted throughout stance. There is also significantly decreased plantarflexion of the foot around toe off (100% stance).

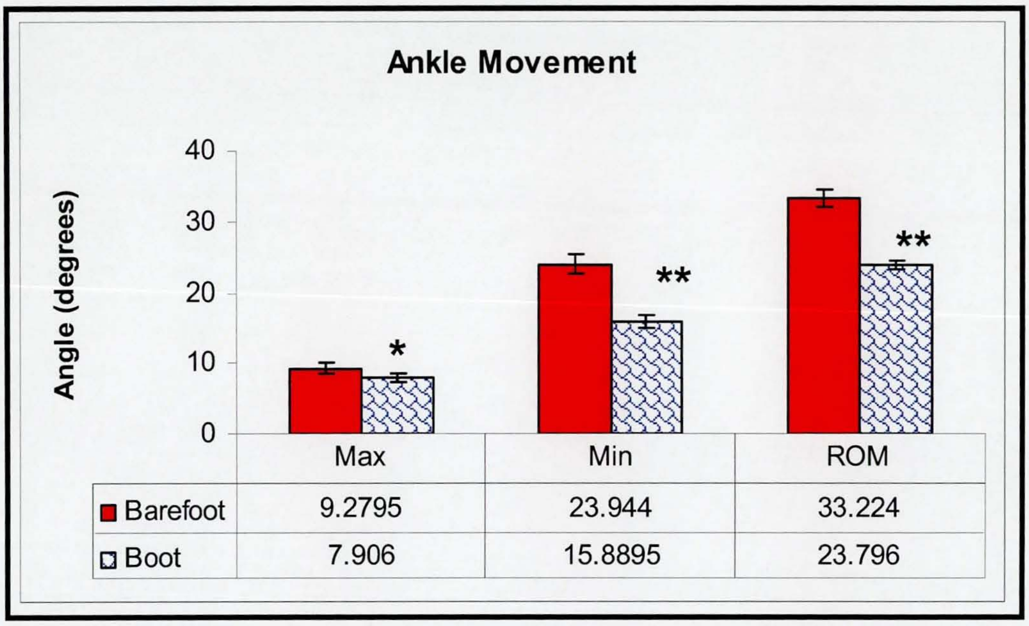


Figure 4.4: Ankle movement whilst walking barefoot and wearing boots. Mean values presented on the figure with error bars indicating standard error of the mean (SEM). Minimum values have been multiplied by -1. Significant differences indicated by * ($p<0.05$) and ** ($p<0.01$)

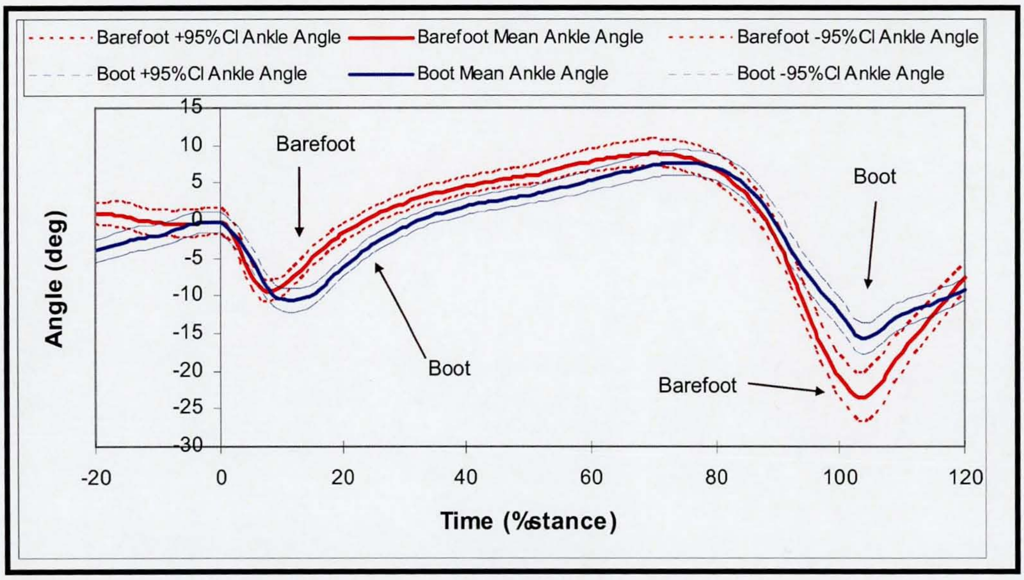


Figure 4.5: Ankle movement as percentage of stance time.

Movement of the other lower limb segments is also altered by the wearing of boots. Knee ROM is increased ($p<0.01$) by decreased minima values at heel strike and increased maxima at toe off (Figure 4.6), and the movement of the femur has a resultant significant ($p<0.01$) increase in ROM (Barefoot: 44.2°; Boot: 45.7°).

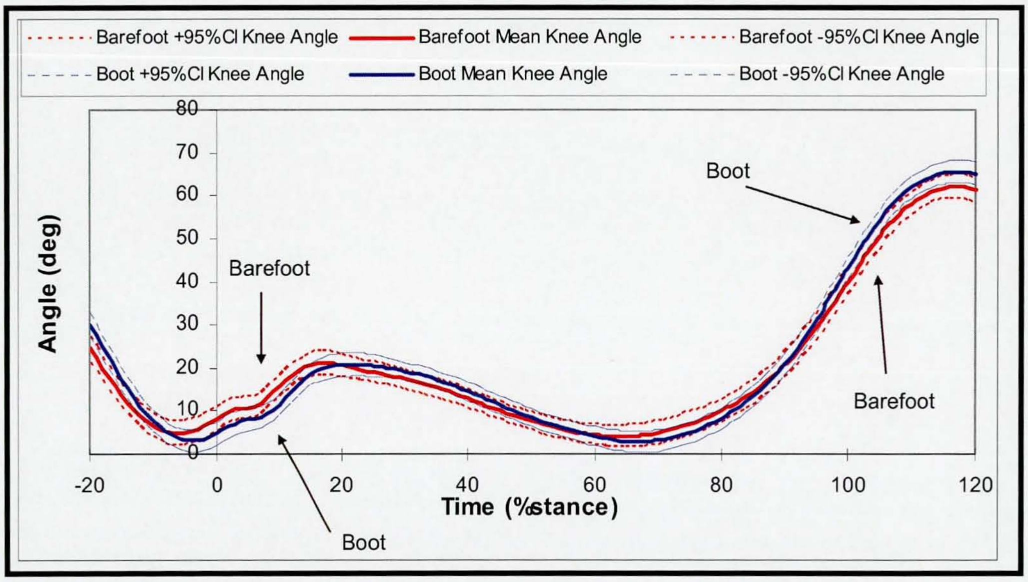


Figure 4.6: Knee movement as percentage of stance time.

In terms of spatiotemporal data significant differences were seen for all parameters (Table 4.1). These descriptive gait characteristics were derived from the heel and toe markers over time. Stride length (SL) was calculated as the distance from heel strike until the following heel strike of the same foot. The corresponding stride time was used to calculate speed and stride frequency (SF). Stance time was calculated as the period from heel strike until toe off. Walking whilst wearing military boots resulted in an increase in SL, stance time and speed and a decrease in SF.

Table 4.1: Spatiotemporal data comparing barefoot and boot walking

		Mean	SD	Significance
SL (m)	Barefoot	1.39	0.11	$p < 0.001$
	Boot	1.50	0.11	
SF (strides/min)	Barefoot	55.34	2.39	$p < 0.001$
	Boot	52.38	2.45	
Stance time (sec)	Barefoot	0.66	0.04	$p < 0.001$
	Boot	0.71	0.04	
Speed ($m.s^{-1}$)	Barefoot	1.28	0.11	$p < 0.001$
	Boot	1.31	0.11	

4.4 Discussion

The data presented in this chapter serve to explain the effect that wearing military boots has on the movement of the lower limb. Under these experimental conditions the movement of the ankle becomes restricted – assuming that the boot is in fact moving with the foot. This assumption has been made as without altering the integrity of the boot system by cutting holes in the material, it is not possible to place markers on the foot whilst inside the boot. As yet no known study has been conducted to examine the movement of the foot within a military boot.

Work examining foot movement inside the shoe has concentrated on the rearfoot complex of the ankle in athletic footwear. Two dimensional methods using two holes punched into the shoe counter have reported heel and shoe movements to be closely correlated, although offset (Clarke et al., 1983). Stacoff et al., (1992) highlights the decrease in shoe integrity when this type of methodology is used. As the sizes of the holes in the counter of the shoe are increased, an increase in in-shoe foot movement is observed. Three dimensional methods have reported no differences in inversion/eversion of the foot (i.e. foot moving the same as the shoe) but an increase in plantarflexion/dorsiflexion when wearing shoes (Attwells & Smith, 2000). The shoes examined in this study (Attwells & Smith, 2000) were athletic footwear, designed for running. In comparison, military boots present a much more rigid environment for which the foot to move in.

The purpose of military boots is to provide a stable, protective environment in which the soldier may complete their daily activity. In order to house the protective elements – items such as steel capped toes, rigid durable sole and protective leather – the flexibility of the system as a whole must be compromised. This serves to explain why the ankle movement is restricted. The loading response around heel strike takes longer as the foot pushes forward on the tongue of the boot and attempts to flex the sole of the boot. The period of dorsiflexion as the body moves over the base of support follows that of the barefoot condition, but remains at a lower value. The most indicative change however comes around toe off (Figure 4.5). The rate of plantarflexion is significantly reduced – predominantly due to the inflexibility of the sole of the military boot. This further serves to explain why the ROM of the knee and femur are greater. In order to progress forward the foot must be able to clear the ground during swing phase. As the plantarflexion of the foot is restricted the other segments must in turn increase their movement to allow the foot to clear the ground. deMoya (1982) examined US military boots in comparison to running shoes and noted that boots are significantly less flexible. He recommended boots need to be worn for a minimum of 100 miles before they become flexible enough to be considered similar to running shoes. Although kinematic data was not examined in deMoya's study, it was suggested this inflexibility may have contributed to a change in foot strike, which altered the force pattern experienced by the foot. Changes in force profile have also been noted when wearing fireman's boots (Camara & Gavilanes, 2005).

This increased ROM may have implications for the physiological cost of walking whilst wearing boots as it is the large muscle groups of the upper leg (quadriceps and hamstrings) which must work to produce the increased movement. The heavy weight of the military boot when compared to normal shoes or barefoot may also play a role. Jones et al., (1986) demonstrated an increase in energy cost when wearing military boots for women walking at speeds of $5.6km.h^{-1}$ and $7.3km.h^{-1}$. The same authors also completed a similar study with males whilst wearing military boots with similar results (Jones et al., 1984). The self selected speeds obtained in this study (4.61 $km.h^{-1}$ barefoot and 4.72$km.h^{-1}$ boot) are slower than the speeds in which Jones et al., achieved significant results. However, even at a speed of 4$km.h^{-1}$ they observed an increase in energy cost (although not significant).

Spatiotemporal data indicates significant differences between the barefoot and boot conditions in this study. Speed was self selected rather than set, as it was deemed an important experimental constraint that the individual moved without restriction. The average speed for the barefoot condition was significantly less than that of the boot condition. It would therefore be expected that the stance time whilst wearing boots would be less, with stride frequency also increased, in order to maintain this greater speed. In fact this data indicates the opposite is true. A greater stride length has been adopted in order to gain this greater speed, but a decrease in stride frequency and increase in stance time is seen. Work by Wiese-Bjornstal & Dufek (1991) examined differences between individuals wearing hiking boots and regular walking shoes. In opposition to the data presented here participants were found to spend less time in double support and less overall time in the stance phase whilst wearing boots. This was more so evident when load carriage was talking place (25%BW and 40%BW) and the authors suggested boots may provide a greater support and present less stress to the foot when under these conditions. It is possible that the comparison between shoes as opposed to barefoot data here may have resulted in the discrepancy between the results.

The experimental work presented in this chapter provides an indication of the effect that the wearing of military boots may have on movement. It may be assumed for all experimental work from this point forward that the lower limb may experience some altered biomechanics, particularly around the ankle. It may also be assumed that there may be some alteration to the spatiotemporal response. However, by conducting all further studies whilst **wearing** military boots it is hoped the effect of both of these possible changes may be minimised. Care is taken when interpreting data against other experimental work where military boots have not been worn.

Chapter 5 – Effect of Increasing Load on Gait and Posture

5.1 Introduction

Military loads are carried in a LCS as described in Chapter 2. Most previous research has concentrated on examining the physiological and biomechanical response when carrying a backpack alone rather than the whole LCS. In particular there is a shortage of information in the research domain that considers the current issue British Military LCS in terms of biomechanics. Before one may examine the different components of military LCSs and begin to suggest ideas for new design, the response of the human body to the loads it is presented on a regular basis must first be examined. This chapter attempts to answer this question by examining the biomechanical response (in terms of gait and posture) when carrying military loads using the standard British LCS. These loads are representative of those required to be carried on a 3 day exercise or mission according to UK equipment carriage policy. Information about the specifics of these loads was supplied by the Ministry of Defence (personal communication Mr Will Tutton).

The opportunity was presented to attend a military base (St Georges Barracks) at North Luffenham, UK for a period of two weeks. The military personnel occupying the base at that time were the 2nd Royal Regiment of Fusiliers (2RRF). This regiment consisted of predominantly infantry personnel, therefore specialising in heavy load carriage, particularly over long distances. The main role of the infantry within the military is to provide support to any operational activities via a ground operating force. This includes mostly outdoor work, encountering all weather conditions with long hours on exercises and operations. Some of the work occurs almost entirely on foot, especially in the role of the light infantryman, whilst equipped with the full range of small arms, mortars, ant-tank weaponry and surveillance equipment. These individuals were therefore considered an excellent participant base in order to examine the human response to carrying heavy military loads.

5.2 Method

Twenty male infantry soldiers participated in this study. In accordance with the ethical approval for these studies given by LUEAC (Protocol R03-P4) all volunteers were deemed physically fit for military duty by their regiment medical staff. All completed a health screen questionnaire prior to commencing the testing sessions and gave informed consent (see Appendices A1-A3). A selection of soldiers of varying ranks (primarily Fusiliers (lowest rank within the 2RRF)) completed this experimental work. There was a wide range in experience from 6 months through to 11 years with an average time of service of 2 years. As the infantry is presently a male only force, only male participants were recruited for this experimental work. The assessment of the effect of gender is considered in the next chapter. Participant characteristics are presented in Table 5.1.

Table 5.1: Participant characteristics (means ± SD)

Number of participants	20
Age (years)	20.2 ± 2.4
Height (cm)	176.4 ± 6.5
Body Mass (kg)	74.9 ± 11.0
Outside Leg Length (cm)	89.7 ± 4.2

The CODA mpx30 was used to obtain kinematic data for this study with marker positions and angular definitions as per those described in Chapter 3 (sections 3.5 and 3.6). For this study the replication of exact military load carriage situations was important as the aim was to evaluate the gait and posture response a member of the military would experience during training or operational activities. The current issue Standard LCS (Figure 3.16) was used. Participants also wore their standard issue military boots, helmet and carried an SA80 rifle in all testing conditions. In the final testing condition a light antitank weapon (LAW) was also carried. See Figure 3.15 for photos of the military weapons.

In total 4 testing conditions were completed by all participants in this experimental work. These were designed to replicate different situations that members of the infantry would experience during normal operational activities. For all 4 testing conditions participants were asked to walk at a self selected walking speed throughout the testing area. A sufficient area at either end of the testing area was given to ensure that natural gait patterns were obtained (5 metres each way). All trials took place in a gymnasium on a flat wooden floor. The 4 conditions were as follows and are indicated in Figure 5.1 below;

1. Control: In order to obtain a control condition for comparison purposes participants wore shorts, t-shirt, standard issue boots, socks, helmet and carried an SA80 rifle. The average weight of this addition was 7.95kg.
2. Webbing: As Control condition with the addition of standard waist belt webbing weighing 8kg. This was packed in accordance with standard marching order instructions.
3. Backpack: As Webbing with the addition of standard issue 90 Patten Bergen (long back) weighing 24kg and packed in accordance with standard marching order instructions.
4. LAW: As Backpack with addition of a Light Antitank Weapon (LAW) weighing 10.1kg under the top flap of the Bergen. Total carried weight under this final condition was 50.05kg.

A successful trial was deemed by the presence of all markers in the field of view following the execution of the movement. Once 7 successful trials for a condition were complete the participant moved onto the next condition. Conditions were always completed in the same order, as it was not pragmatic to randomise their order due to addition of equipment and marker positions in subsequent conditions.

The angles described in Chapter 3 were analysed from -20 to 120% stance phase, ensuring any anomalies around heel strike (0%) and toe off (100%) may be observed. Despite action being taken to minimise marker dropout, trials were removed when equipment failure or marker dropout distorted results. The mean for the 7 repeats was calculated for each participant.

	
Control – 7.95kg	Webbing – 15.95kg
	
Backpack – 39.95kg	LAW – 50.05kg

Figure 5.1: Experimental conditions demonstrating addition of load from control through to LAW condition

To obtain a single representation of data for each experimental condition the mean and 95% confidence intervals (CI's) were calculated for all 20 participants. The width of these CI's gives a representation of how uncertain the unknown parameter (in this case individual differences) is within the experiment. A one way ANOVA (within subjects) with repeated measures was performed on all spatiotemporal parameters and on maximum, minimum, ROM and mean values for all angular data. For the main significant pair-wise comparisons a Bonferroni correction was used and statistical significance was accepted at the 0.05 level of confidence. A Kolmogorov-Smirnov test was also completed to determine distribution of participant characteristics, with normal population achieved in terms of height and weight.

5.3 Results

5.3.1 Spatiotemporal parameters

Descriptive parameters were derived from toe and heel markers over time. Stride length was observed to increase between the control and webbing condition (Table 5.2) but decreased whilst undertaking the backpack condition compared to the webbing. Finally, a further decrease was seen in the LAW condition, bringing stride lengths back in line with the control. Stride frequency followed similar patterns, while stance time trends displayed the inverse effects to compensate (Table 5.2).

Table 5.2: Descriptive statistics of gait parameters (means ± SD)

	Control	Webbing	Backpack	LAW
SL (m)	1.52 ± 0.09	1.60 ± 0.11	1.57 ± 0.10	1.55 ± 0.09
SF (strides/min)	56.02 ± 3.14	58.37 ± 3.61	57.46 ± 4.31	57.03 ± 3.56
Stance Time (seconds)	0.60 ± 0.04	0.58 ± 0.04	0.60 ± 0.06	0.62 ± 0.05
Speed ($m.s^{-1}$)	1.42 ± 0.11	1.56 ± 0.16	1.50 ± 0.15	1.47 ± 0.12

The ANOVA revealed significant changes for all four spatiotemporal parameters. However these differences were inconsistent over the four conditions. Results showed a significantly greater speed in the webbing condition ($1.56m.s^{-1}$) compared to the control ($1.42m.s^{-1}$; $p<0.001$). Consequentially, there were significant differences in the other three parameters between these two conditions (all at significance level $p<0.05$). Differences between the webbing and backpack conditions were only seen with stance time and speed ($p<0.05$), and similarly with the backpack and LAW conditions. The webbing condition produced significantly greater speeds and shorter stance times than all the other conditions, ($p<0.05$).

5.3.2 Lower limb angular data

Measurement of the ankle angle involved the angle between 2 lines (knee-ankle and heel-toe) and an offset of 90 degrees. This produced a data series representing flexion and extension of the ankle over the period of stance. Flexion (foot moving into dorsiflexion) is represented by positive angular positions and extension (foot moving into plantarflexion) represented by negative angular positions (Figure 5.2). At heel strike the foot is in a dorsiflexed position. The ankle then undergoes a period of extension as the lower limb goes through a braking phase and absorbs ground reaction forces. Following this there is a period of flexion as the centre of mass passes over the centre of the base of support. This continues into the push off phase with the peak rate of ankle extension (i.e. plantarflexion) occurring just before toe off (100% stance). In order for the leg to successfully complete the swing phase a following period of flexion and accompanying knee flexion is then required in order for the foot to clear the ground.

The ankle showed a trend (although not significant, $p>0.05$) for an increase in the maximum angle when load was added (Figure 5.2). This maximum occurred at around 85% of stance time, occurring just before toe-off where the ankle is in a more flexed position with additional load. Due to this a trend was also seen with ankle ROM ($p=0.068$) when examining the difference between the control to LAW conditions.

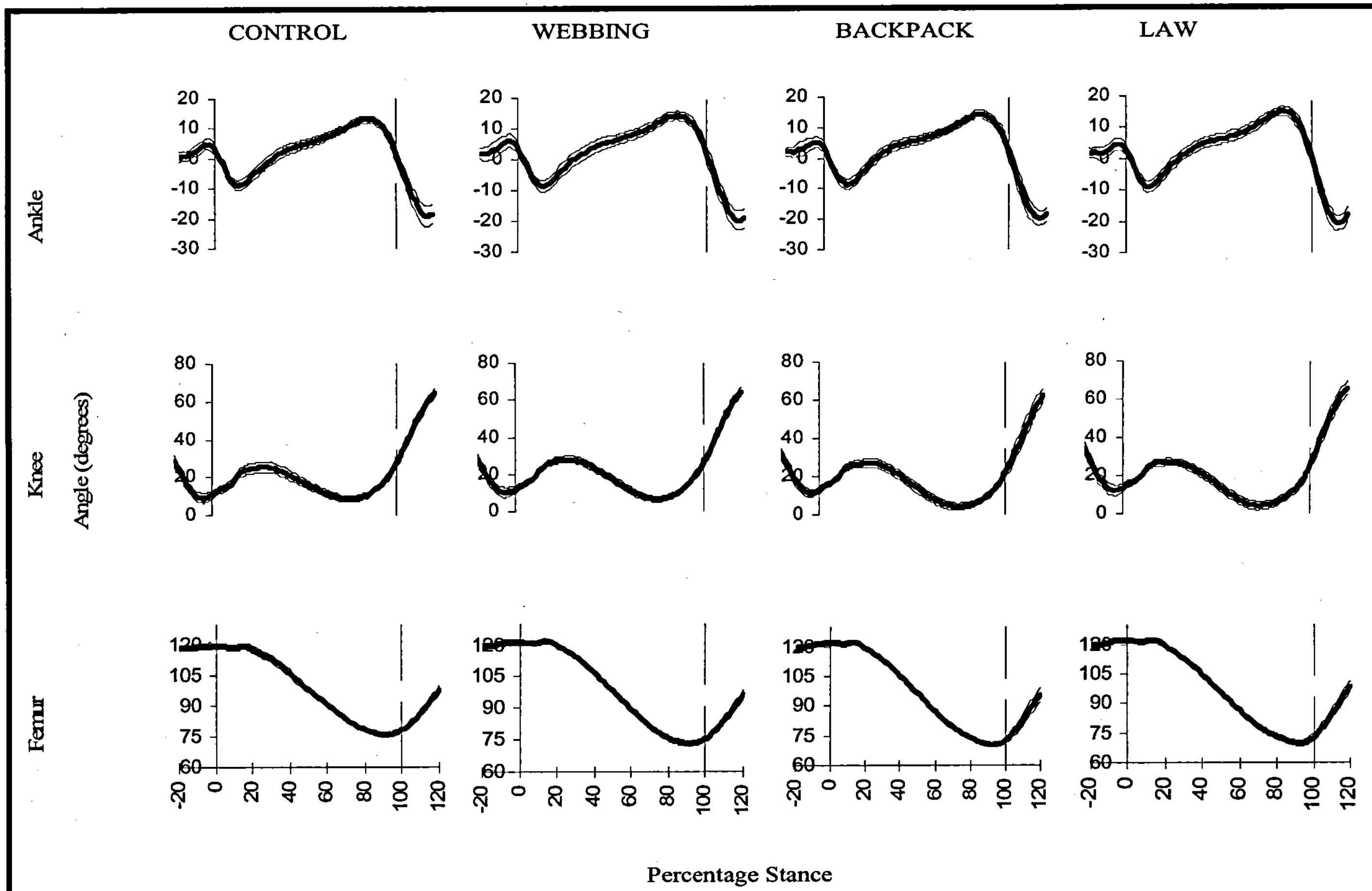


Figure 5.2: Mean ankle, knee and femur angles (±95% confidence intervals) as a percentage of stance phase over all 4 testing conditions. Heel strike at 0% stance and toe off at 100% stance (dashed line)

As with the ankle angle the knee angle represents flexion and extension (Figure 5.2). As the knee angle moves towards the negative the leg is moving into an extended position, whilst positive changes in graphical data indicate flexion. During swing phase prior to heel strike the knee is in a flexed position. This is in order to allow ground clearance of the swinging leg. Following heel strike a period of flexion occurs in order to absorb the ground reaction forces experienced by the lower limb. When walking unloaded forces that pass through the joints can be from 1-2 times body weight (depending on speed), therefore in terms of injury it is important that these forces are absorbed (Keller et al., 1996). When carrying load these forces are increased as demonstrated by a number of previous studies (Harman et al., 2000a; Kinoshita, 1985; Knapik et al., 1992; Lloyd & Cooke, 2000a). As the body moved through mid stance extension of the knee occurs once again. This is to allow the body to pass over the foot, following which there is a flexion of the knee again in preparation for the push off phase. This flexion period allows the propulsion muscles of the thigh to be places in a shortened state ready for lengthening in order to propel the body.

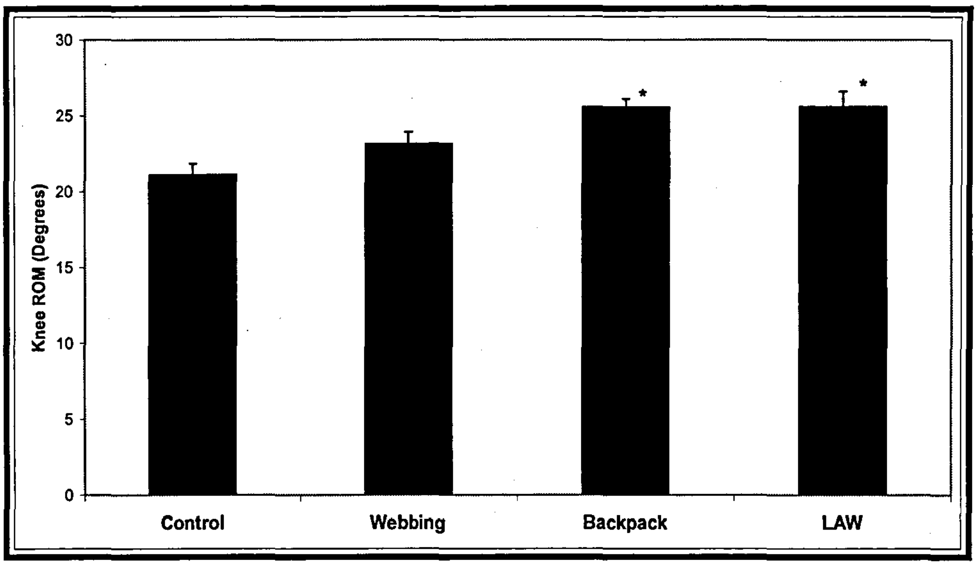


Figure 5.3: Knee ROM throughout all 4 conditions. Measured from 0-100% stance only. (* significance at $p < 0.005$ compared to control condition)

As load was added the ROM at the knee increased (Figure 5.3). Significant differences were observed between the control and backpack and LAW conditions ($p<0.005$), the same trend being seen with the addition of webbing. ROM at the knee increased from 21.1° ± 3.0 in the control condition to 25.5° ± 2.3 with the backpack. The ROM increase at the knee is due to increased flexion at heel strike and during the loading response phase (0-25% stance time), and greater extension at the beginning of toe-off (approximately 80% stance).

In terms of movement of the femur, it is linked by definition to the movement of the knee. At heel strike it is therefore seen to be in a flexed position following ground clearance during swing phase. As the body passes over the foot the angle passes through 90 degrees (which is when the thigh is vertical) and then goes into extension as the preparation for toe off occurs (Figure 5.2). Following toe off there is another period of flexion in order for the leg to be raised and clear the ground ready for the next heel strike.

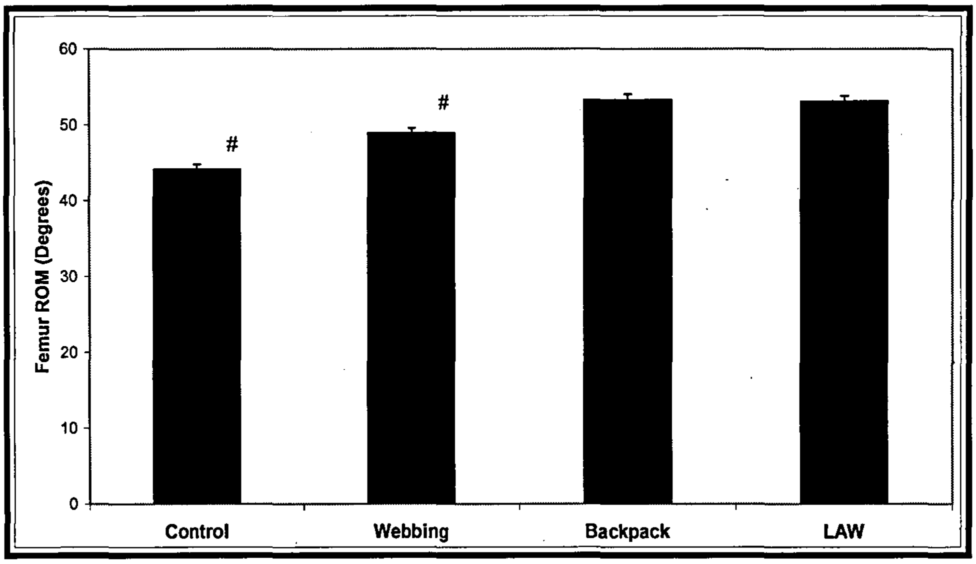


Figure 5.4: Femur ROM throughout all 4 conditions. Measured from 0-100% stance only. (# significance at $p < 0.001$ compared to all conditions)

The femur angle also increased with load (Figure 5.4). There was a significant difference between control and webbing conditions ($p<0.001$). The backpack and LAW conditions were both significantly different from the control and webbing conditions ($p<0.001$) but not from one another. Also, the addition of any load significantly increased the maximum femur angle ($p<0.005$). Femur ROM increased due to increased flexion of the hip at heel strike (or a higher knee lift), and greater extension during the toe-off phase, the knee being further away from the mid-line of the body.

5.3.3 Upper body segment movement

The movement of the trunk throughout stance was only a few degrees within a single condition. The more negative an angle the greater the forward lean being exhibited by the participants (Figure 5.5). Around heel strike there is usually an increase in forward lean but then as the body passes through mid stance there is a tendency for a more upright position. An increase in forward lean is seen again around toe off in order to assist in propulsion of the body. A similar response is seen in the craniovertebral angle (Figure 5.5). A slight increase is seen following heel strike, and then a slight decrease as the body moves through stance phase.

The trunk and craniovertebral angles showed significant changes with the addition of load (Figure 5.5). The trunk angle showed no change in ROM or in the distribution of the data. To counter-balance the effect of load, the participant leant further forward ($p<0.005$) as indicated by decreasing values of trunk angle, becoming negative forward of vertical. During the control condition the mean trunk angle for the stance phase was $4.8° \pm 1.9$, decreasing to $-13.0° \pm 2.7$ with the LAW. The craniovertebral angle showed similar patterns to the trunk angle with no significant change in the ROM or data distribution, but changes to the mean values were observed (Figure 5.5). No significant changes were observed between the control and webbing conditions ($p>0.05$), but adding a backpack and then a LAW had the effect of significantly decreasing this angle ($p<0.001$) indicating a more forward head posture.

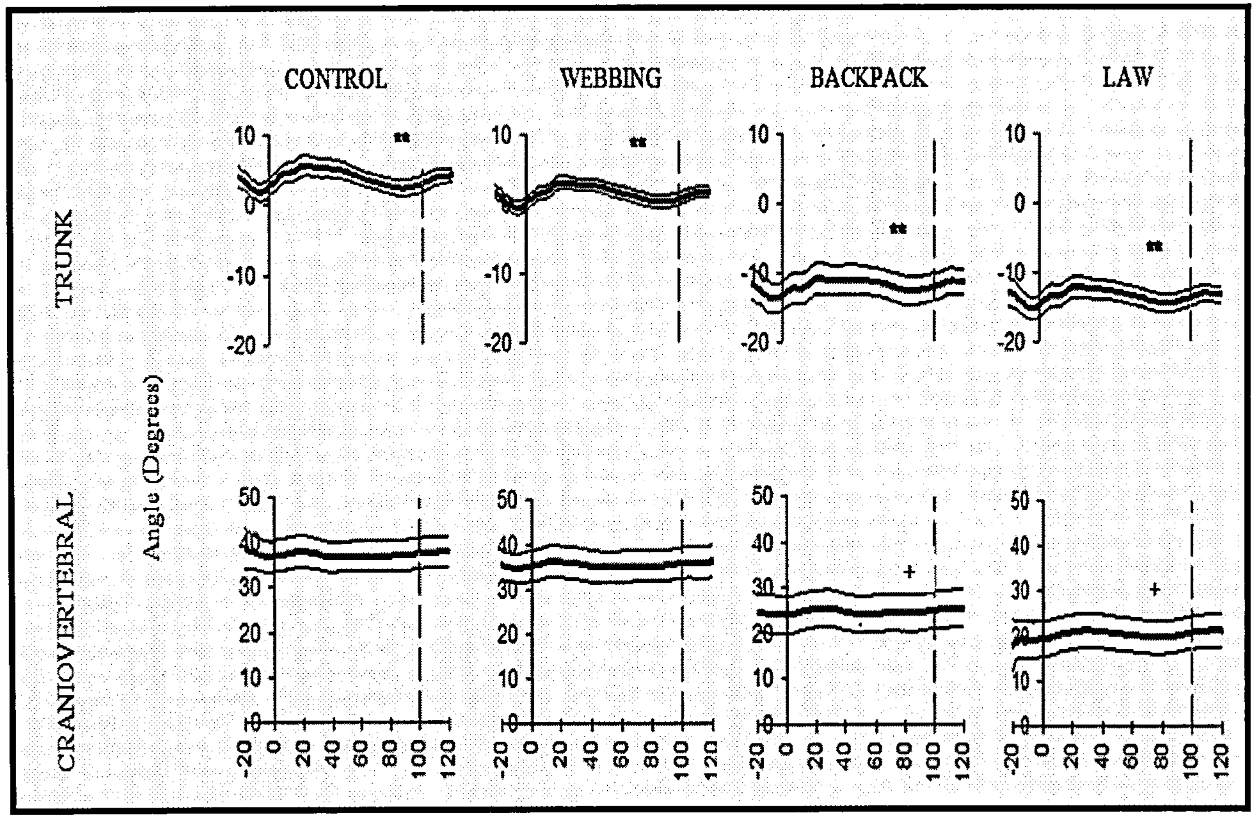


Figure 5.5: Mean trunk and craniovertebral angles (± 95% confidence intervals) as a percentage of stance phase over all four testing conditions

** = significance at $p < 0.005$ compared to all conditions

+ = significance at $p < 0.001$ compared to control condition

5.4 Discussion

5.4.1 Spatiotemporal parameters

As walking speed was participant selected, variation was expected. The higher mean speed observed in the webbing condition was unexpected. A change in speed resulted in changes in stride length and stride frequency. In work by Harman et al., (2000b) similar observations in spatiotemporal data were seen. These resulted in alterations of ankle and hip ROM. However, knee and trunk angular changes were unrelated to changes in spatiotemporal data.

As load increases stride length normally decreases, increasing the period of double support, so providing greater stability. However, this has only been reported at fixed pace. With self selected pacing such observations have not been as clear (Charteris, 1998; Harman et al., 1992). This is supported by the present results as differences in stride length were only seen with the addition of webbing. It also suggests little can be concluded from the faster speed in the webbing condition; it may be artefactual, perhaps a consequence of military training, or due to the fixed order of the conditions presented.

Conclusions from this data are limited as just one CODA™ sensor unit was used, meaning that only unipedal gait could be examined. Double support and swing time measurements were not possible; therefore comments on the changes implemented to increase stability (by having 2 feet on the ground) are unable to be made. From the gait parameters indicated in Table 5.2 it may be suggested that an increase in double support would occur, as an increase in stance time was seen. In the present study only 2-D saggital kinematics were analysed due to the military equipment obscuring marker positioning around the pelvis. It has been suggested that changes in stride length and frequency could result from a decrease in pelvic rotation when a load is carried (LaFiandra et al., 2003). It would be interesting to speculate whether (military) training, especially the use of set pacing, would cause differing responses when compared to civilian participants.

5.4.2 Angular response of the lower limb

As mentioned in section 5.4.1, changes in ankle ROM can occur as speed changes (Harman et al., 2000b). Also, changes in the flexion and extension of the ankle may be affected by the addition of load. Trends for changes in the ankle angle were only observed in this study when comparing control to LAW conditions. Kinoshita (1985) suggests this is due to increased dorsiflexion of the foot that facilitates greater knee flexion, ultimately absorbing the impact forces at heel strike.

Load might be expected to increase both the flexion and extension that occurs at the knee, simply because of the need to transport a greater mass and the associated increased energy requirement. Also, increased knee flexion at heel strike is seen as a protective measure to help absorb impact forces. In the present study there is a significant increase in the ROM as load is increased compared to the control condition (Figure 5.3). This response to load has been found by several researchers (Harman et al., 2000a; Kinoshita, 1985). The work by Harman showed greater flexion at heel strike and extension at toe-off, resulting in significant increases in knee ROM, as load increased.

Range of motion of the femur angle was significantly different between all conditions apart from backpack to LAW, increasing with load. Harman et al, (2000a) noted there was an increase in the degree of hip motion as increased load was applied. They suggest that the increased forward lean of the trunk accounted for this change. The angle measured in their study was relative to the trunk, whereas these data are relative to the horizontal and therefore remove the effect of the trunk. The change in femur angle must be due to other factors. As there is no difference in stride length between the two conditions the effect of load is the most likely explanation. A significant increase in maximum femur angle with added load may be another factor contributing to the absorption of impact forces, increasing as knee flexion increases.

5.4.3 Angular response of the upper body segments

Forward lean of the trunk has been the most commonly reported parameter in the biomechanical literature involving load carriage. An increase in forward lean has consistently been observed as increasing load is applied (Filaire et al., 2001; Goh et al., 1998; Harman et al., 2000a; Kinoshita, 1985; Martin & Nelson, 1986; Pascoe et al., 1997). Craniovertebral angle has not received as much attention. It provides an estimation of the head and neck positioning on the upper trunk (Chansirinukor et al., 2001). Both angles were measured in this study.

The trunk angle was defined as the angle between the vertical and a line joining the virtual greater trochanter and C7 markers. As it was not possible to place markers elsewhere on the spine due to the backpack, movement about the hips may have influenced these data. The more negative this angle the greater the forward lean. What can be clearly seen in Figure 5.5 is the effect that the addition of load has on trunk angle. In the control condition there is a more vertical, upright posture. The addition of webbing causes significant forward lean that is accentuated by addition of the backpack and finally the LAW.

These findings support previous research. Differing methods of measuring trunk angle have been used, but the same result has been produced. Load induces forward lean, necessary to rebalance the moments pivoted around the hips and to stabilise the body's centre of mass (Goh et al., 1998; Gordon et al., 1983; Kinoshita, 1985; Martin & Nelson, 1986; Pascoe et al., 1997). A more upright posture is usually considered more efficient when carrying load (Harman et al., 1999a) but it may inhibit forward advancement of the body with load on the back (Kinoshita, 1985).

Excess forward flexion would be resisted by eccentric contraction of the hamstrings and semispinalis muscles, placing them at risk of fatigue and injury when carrying heavy loads for sustained periods (Gordon et al., 1983). Carrying heavy loads may also be risk factor for lower back injury due to the increased stresses placed upon the back muscles and discs. Stresses acting on different zones of the spinal column are also of importance when considering load carriage. Vacheron et al, (1999b) noted a decrease in inter-segmental mobility in both lumbar and lower thoracic regions of the spine whilst carrying 22.5kg. Compensation for this increased the ROM in the cervical region, suggesting enhanced head/neck movements. These matters must be taken into consideration when examining the trunk as a whole, as in this study, and also the implications of these restrictions for the incidence of back pain.

Occupational or cultural requirements result in loads being carried on the head (African tribes), stabilised around the forehead (Sherpas), a yoke across the shoulders or, as here, in a backpack. The closer a load is to the body's mid-line (i.e. centre of mass), the smaller the change in posture (Harman et al., 1994; Kinoshita, 1985), although even very light loads (3-10% BW) can cause an increase in forward lean (Grimmer et al., 2002). Therefore, carrying loads on the head might be considered advantageous, especially as head carriage is physiologically beneficial (Datta & Ramanathan, 1971; Soule & Goldman, 1969). When considering this as an option, head loads should be carried instead of, rather than in addition to, the load already being carried. Military loading on the head already occurs in terms of helmets, night vision goggles and electronic sights. Set against possible benefits of head load carriage are the increased stresses on the small muscles of the neck and an increase in lateral moment of the body when traversing uneven terrain.

Another key measure of an individual's posture involves examination of head position relative to the position of the upper trunk. Many recent studies concerning the effect of loads have not included this parameter, although it has been reported in a static examination of 160 individuals (Raine & Twomey, 1997) and in a study of school children carrying loaded backpacks (Chansirinukor et al., 2001). In the latter, backpack loads of 15% BW caused an increased forward position of the head. Using loads up to 66% BW (LAW condition) this finding was corroborated here, the craniovertebral angle decreasing with load. The data in Figure 5.5 indicate little, if any, change in the head-to-trunk line with load, the decreased craniovertebral angle resulting from the increased forward lean.

Therefore the moment created by the head about the neck must have increased with load, forming a counterbalancing unit with the trunk. This unit thereby provides dynamic balance to stabilise the body. But, these greater moments imply increased stress on the neck muscles. The resulting strain has been associated with musculoskeletal dysfunction, head and neck aches and craniofacial and shoulder pain (Raine & Twomey, 1997).

5.5 Chapter summary and conclusions

The aim of the experimental work presented here was to examine the effect heavy military loads carried in a British Standard Issue LCS had on the gait and posture of military personnel. The importance of such experimental work is upheld by the fact that load carriage is still a necessity in the military. It is therefore also important that it is as efficient and injury free as possible.

The main biomechanical effects due to increased load demonstrated by this work include increased ROM of the knee and femur in the lower limb, increased forward lean and increased moments created by the head acting with the trunk as a counterbalance when load is increased. All of these changes influence muscular recruitment, necessitating increased muscular force to carry the load, which perhaps may exacerbate the potential for injury to occur. No injury was reported during this experimental work. However, the period of load carriage duration examined was brief and it is expected that periods of load carriage close to those used in operational activities (e.g. 2 hours) or after a long march (e.g. 20km) may impact more highly on the potential for injury to occur. This is examined more closely in the experimental work in Chapter 8.

The current experimental study allowed a baseline of information to be gathered onto which changes due to gender, load carriage duration or changes in LCS design may be compared. In terms of the user group that participated, variability between participants was small, suggesting that the effects seen here would be similar across military personnel with similar roles i.e. infantry. The effect of level of training has not been examined however, and it is expected that more experienced special forces for example would exhibit a different response to new military recruits.

Chapter 6 – Effect of Gender and LCS Design on Gait and Posture

6.1 Introduction

Following the baseline work presented in the previous two chapters, the general effect of military footwear and increased load has been demonstrated. As all members of the military are under constraints to wear and use such equipment, considerations of the possible differences in personnel or military equipment may now be addressed. This chapter is split into two parts. The first experimental trial examines the effect gender plays in the response to military load carriage. The second part then assesses what influence changes in design have on the body's response to carrying military loads. Both of these trials were conducted at Loughborough University in the Load Carriage Laboratory. Although every attempt was made to source members of military personnel for these studies, none were available at the time of experimental trials taking place. There was a particular issue with the availability of female personnel. Therefore, these experimental trials were conducted on civilians whose load carriage experience is outlined within the methodology section.

As mentioned in Chapter 2, current restrictions in the UK do not allow females to serve in close combat roles on the front line; such as being a member of the infantry. A number of factors including physiological and psychological characteristics have been cited as reasons, but a specific issue quoted is the ability to carry military loads (MOD, 2002). Although these issues are noted, no study has been published comparing the genders whilst carrying military load carriage equipment that is currently issued to British personnel. The secret and restricted nature of some military research means that it is possible work has been completed in this area but not disseminated to members of the public. Therefore, in order to gain a full understanding of all factors that may affect the ability to carry loads, a study comparing genders was conducted.

The second part of this chapter highlights the response when the location of the load carried is altered through changes in equipment design. Advancements in technology combined with an array of new equipment are placing an increased weight burden on soldiers, as well as reducing the space in which to carry the load. It has been well documented that moving the load carried closer to the centre of mass produces changes to physiological (Martin & Nelson, 1986; Obusek et al., 1997; Vacheron et al., 1999a) and some biomechanical factors (Bobet & Norman, 1984; Harman et al., 1994; Holewijn & Lotens, 1992a), but trade off's may be present in terms of discomfort experienced by the individual carrying such a load (Johnson et al., 1995). Therefore a prototype LCS and relocation of the load within the current issue LCS was examined.

PART I – Gender experimental study

The aims of this experimental study are as follows;

1. To demonstrate any differences that exist in biomechanics of gait and posture when comparing males and females carrying the same military load.
2. To examine if there is any effect due to body size rather than gender.

6.2 Method

Twenty participants (10 male and 10 female) participated in this study. All participants were experienced in some form of load carriage (University Air Squadron (n=7), Army Officer Training Corps (n=2), Territorial Army (n=3) and regular backpackers (n=8)) but none were members of currently serving military. Participant characteristics are outlined in Table 6.1. This work was supported by the LUEAC (Protocol G03-18) with all participants completing a health screen questionnaire and giving informed consent (see Appendices A4-A6) before undertaking any experimental work.

Table 6.1: Participant characteristics (mean ± SD)

Female		Male	
Age (years)	27.3 ± 7.2	Age (years)	21.4 ± 1.8
Height (cm)	170.0 ± 6.7	Height (cm)	180.7 ± 7.2
Body Mass (kg)	68.8 ± 6.3	Body Mass (kg)	78.6 ± 8.4
Greater trochanter height (cm)	87.4 ± 5.5	Greater trochanter height (cm)	93.5 ± 4.4
C7 height (cm)	142.9 ± 5.4	C7 height (cm)	154.3 ± 7.0

As with the previous experimental study (Chapter 5) the CODA mpx30 was used to obtain kinematic data for this study with marker positions and angular definitions as described in Chapter 3 (sections 3.5 and 3.6). The current issue Standard LCS (Figure 3.16) was also used. Participants wore standard issue military boots (all sizes provided), t-shirt, shorts and military socks and carried a replica SA80 rifle in all testing conditions. A replica rifle rather than actual rifle was used because civilians were the participants in this study. However it was deemed important to replicate as close as possible the stance a soldier would have to maintain, especially since elements of posture were being examined.

All participants in this study completed three testing conditions. These were designed to replicate load carriage conditions that would be experienced by the military during operational activities. During all conditions participants walked at a self selected pace along the walkway with embedded force plate (see Figure 4.3). A successful trial was determined by placement of the right foot fully within the boundaries of the force plate with all markers successfully acquired prior to and for a full stride following the foot strike on the force plate. Following the completion of 7 successful trials within a condition the participant moved onto the next experimental condition. Trials were completed in the same order due to addition of equipment.

The 3 experimental conditions (Figure 6.1) were as follows:

Boot: as barefoot condition with addition of military boots and socks (average total addition to body weight 2.4kg)

Webbing: as boot condition with addition of standard issue belt webbing with 7% body weight (BW) load

Bergen (Backpack): as webbing with addition of standard issue PLCE Bergen with 33%BW load

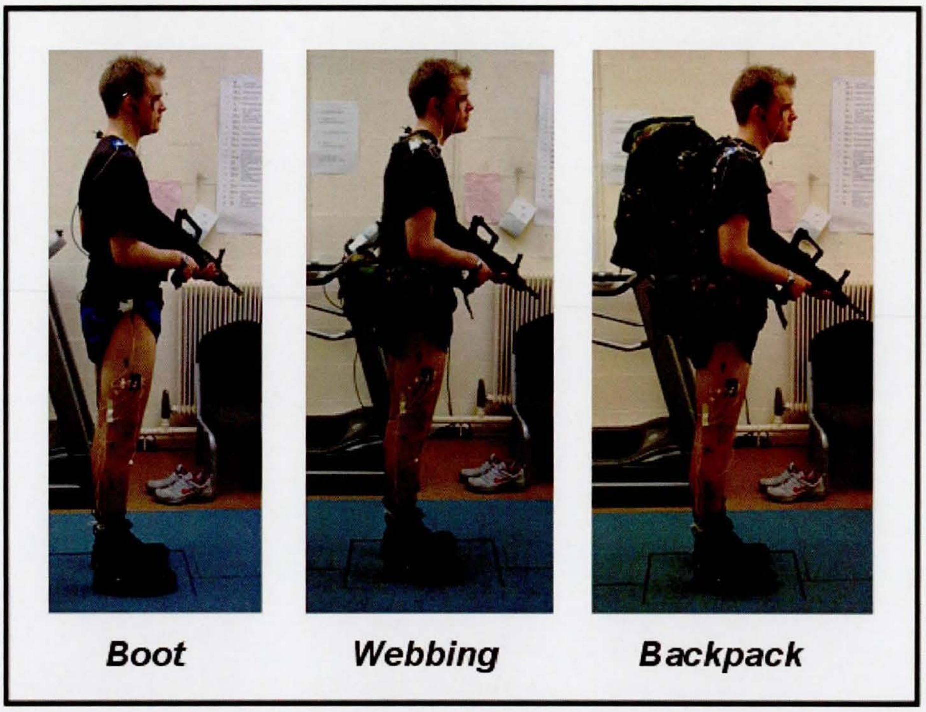


Figure 6.1: Experimental conditions for gender trial demonstrating 3 loading conditions

The angles described in Chapter 3 were calculated from -20% to 120% stance phase ensuring any anomalies around heel strike (0%) and toe off (100%) were observed. Despite action being taken to minimise marker dropout, trials were removed when equipment failure of marker dropout distorted results.

Representing the data as a percentage of stance phase also allowed the effect of time and walking speed to be removed.

The mean for the 7 repeats was calculated for each participant. In order for comparisons to be made between experimental conditions group data was expressed as the mean and 95% confidence intervals for all 20 participants. A 2-way mixed ANOVA was conducted on all spatiotemporal data and maximum, minimum, mean and ROM values for all angles (significance set at $p=0.05$). Post hoc Pearson correlations were examined between angular outcomes and participant characteristics.

6.3 Results

6.3.1 Participant characteristics

A test of normality was conducted across the gender groups to determine if a typical population had been recruited for this study (Kolmogorov-Smirnov). Height and weight for both groups fell within a normal distribution. This was also concluded when adding the entire population together. In terms of age however, males did not show a normal distribution as many were around the same age (mode = 22).

Unpaired t-test analysis was also conducted between the genders. In height, weight, age, greater trochanter height and C7 height, males and females were significantly different ($p<0.05$) from each other with females generally being shorter, lighter and older than the male population.

6.3.2 Spatiotemporal parameters

The addition of load resulted in significant decreases in stride length, stride frequency and speed, therefore increasing stance time (see Table 6.2). Independent t-test examination between boot and backpack conditions indicated women significantly ($p=0.03$) compensating more in terms of stride frequency as load increased. All other spatiotemporal parameters showed no gender differences.

Table 6.2: Descriptive statistics of gait parameters (mean ± SD)

	Boot	Webbing	Backpack
Stride Length (m)	1.50 ± 0.11	1.50 ± 0.13	1.48 ± 0.14#
Stride Frequency (strides/min)	52.38 ± 2.45	51.95 ± 2.90	51.20 ± 3.14# *
Stance Time (seconds)	0.71 ± 0.04	0.72 ± 0.04*	0.75 ± 0.05#*
Speed ($m.s^{-1}$)	1.31 ± 0.11	1.30 ± 0.13	1.26 ± 0.14# *

* significantly different to boot ($p<0.05$)

significantly different to webbing ($p<0.05$)

6.3.3 Lower limb angular data

The movement of the lower limb through stance is described in section 5.3.2. Gait kinematics examined here did have some gender specific qualities with females having less ROM at the knee (Figure 6.2) and greater ROM in the femur angle (Figure 6.3) (average 4.6° for both – these angles linked by definition). There was also a trend for greater ROM in the ankle for females (Table 6.3).

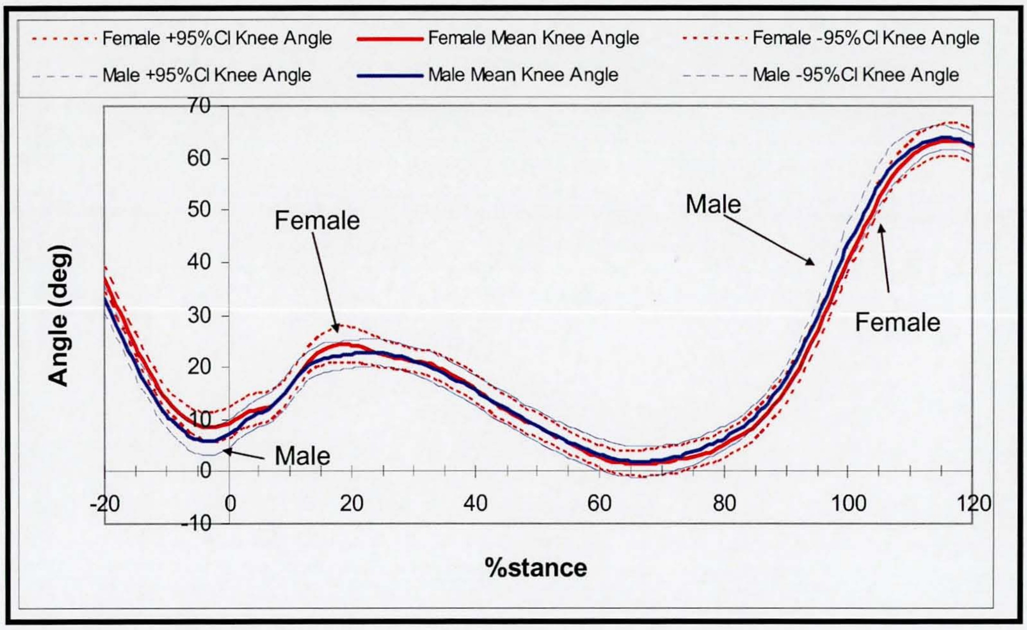


Figure 6.2: Gender differences in knee angle in backpack condition as a percentage of stance time. Males (blue) demonstrating a greater rate of flexion towards 100% stance

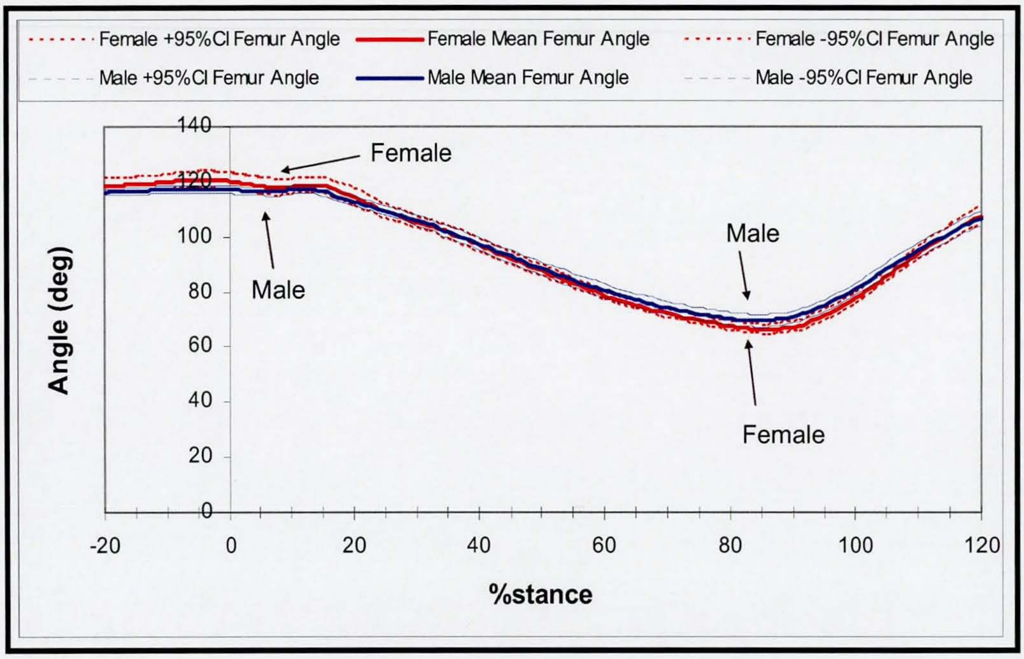


Figure 6.3: Femur angle in backpack condition as a percentage of stance time. Females (red) indicate a greater ROM throughout stance

In terms of the effect of load, as load increased significant increases were seen in ankle ROM ($p<0.01$) and femur ROM ($p<0.01$) with associated significant changes in maxima and minima values ($p<0.01$ in all cases). No changes were seen in knee angular data with addition of load. These data are also indicated in Table 6.3 below.

Table 6.3: Changes in gait angular data ROM (degrees) with changes in load (mean ± SD)

	Ankle		Knee		Femur	
	Female	Male	Female	Male	Female	Male
Boot	21.00±2.36	20.31±2.66	38.72±3.29	44.03±2.99	47.70±3.96	43.62±4.03
Webbing	22.15±2.35	21.10±2.01	39.60±3.67	44.84±2.86	49.90±4.23	45.76±4.47
Backpack	22.88±1.90	22.01±2.03	39.28±5.28	45.54±2.83	54.28±4.55	48.65±4.98

Post hoc Pearson correlations were conducted on the differences in ROM against participant characteristics. This was completed for all 3 experimental conditions. Height (cm) and body mass (kg) of the entire population was positively correlated with knee ROM and negative correlated with femur ROM. Figures 6.4 and 6.5 demonstrate these relationships with Table 6.4 indicating the Pearson correlation (r^2) and significance values (p).

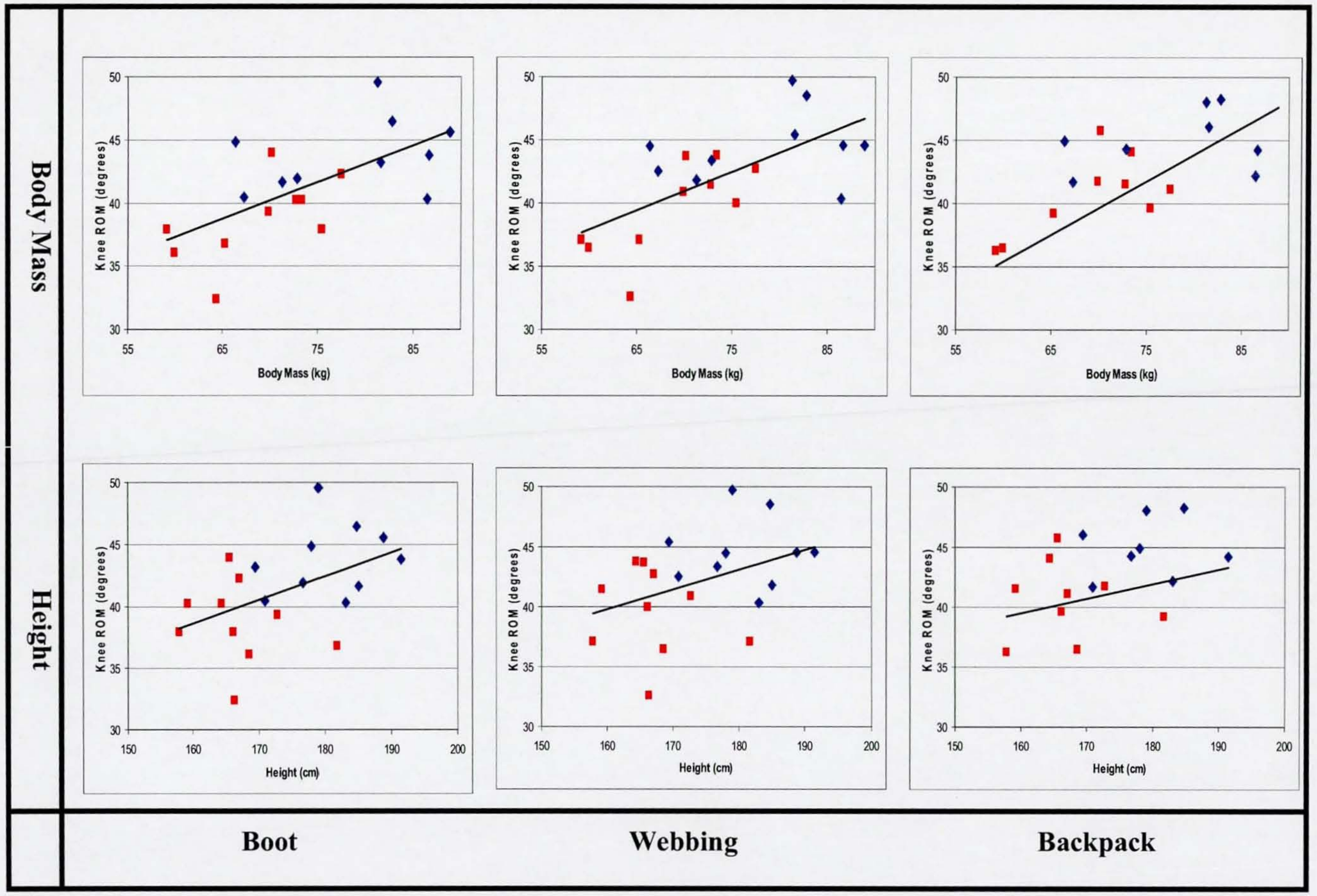


Figure 6.4: Knee ROM correlations with height and body mass for all 3 experimental conditions. Individual data points are shown for females (■), and males (◆)

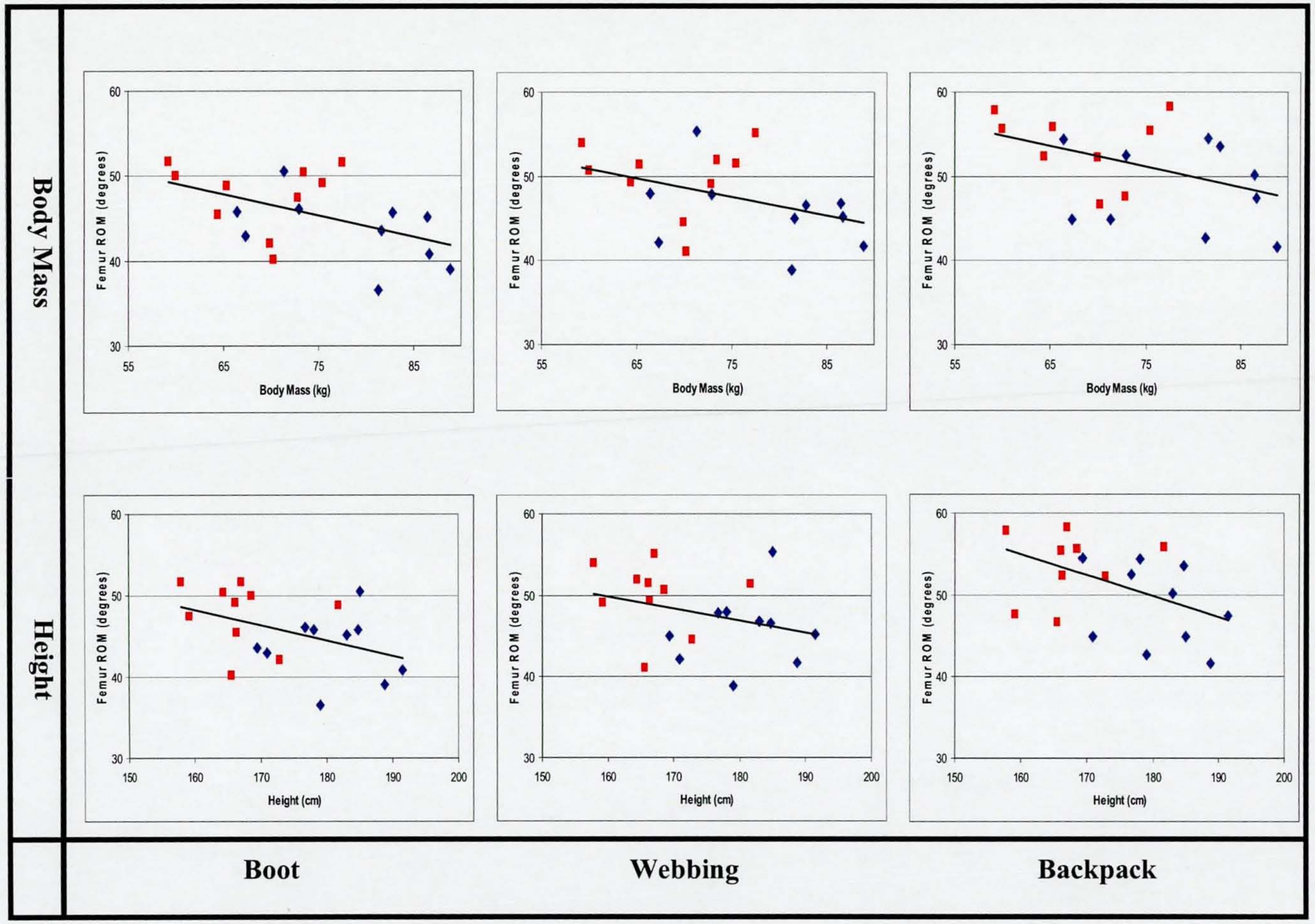


Figure 6.5: Femur ROM correlations with height and body mass for all 3 experimental conditions. Individual data points are shown for females (■), and males (◆)

Table 6.4: Pearson correlation (r^2) and significance (p) values of correlations between height and body mass across conditions for knee and femur ROM. Correlations significant at the 0.01 level ** (2 tailed) and 0.05 level * (2 tailed)

		Knee ROM		Femur ROM	
		Height	Body Mass	Height	Body Mass
Boot	r^2	0.224	0.411	0.240	0.176
	p	0.035 *	0.002 **	0.027 *	0.065
Webbing	r^2	0.158	0.430	0.172	0.091
	p	0.082	0.002	0.069	0.198
Backpack	r^2	0.029	0.283	0.152	0.215
	p	0.476	0.016 *	0.089	0.039

6.3.4 Upper body segment movement

The movement of the upper body segments through stance has been explained in section 5.3.3. Minimal gender differences were seen in all body posture angles measured. Trunk ROM (Figure 6.6) was the only variable showing any significant difference, where females exhibited a greater ROM over the testing conditions averaging 1.9°. A trend for a more forward head posture indicated by a smaller craniovertebral angle in females was also seen in the backpack condition although not significant (p=0.063) following independent t-test analysis. As experimental conditions changed females showed a differing response to males, being more upright until the addition of the backpack, when they were in a more forwardly inclined position (Figure 6.7). This correlates with the females having a trend for a more forward craniovertebral angle. Post hoc Pearson correlations showed no correlation for trunk ROM with any participant characteristics with the exception of height in the boot condition (Figure 6.8). This indicated a significantly negative correlation (r^2=0.264, p=0.021).

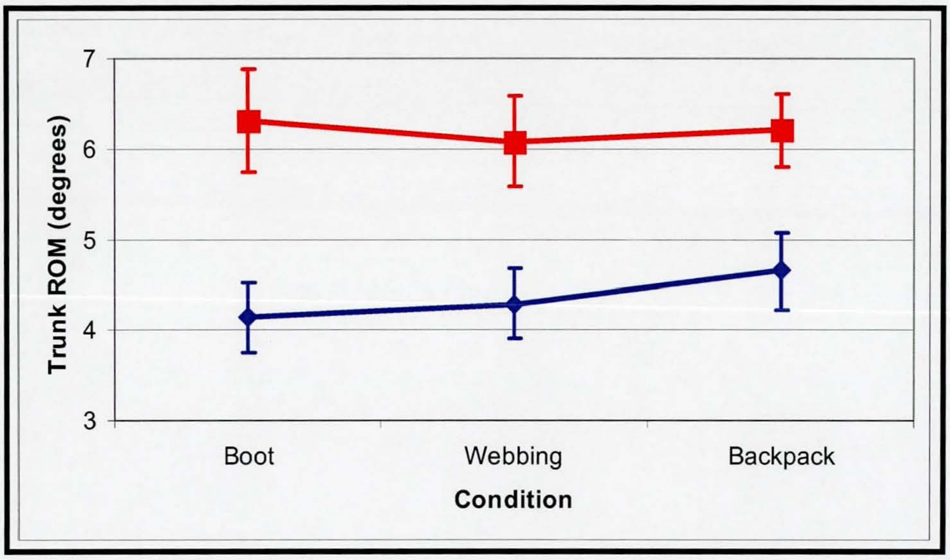


Figure 6.6: Trunk ROM over the three experimental conditions. Significant effect of gender noted at $p<0.05$

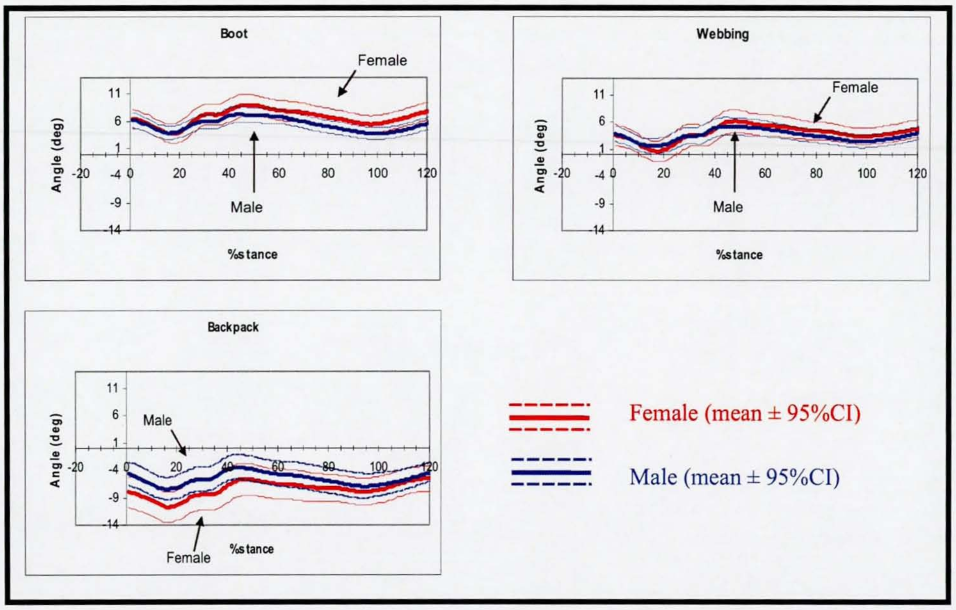


Figure 6.7: Gender differences in trunk angle over the three experimental conditions. Movement of females from more upright (boot) to exhibiting greater forward lean (backpack)

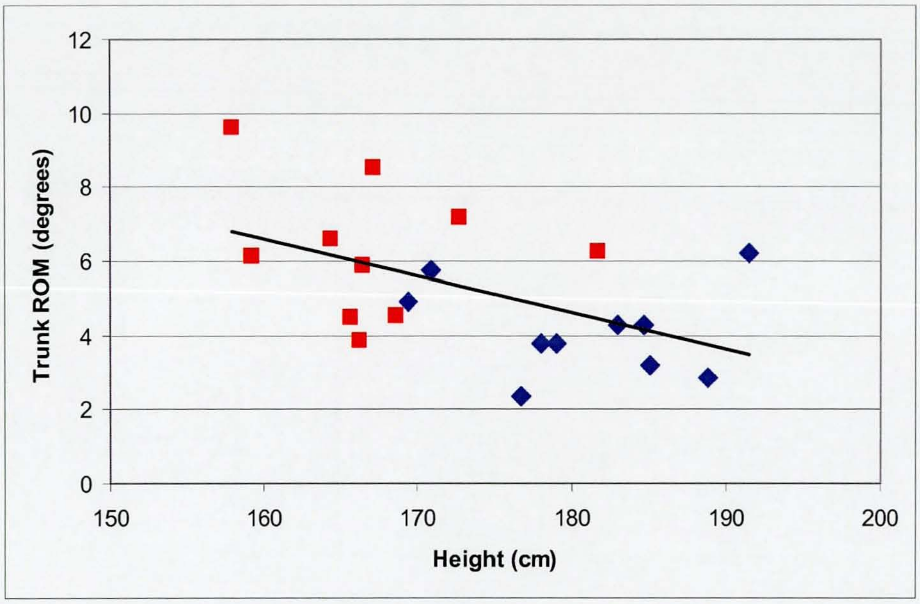


Figure 6.8: Trunk ROM correlation with height (r^2=0.264, p=0.021) in the boot condition. Individual data points are shown for females (■), and males (◆)

In terms of effect of addition of load, a significantly greater forward lean (average value) was seen as load increased ($p<0.01$). There is also a main effect of load for maxima ($p<0.01$) and minima ($p<0.01$) values of the trunk angle. The greater forward lean as load is added is demonstrated in Figure 6.7 with the positions of the graphed data becoming more negative (a more upright body position is indicated by a more positive number). The response of the craniovertebral angle was similar with a main effect of load seen across conditions ($p<0.01$) for maximum, minimum and mean values. No change in ROM was seen. Finally the craniohorizontal angle showed minimal difference until the addition of the backpack when a significantly more forward position was seen for maximum, minimum and mean values ($p<0.01$ for all).

6.4 Discussion

This study examined the biomechanics of males and females when carrying loads. Several gender differences were seen, although in most cases the responses of females were similar to males. It is more evident that there may be an effect of body size rather than gender.

6.4.1 Lower limb and spatiotemporal response

In terms of spatiotemporal parameters, changes occur in order to increase the stability of the individual whilst load carrying; i.e. increasing the time when both feet are on the ground by increasing stance time and decreasing stride length, stride frequency and speed. The extent and nature of these changes is dependent on pace characteristics of locomotion with differing responses being seen in set paced as opposed to free pace investigations. Results seen in this study are similar to those seen in set paced studies (Charteris, 1998; Harman et al., 1992; Martin & Nelson, 1986), whereas a self-selected pace study by Ghori & Luckwill (1985) showed no changes in stance time for loads up to 50% BW. They did however indicate a decrease in swing time as load increased, suggesting that the percentage of stance time throughout the stride was increased as load increased.

Response due to gender has also resulted in differing conclusions in the literature; minimal differences when walking at a controlled speed of $1.25 m.s^{-1}$ (Nigg et al., 1994), women with slower speed and shorter stride length (Cho et al., 2004) and decreased stride length and greater stride frequency when walking at a self selected speed (Kerrigan et al., 1998).

These studies have all examined the effect of gender whilst walking but not whilst carrying a load. The only known study to date examining these parameters when carrying military loads is by Martin and Nelson (1986). At a set walking speed of $1.78 m.s^{-1}$ females were shown to have a decreased stride length and consequential increased stride frequency when compared to males. The speed in this current study (Table 6.2) was significantly slower than that used in the Martin and Nelson study and may have influenced the results obtained here. However trends in the current data were seen for females to have lower stride length (as noted in Martin and Nelson's study) and speed in all conditions (Figure 6.9) but no difference at all in stance time.

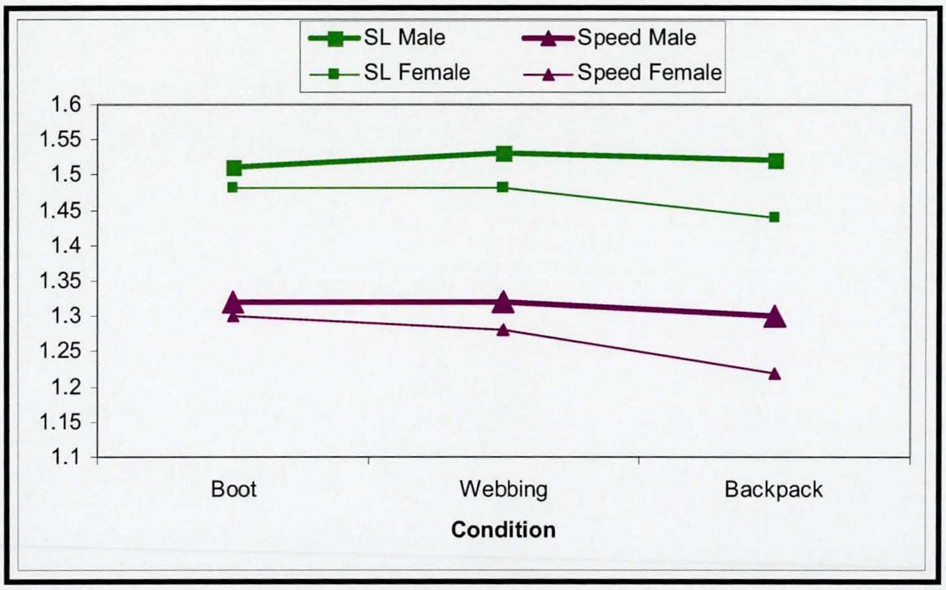


Figure 6.9: Gender differences in stride length (m) and speed ($m.s^{-1}$) for 3 loaded conditions

In contrast to the Martin and Nelson study, stride frequency here was initially greater in females but then showed a greater decline as load increased, being less than males in the backpack condition (Figure 6.10). Independent t-test analysis examining the difference between backpack and boot values showed a significant gender difference, suggesting females were compensating more due to load than males. This is also indicated in the Martin and Nelson study by a sharper incline in the female data than in the male (Figure 6.10).

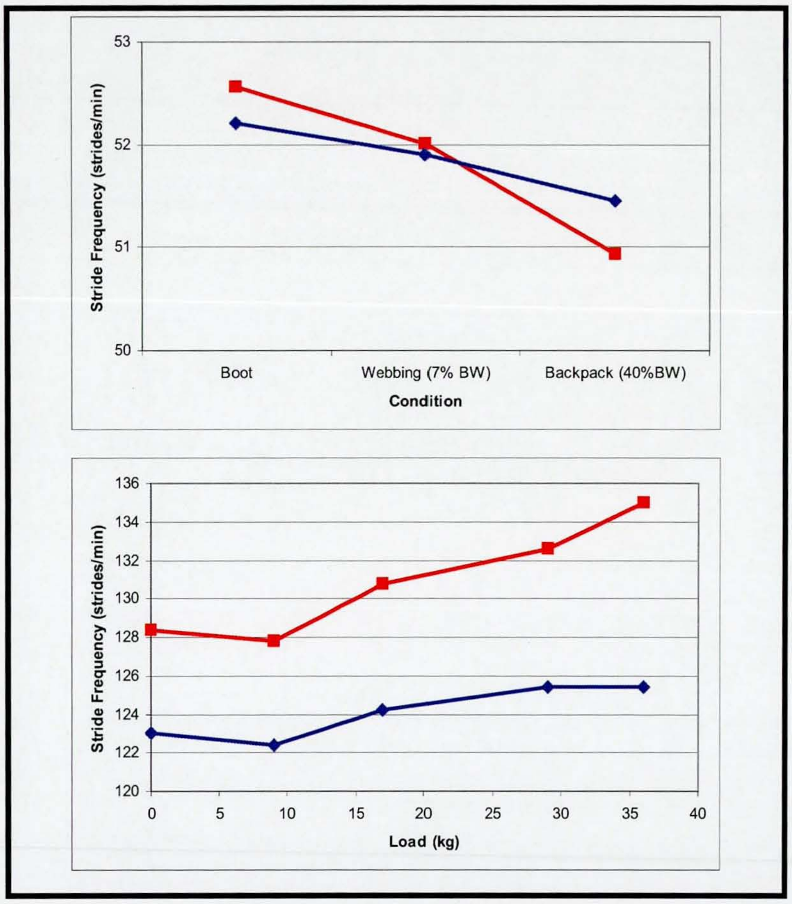


Figure 6.10: Gender differences in stride frequency data for 3 experimental loading conditions (top) and Martin and Nelson (1986) study (bottom). Data points are shown for females (■), and males (◆)

Measurement of gait information in the lower limb in the form of ankle, knee and femur angles was conducted. Significant effects of load were seen and gender differences noted in knee and femur ROM. With addition of load the ROM in the ankle and femur increased. The work presented in Chapter 5 indicated no difference in ankle angle as load was increased, or with femur angle, with the exception of the period around toe off in the femur angle when the push off phase became further back as load was applied. Harman et al., (2000a) suggest that as load is added to the body there is an increase in the degree of hip motion (however movement of the trunk influences their hip angular data). They also suggest ankle

ROM would change as speed increases but no effect of load has been reported on ankle kinematics.

Surprisingly, in the current investigation no changes due to load were seen in the knee angle, in particular knee ROM. Earlier work (including that presented in Chapter 5) examining the effect of load has indicated increases in knee ROM in order to transport the mass and the energy required to do so as well as increasing the stability of the system as a whole (Harman et al., 2000a; Kinoshita, 1985). This is particularly evident in the shock absorption and push off phases of the gait cycle. In the case of the present study it is possible that this increase is reflected in the changes to the ankle and femur angles rather than the knee, particularly in the case of the femur angle as it is inherently linked (by angle definition) to the knee angle. Another possible reason for no change in knee ROM may have been the average walking speed chosen.

In terms of gender, Nigg et al., (1994) noted no gender differences in ankle movement, females having greater knee flexion path of motion; Kerrigan et al., (1998) showed a trend for increased ankle plantarflexion in females, decreased knee extension and increased peak hip flexion; and Cho et al., (2004) observed no angular ankle or knee differences but females had significantly greater hip flexion than males throughout the gait cycle. The present data shows correlations between height or weight of individuals and knee and femur ROM, thus it is possible that anthropometric variables were the contributing factors rather than gender in the published studies. Cho et al., (2004) also suggest increased anterior pelvic tilt in women may also contribute to greater ROM in the hip region.

In order to closer examine the effect of body size, 2 individuals from the participant base were chosen; their data are presented Table 6.5. The data tabulated is that in which a gender difference was found. Examination of the knee and femur data indicates similar data for all conditions (with the exception of the femur ROM in the pack condition). This therefore confirms in terms of the lower limb that a smaller male may demonstrate a similar response to a larger female. Either way these increases in ROM of lower limb angles may have implications for physiological cost when load carrying and may contribute to injury problems in those people who must move through a greater ROM than those who don't. Therefore the selection of individuals due to their size and relative weight load they are carrying should be taken into consideration.

Table 6.5: Selected parameters of 2 individuals closely matched in terms of height and body mass

	Participant 4 (Female)			Participant 17 (Male)		
Height	172.8 cm			170.9cm		
Body Mass	69.9 kg			67.3 kg		
Body mass index	23.41			23.04		
	Boot	Web	Pack	Boot	Web	Pack
Knee ROM (deg)	39.36	40.93	41.75	40.45	42.51	41.72
Femur ROM (deg)	42.10	44.56	52.26	42.90	42.19	44.80
Trunk ROM (deg)	7.16	7.48	7.43	5.75	5.62	6.09

It is pertinent at this point to mention the number of trials collected during each of the studies referred to above. Examination of a single trial (Cho et al., 2004; Harman et al., 2000a; Nigg et al., 1994) or 3 trials (Kerrigan et al., 1998; Martin & Nelson, 1986) may not fully represent the normal gait cycle of the individuals (as discussed in Chapter 3), both for comparison of genders and for examining the effect of load. In the present examination a mean of 7 successful trials was used in order to counteract for possible artefacts in the data.

6.4.2 Upper body angular response

Upper body posture was investigated by examining the trunk, and head posture with measurements of craniohorizontal and craniovertebral angles. These angles have been examined in previous studies in static conditions and on school children carrying backpacks (Chansirinukor et al., 2001; Raine & Twomey, 1997). Minimal gender differences were seen in all angles with trunk ROM being the only variable affected (females exhibiting greater ROM than males). A trend for a more forward head position was also seen.

Measurement of trunk angular data in previous research supports the result presented here; backpack loads induce greater forward lean of the individual This is in order to compensate for the displacement of the centre of gravity caused by the load (Filaire et al., 2001; Goh et al., 1998; Harman et al., 2000a; Kinoshita, 1985; Ling et al., 2000; Martin & Nelson, 1986; Pascoe et al., 1997). This increase in forward flexion is resisted by eccentric contracture of the hamstrings and semispinalis muscle groups, which could be a fatiguing factor during heavy load carriage (Gordon et al., 1983). Increased forward lean results in an increase in the energy cost required for locomotion, therefore being less efficient (Harman et al., 1999b) but also serves to facilitate forward advancement of the body in comparison to a more upright position (Kinoshita, 1985).

Head posture measurements were also affected by carrying loads, a more forward head posture resulting as load increased. Assessment of head position when carrying load has received little attention in the literature. To date the only known measurements of these angles whilst carrying loads are with school children's backpack loads (Chansirinukor et al., 2001) and the work presented in Chapter 5. Rather than continuous measurement whilst moving using a motion analysis system, Chansirinukor's methods involved measurement of angles from a series of photographs after a 5-minute walk whilst stationary. Loads carried were 15%BW and significant changes were seen in craniovertebral angle when carrying the load on the back and after the 5-minute walk. It is therefore not surprising that a more forward head posture is seen when carrying much heavier loads as in the current investigation and that presented in Chapter 5.

Gender differences in posture measurements are not as clear cut. An increase in ROM of the trunk was seen in females over all load carriage conditions. As experimental conditions changed females showed differing response to males, being more upright until the addition of the backpack, when they were in a more forwardly inclined position (Figure 6.7). This correlates with females having a trend for a more forward craniovertebral angle in the backpack condition. In contrast Martin & Nelson (1986) found that without a backpack load females had a greater forward lean than males, but when backpacks were added this gender difference no longer existed. In terms of static head posture measurements without load, no gender differences are seen in the saggital plane (Raine & Twomey, 1997). Therefore the gender response shown in this investigation may be a result of the load or a result of the dynamic movement taking place. Trunk ROM was not correlated with any particular anthropometric datum (except for height in the boot condition), therefore must be due to a different response to dynamic load carrying by males and females. This is further highlighted by the example shown in Table 6.5 with members with similar anthropometric characteristics showing differing trunk response. The greater change in ROM seen by females may also have implications for injury due to the stresses placed on the small muscles of the back, neck and other supporting structures of the spine.

6.5 Limitations

The unavailability of full time military participants may limit the applicability of the present study to the military in general as training specific adaptations to this type of load carriage most likely occur, some results perhaps being a consequence of the untrained response to military loads. However, participants with load carriage experience were recruited, minimising this potential impact. As a result of the difficulty with sourcing appropriate participants for this experimental work, the gender groups were not age, height and weight matched. However both groups were shown to fall within the normal distribution in terms of anthropometric data. In order to compare this data to the military, matching for age, height and weight may not be the correct approach. Personnel are required to carry load regardless of their physical characteristics and it is rare that these play a part in the consideration of the load to be carried. The restriction of the load in the current study to a percentage of body weight may in itself be false as this is also rarely the situation a member of military personnel encounters. One must carry what they need to in order to complete their missions or training successfully. Ethical restrictions in the current study due to using civilian participants made the carrying of true military loads not possible. Finally, the duration of load carriage was brief and it is not possible to extrapolate this to individuals who carry loads for long periods of time, such as during military operations. Consideration of longer duration load carriage is therefore discussed later within this thesis work.

6.6 Conclusion

Women are currently restricted from engaging in any close combat roles, the predominant roles where personnel must carry military loads. There are a variety of explanations given for this restriction including personal and psychological factors however the ability to carry loads also plays a part. In the current study minimal differences in response were seen between males and females when carrying loads of 40% BW. Body size differed between the groups and may be the crucial determinant. It is possible that a smaller male would experience the same response as a larger female and raises the question whether members of the military of smaller stature and lower body weight may need different training or perhaps lighter loads, so as to experience the same relative risks as larger colleagues.

PART II – Load configuration study

6.7 Introduction

The attainment of baseline data examining the response to load carriage and the examination of the effect of gender has been completed. The area of design is yet to be examined in this thesis work. Changes in design are important in the development of the modern day soldier, with a large amount of work currently taking place in the UK to redevelop the total soldier system to fit in with the FIST (Future Integrated Soldier Technology) programme to be rolled out across the Defence Force in 2010. The different types of LCSs currently available for examination are outlined in section 3.7.

An initial pilot study was undertaken examining the Standard and Airmesh Phase II (from this point forward referred to as Airmesh) LCSs with three of the participants who completed the study discussed in Chapter 5. Participant statistics (mean ± SD) age 22.0 ± 1.0 years, height 182.77 ± 4.09cm and body mass 77.6 ± 11.08kg. As these participants were serving military personnel the full military load including LAW was examined. The same protocol as undertaken in Chapter 5 was followed and comparisons were made between webbing, backpack and LAW conditions (Figure 6.11).

Figure 6.11: Differences in webbing, backpack and LAW conditions for case study. Top row demonstrates Belt Webbing, Standard LCS and LAW conditions, bottom row Vest Webbing, Airmesh LCS and LAW (from left to right)

The vest webbing resulted in a decrease in forward lean (-1.56 ± 0.33°) throughout stance phase when compared to belt webbing but no other changes in gait or posture measures were noted. Following on from this the Airmesh LCS showed a trend for reduced forward lean (-1.03±0.23°) when compared to the Standard LCS in the first 50% of stance phase. This trend continued in the LAW condition (-1.07±.36°). The craniovertebral angle also showed similar changes in the LAW condition (-0.98±0.22°) over the whole of stance phase. Gait parameters showed little difference between LCSs with the exception of a slightly increased ankle flexion with the Airmesh LCS.

This pilot work therefore begins to investigate the response to alteration of load position through changes in design. A more upright walking posture with loads placed closer to the body's COM is more economical (Harman et al., 1997; Martin & Nelson, 1986; Vacheron et al., 1999a) and the Airmesh LCS appears to produce such an effect by transferring weight to the chest rather than the waist when wearing webbing and incorporating a fully functional hip belt. Further investigation of this prototype is therefore warranted and comprises the experimental work of this part of Chapter 6. Another distribution of load (50/50 prototype) is also considered in accordance with evidence of LCS packing practices by serving members of the military (data obtained during Operation Telic in Afghanistan).

6.8 Method

Twenty participants (10 male/10 female) as described in section 6.2 and Table 6.1 were examined under 2 experimental conditions (indicated in Figure 6.12). These were;

1. Webbing
2. Webbing + Bergen (LCS)

Three load distribution scenarios were examined in these 2 experimental conditions. These were as follows:

I. Standard LCS (PLCE webbing weighing 7%BW, 90 Pattern Bergen weighing 33%BW);
II. Airmesh LCS (Vest webbing weighing 7%BW, Airmesh Bergen weighing 33%BW); and
III. 50/50 Prototype LCS (Standard LCS with different weighting. Webbing weighing 20%BW and Bergen weighing 20%BW).

Figure 6.12: From left to right; standard issue PLCE webbing, PLCE webbing and Bergen (Standard LCS), Vest webbing and Vest webbing with Airmesh Bergen (Airmesh LCS)

Participants were split into two groups. Those in Group 1 (5 male/5 female) carried the Standard LCS and the Airmesh LCS. Those in Group 2 (5 female/5 male) carried the Standard LCS and the 50/50 Prototype LCS. Order of completion of LCS conditions within these groups was balanced to negate potential order effects. Participants wore standard issue boots, socks and carried a replica SA80 rifle in all experimental conditions. This work was supported by the LUEAC (Protocol G03-18) with all participants completing a health screen questionnaire and giving informed consent (see Appendices A4-A6) before undertaking any experimental work.

For all conditions participants walked at a self selected pace along the walkway with embedded force plate (see Figure 4.3) in front of the CODA™ Mpx30 motion analysis system. Markers were placed on the body as per the positioning described in Chapter 3. A successful trial was determined by placement of the right foot fully within the boundaries of the force plate with all markers successful acquired prior to and for a full stride following the foot strike on the force plate. Following 7 successful trials the participant moved to the next experimental condition.

In order for comparisons to be made between participants all data were calculated as a percentage of stance phase (from -20% to 120%); making them independent of time and walking speed. The means for the 7 repeats of each condition were calculated for all participants. Group data for each experimental condition were expressed as the mean and 95% confidence intervals were calculated for all participants in each load carriage grouping (i.e. Standard + Airmesh OR Standard + 50/50). Paired t-tests were conducted between Standard-Airmesh and Standard - 50/50 on all spatiotemporal data and maximum, minimum, mean and ROM values for all angles for both experimental conditions (significance level set at $p = 0.05$).

6.9 Results

Comparison of participant characteristics (age, body mass, height) showed no differences between Group 1 and Group 2. Therefore the experimental conditions using the Airmesh and 50/50 Prototype LCS components (i.e. webbing or webbing + backpack) were compared using independent t-test.

Significant differences did exist between Group 1 and Group 2 when examining kinematics whilst carrying the Standard LCS (i.e. webbing + backpack condition). As indicated in Figure 6.13 those participants in Group 1 were significantly ($p<0.05$) more upright (-4.2°) in terms of average trunk angle when compared to those in Group 2 (-8.5°). This relationship was also true for the maximum and minimum values for trunk angle ($p<0.05$).

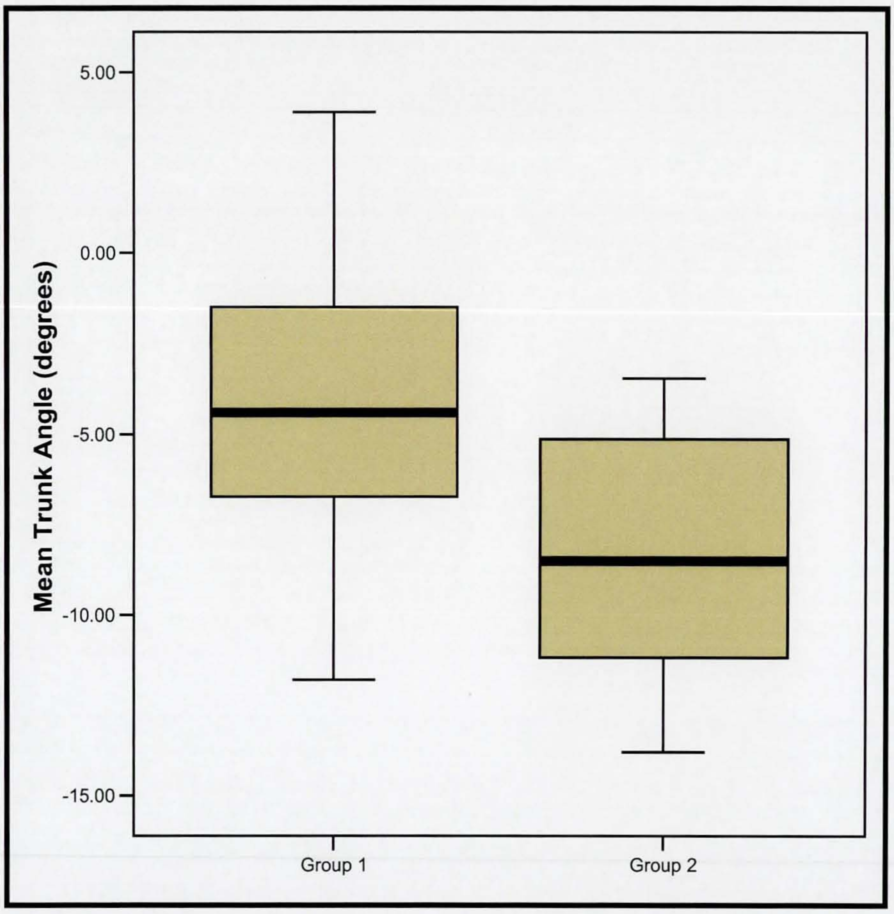


Figure 6.13: Average trunk angle when carrying the Standard LCS. Participants split into Group 1 and Group 2.

6.9.1 Webbing condition

Examination of the lower limb data yielded no significant differences when comparing the Airmesh and 50/50 in the webbing condition (independent t-test). Significant differences were however seen when comparing the Standard to the Airmesh (Vest) webbing (Table 6.6). Comparisons between the Standard-50/50 webbing were expected to display differences due to the nature of the load being carried in the 50/50 condition (heavier). There were however no differences in lower limb angles at all. Only those of the trunk and head displayed significant results.

Vest webbing resulted in a more upright posture (average 5.9°) when compared to the other 2 possibilities (4.7° Standard, 1.8° 50/50). This is indicated in Figure 6.14. The figure also demonstrates the closeness between the vest webbing response and unloaded data (from experimental work in Part I of this chapter). This change in posture was significant in the Airmesh-50/50 comparison with greater maximum ($p<0.05$), mean ($p<0.05$) and minimum ($p<0.01$) values. Again this is possibly an unfair comparison due to the load carried. However the comparison between Airmesh-Standard also yielded significant differences in trunk movement as outlined in Table 6.6. In addition to this the craniohorizontal angle was also affected with 50/50 webbing having a lower minimum ($p<0.05$) and greater ROM ($p<0.01$) than the standard condition.

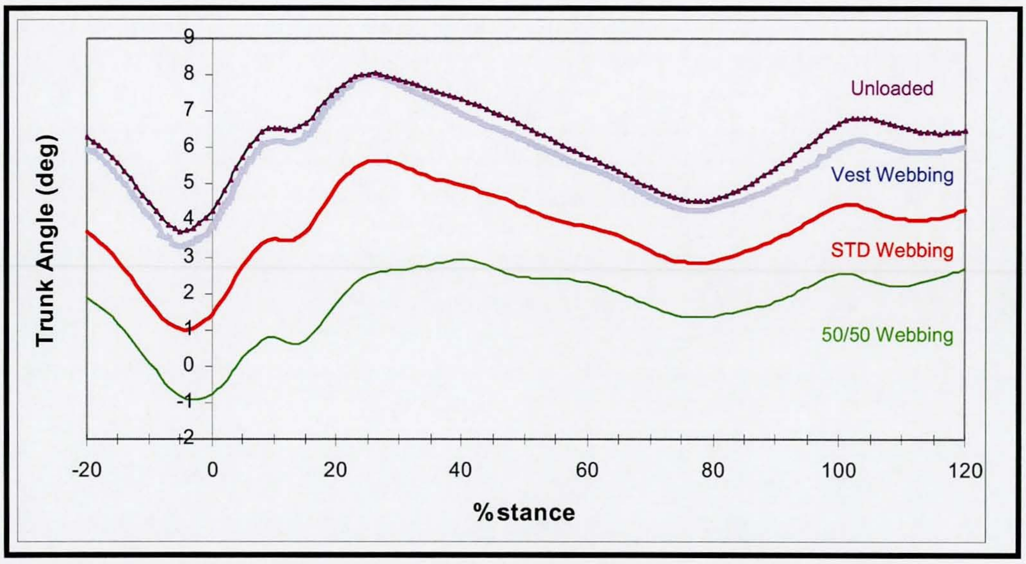


Figure 6.14: Average trunk angle response whilst wearing webbing. Conditions presented are standard webbing, vest webbing, 50/50 webbing and an unloaded condition

Table 6.6: Paired t-test results for comparison between Standard and Airmesh (vest) webbing

Variable	Angle	Standard webbing (Mean ± SD)	Airmesh (vest) webbing (Mean ± SD)	P value
Maximum	Trunk	7.04 ± 3.60	8.35 ± 4.36	0.021
Mean	Femur	91.03 ± 3.30	91.57 ± 3.72	0.045
	Trunk	4.67 ± 2.74	5.89 ± 3.52	0.016
Minimum	Knee	1.96 ± 4.71	2.84 ± 5.22	0.028
	Femur	69.12 ± 3.69	69.80 ± 3.77	0.013
	Trunk	1.93 ± 2.62	3.37 ± 3.45	0.009
ROM	Ankle	25.85 ± 2.89	24.75 ± 2.97	0.029

The webbing condition also resulted in some differences in spatiotemporal data with significant differences seen between Standard webbing and Airmesh (vest) webbing for stride frequency (Standard 51.55, Airmesh 52.42, $p<0.05$) and stance time (Standard 0.72, Airmesh 0.71, $p<0.05$). Speed was consistent between this pairing. Significant stride length differences were seen between Airmesh (1.55) and 50/50 (1.44) webbing.

6.9.2 Backpack (LCS) condition

Differences between the full LCS conditions were minimal. No significant differences were found between the Airmesh-50/50 comparisons. The Standard-Airmesh comparison resulted in a significant difference in trunk ROM ($p<0.05$) with the Standard LCS resulting in a greater ROM. The 50/50 LCS resulted in a more upright position in the second 50% of stance and a reduced ROM (1.85°) compared to the Standard (2.47°) and 50/50 (2.41°) LCSs as indicated by Figure 6.15. No differences in any other angle or spatiotemporal data were observed.

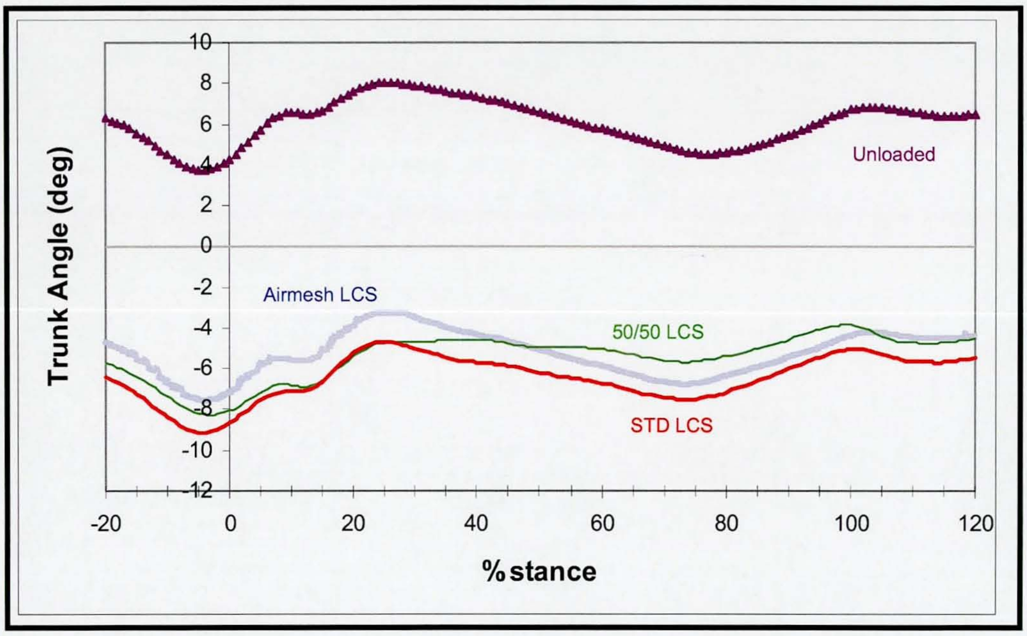


Figure 6.15: Average trunk angle response whilst wearing LCS. Conditions presented are Standard LCS, Airmesh LCS, 50/50 LCS and an unloaded condition

6.10 Discussion

It is well documented in the literature that a change in the position of load results in an altered physiological cost to the individual, with loads placed closest to the centre of mass of the individual resulting in the smallest physiological cost (Martin & Nelson, 1986; Obusek et al., 1997; Vacheron et al., 1999a). As loads carried in a backpack are placed on the back, resultant changes in biomechanics are also expected, as have been seen in this thesis work. Loads carried high on the back as opposed to low cause different responses, particularly when looking at performance of mobility tasks (Holewijn & Lotens, 1992a). Load placement also affects the EMG response of the back muscles (Bobet & Norman, 1984). In relation to trunk angular data, research has been conducted on the use of double packs, thus locating the load closer to the centre of mass (similar to wearing vest webbing and carrying the Airmesh LCS). These double packs result in a more upright walking posture (Harman et al., 1994), less discomfort in the lower back region during a 20km march (Knapik et al., 1997) but increase discomfort in the neck and hip regions and have serious implications for heat illness and distress when compared to single packs (Johnson et al., 1995). Therefore finding the most efficient LCS requires examination of all of these factors.

The use of vest webbing is warranted both in terms of increasing vision and ease of access to items within the pouches, as webbing contains all items necessary for survival, including ammunition. Access to rear pouches on waist/belt webbing does not allow the user to view what they are doing, thus increasing time and difficulty in removing objects. Vest webbing resulted in a more upright body posture when compared to the other two webbing possibilities. The load is also located closer to the centre of mass so should reduce physiological cost as mentioned above. The comparison of the three styles/loading of webbing may be unfair as on the 50/50 çondition there was a heavier load carried than in the other 2 conditions. Thermal issues have not been considered in either this or other referenced studies (Martin & Nelson, 1986; Obusek et al., 1997; Vacheron et al., 1999a) and do play a significant role. By covering the front of the body (in the case of the vest webbing) the body surface area for heat transfer has been reduced, therefore examining thermal factors may conclude a disadvantage of this system. Other possible detriments for vest webbing include injury when going to ground and the negative impact on soldier profile (i.e. a larger target).

Considering the LCS as a whole indicates minimal change in any gait or posture variables. It was expected that the Airmesh LCS would result in a more upright posture as load is distribute differently, with a trend in the data recognised (Figure 6.15). Significant differences in trunk angle between groups when carrying the Standard LCS may have masked any differences that may have been seen between LCSs. It is possible normalisation of data relative to body size would obviate these differences, however, overall anthropometric data showed no correlations with trunk data. It may therefore be a case of individual response to load, which cannot be accounted for. The 50/50 split of load resulted in the least ROM of the trunk for 80% of stance (Figure 6.15); an important factor in terms of physiological cost to the individual. The configuration for this packing arrangement (i.e. 20% BW each in webbing and backpack) was derived from information fed back through the Ministry of Defence from a serving unit in the Afghanistan prior to this experimental work taking place. Any reductions in physiological cost should be considered when instructions for packing loads are given to soldiers, possibly reducing fatigue due to load carriage and therefore improving the efficiency and capability of the soldier. In this case it is possible that these types of instructions had taken place.

6.11 Conclusion

Alteration of the position of the carried load may cause change to the biomechanical response of the carrier. Vest webbing appears to be beneficial compared to the current issued belt webbing in terms of posture and view/accessibility to items within the webbing. However, it is crucial that the LCS is considered as a whole rather than as separate entities. If vest webbing combined with the Airmesh backpack does not produce beneficial effects compared to the Standard LCS, there is little reason to change, unless cost driven. It may be more advantageous to change the packing configuration of the current issued equipment. Future load carriage design must consider the trade off between position of the load and the effect this will have on mobility and sustainability. Consideration must also be given to the area of body coverage and the levels of physiological stress imposed. It is possible that the coverage of the front of the body by the vest webbing may increase the physiological cost due to increased thermal stress.

6.12 Overall chapter summary

This chapter has presented data indicating the effect both gender and load positioning (in terms of LCS design) have on gait and posture biomechanics. Whilst these factors are important to consider, the duration of the load carriage that has taken part here and in the experimental work in Chapter 5 has been very brief. In the military context the periods of time in which loads are carried is much greater. Small exercises may consider 30 minutes load carriage, large tactical exercises or missions may involve an individual to carry loads for days on end. Depending on the situation they are working in there may also be minimal periods for rest. Therefore, the small differences seen from an experimental trial where the participant is carrying loads for period of approximately 5 minutes may be magnified over time and/or by fatigue, or may alter as a consequence of this time period. The examination of longer term load carriage is therefore essential. By measuring against a well known and used military test it will allow a better understanding to be gained and may also further assess how changes in military LCS design alter the response of the individual.

As a consequence the next section of this thesis discusses issues of long term load carriage in detail. Chapter 7 provides an in-depth literature review concentrating on the effects of longer term load carriage only. It also considers subjective responses when carrying loads on the body. Chapter 8 then discusses an experimental trial conducted on members of the military assessing changes in biomechanics, subjective comfort and LCS design whilst carrying a military load for 2 hours. The subjective response of such individuals is then further assessed on a field trial where a similar load carriage exercise has taken place (Chapter 9).

Chapter 7 – Longer Duration Load Carriage: A Review of the Literature

7.1 Introduction

The work stated in the previous chapters gives an overview of some general principles associated with the carriage of loads. Highlighted however, is the duration for which these loads were carried. Periods of load carriage in the order of 5-10 minutes are not substantial enough to give an overall indication of the changes possibly seen when loads are carried in the military environment. The fatigue experienced by an individual when carrying military loads may impact on their ability to complete their objectives. It has been said by members of the UK Army Personnel Research Establishment that "it is a measure of the success of the selection and training of the troops deployed that they are able to meet the demands made of them, albeit at the cost of considerable fatigue" (McCraig & Gooderson, 1986). When one considers this statement, the military objective of getting the job complete at any cost to the body is brought to the forefront. However the examination of how this fatigue affects body movement has received limited attention.

Maintaining natural posture and gait whilst carrying loads is desired, as it allows the individual to optimise their ability to perform (Anderson & Thompson, 2000). Biomechanical evaluation of gait and/or posture whilst load carrying has been restricted to short periods of load carriage, or pre/post longer duration carriage. The measurement of these biomechanical factors over time is yet to be examined in the military context. Successfully completing military objectives often requires soldiers to maintain physical activity for prolonged periods (days/weeks), completing such missions as rapidly as possible with minimal fatigue and discomfort. Heavy loads carried on such marches can lead to symptoms of body soreness, aches, pains and tiredness, all of which could possibly interfere with the accomplishment of a mission.

In the late 20th century a British Royal Commission investigated the maximum load a soldier should carry; primarily due to the fact the men were reaching the battlefield "too exhausted to fight" (Soule & Goldman, 1969). In 2002 the US Army became concerned with soldiers being left "drunk" with fatigue following combat (Sabo, 2003). Worried this fatigue would inhibit the ability to perform crucial military tasks such as firing a weapon, recognising the enemy and using logical reasoning before taking action, they examined the effect of periods of sleep deprivation and prolonged combat activity. All of the above-mentioned abilities were substantially impaired.

This chapter outlines the literature discussing longer term load carriage and the collection of subjective responses whilst conducting biomechanical research. It focuses on the carriage of military loads and the response of the body as a consequence of experiencing such load carriage. Following on are two experimental chapters examining longer term load carriage more closely in terms of biomechanics and subjective comfort. This section of the thesis work is crucial in filling the void that currently exists in load carriage research.

7.2 Field visits

In an endeavour to gain a further understanding of some of the main issues associated with longer term load carriage, and the logistics of conducting such research, a field visit occurred in Townsville, QLD, Australia (August 2003) with researchers from the Defence Science and Technology Organisation (DSTO) of the Australian Defence Force. The research being conducted at the time took place in the environmental chamber within the Institute of Sport and Exercise Science at James Cook University. Located close to the university is Lavarack Barracks from which members of the Australian Army Infantry volunteered for this project. Soldiers (n=18) carried a load totalling 50kg and walked on a treadmill at approximately 4.5km.h^{-1} for 2 hours under three environmental conditions; (i) Temperate 20°C/50% humidity; (ii) Hot-Wet 30°C/70% humidity and (iii) Hot-Dry 30°C/30% humidity. The loads were designed to mirror a standard 3-day operational kit load and all participants carried their own equipment. Whilst the emphasis was centred on gaining physiological data, such as energy expenditure and blood assays, temporal factors of gait were also examined every 30mins across the 2 hour period. There was also an interest in body posture, captured using 2 saggital video camera views (one lower limb and one upper body). The biomechanical analysis of this data unfortunately did not take place due to time constraints and the work being conducted with video – hence requiring manual digitisation. A trend was noted towards increased step frequency/double support and decreased step length as time increased with a greater forward lean occurring as fatigue set in over the two hour period. Further prolonged load carriage trials are currently being proposed at DSTO with examination of 3D biomechanics (M. Jaffrey, personal email communication, October 18th 2005).

In addition to this visit, a meeting was attended with US military researchers at the US Army Soldier Systems Centre, Natick, Massachusetts (June 2004). As well as an exchange of research work taking place, a discussion occurred regarding the need to collect load carriage data for longer durations. Similar work to that mentioned above was to be undertaken by this group of researchers in late 2004 (L.Hasselquist, personal communication, June 23rd 2004). As yet no further information is known on the outcomes of this study.

These two visits reinforce the requirement to assess load carriage closely over a longer duration. As mentioned above, previous work has concentrated on short durations or looked at pre/post longer duration load carriage. This approach does not allow any time point to be defined should a change in response have occurred. By conducting research examining biomechanical and subjective data a more in-depth knowledge of the longer term response of the soldier will be gained. This may allow changes to current practices of load carriage (such as ratio of carrying time to rest time) to be altered in order to achieve the most efficient movement of troops. It may also be crucial in identifying possible areas in which injury (or severe discomfort) is prone to occur, with attempts then made to alleviate such problems.

7.3 Fatigue

Muscular fatigue is a topic that has drawn attention from physiologists for over a century. It is a common experience in daily life, with many definitions existing in the literature in an attempt to define its aetiology. At present there is still a great deal of controversy as to the causes and their importance. Muscular fatigue may be defined as "a loss of force and power output leading to reduced performance of a given task" (Fitts, 2004); a decrease in the maximum force generating capacity of a muscle (Bigland-Ritchie, 1984); or "any exercise induced reduction in the capacity to generate force or power input" (Vollestad, 1997). Fatigue can be of a central or peripheral origin and may result from changes in the muscle itself, or depletion of fuel sources, and is also dependent on the intensity and duration of the work and the fitness of the individual undertaking the work. Factors such as pain tolerance, competitiveness of an individual and/or boredom can also influence the ability of an individual to resist fatigue (Mannion & Dolan, 1996).

For the purpose of this research, rather than attempting to define and measure specific muscular fatigue, the interest lies in the effect overall fatigue of the body will have on the ability to carry a load, and the ability to perform tasks crucial in the military context. Physical performance decrements can negatively affect a warfighter's lethality, mobility and sustainability (Welsh et al., 2004). Well designed LCSs serve a function in altering mission performance by reducing localised stress and fatigue on the body, also serving to decrease the number of injuries that occur (Knapik et al., 2004).

The ability to resist fatigue, whether muscular or whole body may be termed endurance. This is a crucial factor in determining the capability of the soldier and the ability to perform crucial tasks. A review by Hicks et al (2001) examined the differences that exist between the genders when considering muscular fatigue. Although still an area of increasing research, it is apparent that females show a greater resistance to fatigue than males when working at less than 60% of their maximal performance. The magnitude of this advantage declines as the percentage of maximal workload increases. This greater resistance to fatigue may be due to a number of factors including the presence of oestrogen, lower muscle oxygen demands (due to females producing less force in a muscle at a specific relative workload) and changes to the neuromuscular activation patterns of the muscles. This is an area that requires much more research; however it highlights the variety of influences that may affect an individual's ability to perform. Annett (2002) associates five factors with fatigue following work; lack of energy, physical exertion, physical discomfort, lack of motivation and sleepiness.

7.4 Prolonged load carriage

The predominant emphasis in the area of prolonged load carriage has been on physiological investigations (Kirk & Schneider, 1992; Legg & Mahanty, 1985; Mengelkoch et al., 1996; Reading et al., 1996; Sagiv et al., 2000; Scott & Ramabhai, 2000; Shoenfeld et al., 1977; Yu & Lu, 1990), with only a small number of kinematic investigations being completed (Gefen, 2002; Johnson et al., 2000; Lang et al., 1992; Martin et al., 1982a; Orloff et al., 1999; Pierrynowski et al., 1981a; Vacheron et al., 1999a). Treadmill walking is a common methodology used to induce fatigue in participants whilst measuring a number of variables. This technique, with varying protocols, has been utilised on a number of load carriage trials. Walks of 12-15 minutes (Johnson et al., 2000; Pierrynowski et al., 1981a), 40-45minutes (Mengelkoch et al., 1996; Quesada et al., 2000; Sagiv et al., 2000), and up to 4 hours (Reading et al., 1996; Sagiv et al., 1994; Scott & Ramabhai, 2000) have been conducted whilst participants carry loads. The load carrying experience of these participants has ranged from military personnel who carry loads as part of their daily activities to novice hikers with relatively little experience in the area.

Two measurements taken in almost all of these investigations, whether physiological or biomechanical in nature, are the changes in heart rate and the rating of perceived exertion (RPE). RPE is a crucial measure when considering participant exertion levels and for comparisons between different equipment and loading configurations (see section 7.6.3). Heart rate is equally important as it can be used as an indicator of stress as well as a monitoring device to ensure safety for the participant. Other subjective measures such as comfort ratings at specific body sites allow comparison between equipment, and serve to distinguish between overall exertion as opposed to overall comfort (section 7.6.4). It has been stated that subjective measures are; 'the ultimate criterion of comfort against which other more convenient and more objective measures may be validated' (Shackel et al., 1969).

7.4.1 Physiological response to prolonged load carriage

The energy cost associated with load carriage is dependent on the amount of load being carried and its dimensions. The level of intensity of energy cost also determines the timing of fatigue onset. Examination of longer duration exercise (2 hours) with loads showed different physiological responses for 25kg and 40kg loads (Epstein et al., 1988). A 25kg load shows no difference in energy cost over time, does not affect VO_2/kg and shows a relative work intensity of 45.5%. On the other hand the 40kg load yields a highly significant increase in energy cost over time, a gradual increase in energy cost per kilogram and a gradual increase in work intensity from 52.1% to 56.2% at 120 minutes. These results confirm other research in that workloads below 50% VO_{2max} can be sustained at steady state. However workloads greater than 50% are characterised by anaerobic metabolism which results in the production of lactic acid, possibly causing decrease in performance. From this work the author suggests efficient load carriage only occurs when energy cost is kept below 50% VO_{2max}. This increase in energy cost is associated with physical fatigue, which alters locomotion biomechanics as an individual recruits additional muscle mass to carry the load (Anderson & Thompson, 2000).

Prolonged load carriage physiology has also been examined by Patton et al. (1991). Participants were asked to complete a 12km treadmill walk carrying 3 different loads (5.2, 31.5 and 49.4kg) at 3 speeds (1.10, 1.35 and 1.60 $m.s^{-1}$).

Results demonstrated that VO_2, V_E and heart rate all increase significantly throughout the duration of the walk. One suggested factor influencing these changes was the reduced mechanical efficiency of an individual when carrying a load. This included work intensities of less than 30% VO_{2max}, which conflicts with the data presented above from Epstein et al. (1988). The physical fitness and load carriage training of participants may have influenced these findings.

Both of these studies have examined walking times on the treadmill that may only represent a small component of a military operation. Marches from one position to another usually take at least 1-2 hours to complete but it is possible they could continue for days on end, particularly in a war situation. The effect of load carriage and the associated factors such as injury incidence and failure to complete other tasks as a result of fatigue play an important role in such situations. One such investigation by Yu and Lu (1990) attempted to determine the acceptable load that could be carried whilst marching at $5km.h^{-1}$. In this investigation a LCS of a waist belt and backpack were utilised, with weights of 0, 15, 20, 25 and 30kg being carried over a 9-hour period (with rest breaks every hour and for 1 hour in the middle of the march). Ratings of tiredness and heart rate responses were recorded, with both increasing as load increased. It was determined that 20kg was the acceptable load for walking at this speed for this period of time.

In a similar study Johnson et al. (1995) examined the effect of carrying loads of 34, 48 or 61kg on a 20km road march. These loads are more indicative of the actual loads that a soldier would be required to carry either on exercise or during combat. The Environmental Symptoms Questionnaire was administered before and after each march and marches were completed at all weights with both the ALICE pack (standard configuration) and a double pack configuration. A minimum of three days separated these trials in an attempt to remove any effect of residual fatigue. As load increased muscle discomfort and fatigue intensified, and alertness and well being of participants decreased. The double pack configuration also resulted in an increase in thermal stress on the body, particularly in the 61kg condition. Both of these studies indicate the importance of gathering subjective data whilst completing such trials.

The physiological response to load carriage limits an individual's ability to complete a defined task. This response is altered when carrying a load and a reduction in the time an individual can perform a task may occur due to this increased physiological load. Holewijn et al. (1992b) examined the effect of wearing military boots and carrying waist webbing (12kg) on physiological response. Differences were seen between males and females, and at different walking speeds. In particular walking speed of $6.4 km.h^{-1}$ resulted in a marked increase in perceived exertion and heart rate. This speed is the equivalent to that used on a forced march or during combat fitness tests conducted by the British Military. Addition of just military boots resulted in an increase in the physiological response, due to the increased mechanical work required by the lower extremities to move the increased weight. Using a regression equation, the authors also suggest when walking at set pace, and over 50% VO_{2max}, a limitation of endurance time occurs; females being limited to 30 minutes when wearing military boots and carrying the waist load. With no load they are limited to 110 minutes and even at the slower speed of $5.25 km.h^{-1}$ they are limited to 120 minutes with boots and waist load. Therefore the percentage of VO_{2max} that an individual is working at is crucial in determining endurance time.

In an attempt to determine a suitable physical fitness assessment task for occupations encompassing load carriage Bilzon et al. (2001) examined the effect of carrying no load and 18kg whilst running ($9.5 km.h^{-1}$) on a treadmill for 4 minutes. Heavier participants were able to perform this task at a lower relative metabolic cost than lighter participants, which suggests that those of smaller body mass could have an earlier onset of fatigue when carrying loads. This observation was reinforced when exercising participants to volitional fatigue whilst running and carrying 18kg. Heavier participants lasted longer during this test (47.1 ± 11.4 min versus 35.3 ± 7.3min) although this difference was not significantly different. Therefore body size (and therefore gender as women tend to be on average smaller than males) could have a significant influence on the ability to carry loads and the time at which fatigue occurs.

Vanderburgh and Flanagan (2000) predicted the physiological cost of carrying a backpack load from the American military 2-mile run test. When considering body size, individuals are best matched at loads of 20-30kg, which reflects similar loads to those that may be required during a military operation. These loads eliminate the problem of body-size basis. The other load they examined which showed even stronger results was 50kg. This load was deemed too heavy a weight for load carriage, although in reality in the military setting this may not be the case. Whilst the addition of loads to be carried for a prolonged period were considered here, the calculations are based on an addition to an individual's body weight. They do not consider the positioning of the load, which would also have a serious physiological effect and, depending on body size of an individual, may serve to disprove this model.

Load positioning on the body changes with the occupation. Bloswick et al. (1994) showed no difference in metabolic load for mail workers carrying a 15.9kg load either on the side or on a waist belt (mailbag carry). However, time to fatigue of lateral trunk flexors was greatly reduced wearing the load around the waist following a 1 hour walk – suggesting that load placed closer to the body's centre of mass results in less stress on the trunk musculature. Fire fighters are another group whose occupation requires the habitual carrying of loads. Personal protective equipment can weigh up to 25kg with an addition of self-contained breathing apparatus (SCBA) weighing approximately 15kg (to allow breathing for 25 minutes) (Griefahn et al., 2003). When examining the performance of a fire-fighting task, Griefahn and colleagues found that changes in load distribution, not weight, resulted in the greatest alteration to homeostasis. As load was moved further from the body centre of mass, increases in heart rate and changes to subjective responses were seen for exercise lasting almost 15 minutes. However, no control condition (i.e. no load) was conducted here – constrained by working in heat/fire conditions.

Walking with loads of up to 20% body weight for 20 minutes has been conducted on school children to analyse the effect of school backpack weights – a key area of research in developing children (Hong & Brueggemann, 2000). When considering changes over time, no differences were seen for any biomechanical variables for 0%, 10%, 15% and 20% BW loads. In physiological terms changes in heart rate are noted in the first 5 minutes of exercise before the participant moved into a steady state and then no further changes were seen. Similar response was seen in blood pressure; however recovery rates following exercise were significantly longer when carrying the 15% and 20% BW loads. As children develop and bones, muscle and joints mature, excessive stresses placed on the body can cause irreparable damage. It has been recommended that a load no greater than 15% BW be carried by children to avoid these problems. In the military context loads are proportionally at least twice as heavy as these school loads. Although military personnel have a "laid down" skeleton as opposed to one which is developing it is still expected these military loads would cause an even greater influence over time in terms of physiological variables and also some alteration to the biomechanics of an individual.

Determination of the optimum load an individual can carry for an extended period is dependent on the position and weight of the load and the metabolic cost that is entailed to carry such a load. Pierrynowski et al. (1981b) attempted to quantify optimum loads by examining a variety of loads (0, 15.16, 19.3, 22.65, 28.63 and 33.85 kg) whilst standing still for 12 minutes and walking on a treadmill for 12 minutes at $1.54 m.s^{-1}$. When only considering the load on the back during walking an optimum load of somewhere near 40kg was recommended from metabolic data. This is based on predictive data as 40kg is above the weight range examined and may not be a true indication. However when considering the need for the individual to transport their own body weight as well, this load decreases. If the task of carrying bodyweight is given 50% credit (i.e. in terms of metabolic cost) the optimal load is 29kg. This further decreases to 18kg for 75% credit and 12kg for 100%. The authors suggest in a military situation where it is important an individual arrives at their destination in a non fatigued state (i.e. has the ability to engage in battle etc), at least 50% credit be given for carrying their own bodyweight hence arriving at the figure of 18kg for optimal load. It is questionable as to the development of this figure given participants only walked on the treadmill for a period of 12 minutes which is unlikely to place the carrier in a fatigued state. Also the possibility of drift over time of metabolic measures may play a role here such as occurred in the work of Warber et al. (2000) who examined 4 hour load carriage on a treadmill carrying 34.1kg. In this research significant increases over time of both heart rate and RPE were recorded. However, if this figure of 18kg as suggested by Pierrynowski is correct it represents one of the lightest load carrying scenarios to occur in the military context.

7.4.2 Biomechanical response to prolonged load carriage

When considering military loads two studies in particular have examined the effect these types of loads (usually much heavier than those normally examined) have on biomechanical elements such as kinematics and kinetics over time. Changes in locomotor ability (such as may occur during fatigue) may result in limitations of mobility and restriction of motion. With the addition of a load this could lead to functional alterations in locomotion (Falola et al., 2000). Johnson et al. (2000) examined the effect of a 15min march on a treadmill whilst carrying 4 differing load configurations (36kg at high, mid and low positions or a front pack/backpack configuration with 18kg in each). Whilst considering these loads as military, and completing the trials in military clothing, the actual make up of the LCS consisted of a metal frame with specific weights attached and no webbing included. As mentioned previously, in the military context webbing is always worn and is an important component of the LCS, containing all items essential for survival (ammunition, rations, water etc.). In the front pack/backpack condition a load carriage vest was used which resulted in significantly greater thermal distress for participants. Results of this investigation indicated significant differences between packs on trunk lean angles, minimum induced hip angles and knee angles, however no comment was made on the effect of time on these measurements, nor in fact when these measures were made during the 15 min trial on the treadmill. Positioning of markers on the military clothing rather than the skin may have also influenced the data reported.

Martin et al. (1982a) completed a similar trial on military participants, this time walking on a treadmill at $4.8km.h^{-1}$ for 18 minutes. Measurements were made at 4min, 11min and 18min with spatiotemporal and some kinematic data collected. The purpose of the study was to examine the effect that different frame lengths had on load carrying behaviour with total load carried being 26kg. Over time differing responses were seen in trunk angle with women showing a decrease and men an increase. The statistical significance of this however was thought to be of little practical importance. For all other variables such as angular data the effect of time was negated with examination only taking place at the 11min mark. Also this data was taken from a singular stride for each participant and therefore may not be representative of the overall motion occurring (see discussion in Chapter 3).

Assessment of body posture is also an important component in this thesis. One study that has attempted to look at such postures over time examined the effect of carrying 11.4kgs for 3.2km with measurements made at 400m and 2800m (Orloff et al., 1999). The total time taken to complete these trials was approximately 30 minutes with RPE collected every 800m to gauge fatigue levels of participants. Fatigue related differences were seen in both head flexion and maximum trunk flexion, with both increasing from the rested to fatigue measurements. RPE values supported these measurements indicating participants were more fatigued at 2800m than at the 400m measurement. The loads used in this investigation are much lower than those utilised by the military and it is expected these results would be exacerbated when carrying military loads. Kinoshita (1985) found in their load carriage study significant differences for more than half of the gait parameters measured when comparing carrying load to no load. They also postulated these changes would be of even greater magnitude if the loads were carried for long periods of time, particularly in field situations.

Walking with 10%BW load in a trunk jacket for 15 minutes showed a decrease in the energetically optimal speed for an individual, with participants not choosing this optimal speed as they would do when not loaded (Falola et al., 2000). A relationship between physiological cost and stability was not noted in the loaded condition suggesting any addition of load onto the body is not the same as an increase in body mass, even in this condition where load was added onto the trunk in the form of a jacket. The authors suggest that walking at an optimal speed for stability will lead to a reduction in the impact shock or neuromuscular fatigue even though the physiological cost may be higher. This is more likely the case in a loaded system where an individual is more unstable, whereas when unloaded individuals adopt the energetically optimal speed.

Measurements of EMG of the back muscles provide an indication of the amount of fatigue that is being experienced due to load carriage. Measurements of these muscles are difficult due to their positioning and size, with groups of muscles often being reported rather than singular muscles. Investigation in this area is however important as fatigue may place additional stresses on the supporting structures and passive tissues of the spine – possibly leading to injury. Repetitive lifting of a weight block over a period of 20 minutes or 2 hours showed differing responses in the erector spinae (Potvin & Norman, 1993), suggesting some sort of protective mechanism after a certain time period. At 20 minutes an increase in lumbar EMG was seen, whereas at 2 hours the changes in EMG fatigue indicators were more enhanced in the thoracic region. When carrying a backpack the expected response will be different to that seen here as the load is in a different position and constantly being carried. However the suggestion of progressive fatigue through the back muscles within this study is important to consider. Substantial reductions in strength and endurance times for contractions were also seen over this 2-hour time period. Analysis of repetitive lifting also indicates an increase in lumbar flexion, and causes measurable fatigue in the erector spinae muscles (Dolan & Adams, 1998). The amount of lumbar flexion experienced is critical in determining the likelihood that an individual will experience a disc injury. As carrying a load places an individual in a more forward flexed position, it is possible a similar response is seen when carrying load for a large period of time, especially when considering the range of motion the trunk moves through whilst load carrying.

Recently a novel attempt at measuring spinal curvature whilst carrying backpacks has been developed by Orloff and Rapp (2004). Rods that are attached to a data recorder inside a backpack allow measurement of curvature of the spine. Up until this point the trunk has been considered as a segment due to the positioning of the backpack. A significant increase in spinal curvature was seen in the upper spine when a participant was fatigued; changes in trunk and head flexion over this period were however not observed. Participants were asked to carry a load of 9kg for 20 minutes whilst walking at a fairly brisk pace ($1.79 m.s^{-1}$). Measurements were made at 3 minutes and 18 minutes as a measure of pre and post fatigue. The participants in this experiment were experienced backpackers; therefore a fatigued state is questioned; however a significant increase in RPE was seen over time. Of greatest significance here though is that if such changes occur so quickly, with light loads using experienced carriers what are the possible implications for those who carry heavy loads such as the military for extended time periods. This also may serve to explain the changes seen in the EMG analysis by Potvin (1993).

As fatigue occurs a change in the acceleration characteristics of the tibia and sacrum may also occur. When considering a 30 minute run an increase in the accelerations measured on the tibia and sacrum at heel strike occurs over time when measured by accelerometers (Voloshin et al., 1998). This suggests that the ability of the musculoskeletal system to attenuate and dissipate these shock waves has been diminished as a result of the fatiguing exercise – which is an important consideration when looking into injury caused by fatigue. These shock waves are possible contributors to stress fractures. Yoshino et al. (2004) suggests a hypothetical gait model of fatigue, with muscle fatigue occurring at the tibialis anterior, followed by instability of the gait pattern. This is turn results in participants slowing their gait rhythm in order to increase local dynamic stability (vertically) and decrease the chance of falling. With the addition of an external load these changes in shock attenuation and stability are exacerbated, possibly resulting in increased injury risk.

7.4.3 Summary

In summary, the physiological response of an individual carrying load is influenced by the period of time they perform this task. Combining with this are changes to energy costs due to load weight, size of the individual carrying the load, and the position of the load on the body. An optimum load for the military based on physiological measures alone has been suggested at 18kg, however operational requirements makes it unlikely that this will be put into practice. In terms of biomechanical measurements, these are typically taken either before and after treadmill walking, whilst walking overground, or for only one stride at particular time points during the treadmill walk. Where examination over time has occurred the time period for these studies have been relatively short; well below durations a member of the military would be expected to walk/march. Collection for a period of up to five strides at intermittent times whilst the participant is walking/marching would give a more accurate picture of the changes that may occur in gait and posture over time. At present in the literature there is a void of information specific to such measurements.

7.5 Comparison of overground vs. treadmill walking

In order to examine changes in movement response over time, it is essential that a controlled environment is utilised. The use of a treadmill is a common strategy in which to gain this type of environment. Although this may not replicate the ground surfaces that one normally walks or runs over, from a logistical point of view it allows the research data to be collected quickly and effectively. When using biomechanical equipment in particular, and wanting to examine long duration walking or running, lab space is rarely large enough to allow a participant to continue walking in their normal pattern. Also, due to the nature of the biomechanical equipment it is unable to be used in an outdoor setting (due to the use of infrared light to examine movement of markers on the body). Another option is to have participants walk through the collection area in the laboratory and then head outside, continue the movement to be examined (e.g. carrying loads) and then at each collection time have them come back through the laboratory. There are however other issues with this including loss of markers on the body, weather conditions and requirement of personnel to be following such individuals at all times from an ethical standpoint. For these reasons the choice of conducting such experimental work on a treadmill is justified. There are however changes that occur as a result of treadmill walking when compared to walking overground. These are outlined below.

7.5.1 Energy cost

Examination of energy cost during locomotion on a treadmill is well documented in the research domain. Reports as early as 1915 (Benedict and Murschhauser quoted in Custance (1970)) have attempted to examine energy cost in this manner. Using a treadmill provides a controlled environment in which to examine the response of an individual to a number of external factors. There are however questions over the validity of comparing such information to information gathered whilst walking or running overground.

Energy cost on a treadmill is altered for a number of reasons. Air resistance to forward movement is virtually non-existent and there is no need to produce forward thrust in order to sustain forward progress. There is also no cooling effect from movement of the air past the body, as would be experienced when walking overground. It is possible to train oneself to almost "ride" the treadmill using minimal energy expenditure. Weight of the participant is also crucial in terms of energy cost outdoors, but this becomes less of an importance when on the treadmill (Custance, 1970). As a consequence of these factors Custance believes equipment such as load carriage systems cannot be properly evaluated on the treadmill when examining energy requirements. His experimental work (conducted on 2 males) indicated walking outdoors required 15% more energy unloaded and 23% more energy when carrying a 21lb (~9.5kg) backpack when compared to walking on a treadmill. On the other hand, examination of heart rate by Murray et al., (1985) showed the opposite effect. Heart rate was significantly higher on the treadmill than walking on the floor when walking at a faster than normal speed, and a similar trend seen when participants were walking at their comfortable speed. This difference is possibly attributed to apprehension about walking on the treadmill and brings into question the issue of acclimatisation to treadmill walking (see section 7.5.3), although in this particular experimental work several sessions of approximately 30 minutes walking time on the treadmill were completed. Therefore, other factors may have caused the apprehension of the participants, such as experimental equipment including positioning of EMG equipment and collection of telemetry energy expenditure data.

Whilst attempting to determine the "optimum" load that an individual can carry, Pierrynowski et al., (1981b) noted higher energy requirements when walking on a treadmill than those suggested by the model created by Pandorf et al., (1977). Pandorf's model examines metabolic rate by taking into account participant mass, external load, velocity of walking and the terrain over which the individual is moving. When examining results closer Pierrynowski concluded these discrepancies were due to speed fluctuations of the treadmill and the effort of the stabilising muscles of the body to stop the participants from falling. Therefore although not compared to overground walking in this particular study, one could suggest that the proposed model by Pandorf supports walking overground and that there are some subtle physiological differences involved with walking on the treadmill.

7.5.2 Alterations to biomechanics when treadmill walking

Biomechanical differences between walking overground and on a treadmill have been examined both whilst walking and running. There are differing opinions as to the specific changes treadmill walking induces on kinematics. Alton et al., (1998) examined gait of 17 individuals on the treadmill following speed determined from overground trials. Significant differences were seen in stance time (shorter on treadmill) and cadence (increased on treadmill). Hip range of motion and maximum hip flexion angle were also altered, with higher values seen on the treadmill. The measurement of hip angle in this study included a marker on the shoulder and shoulder rotation and trunk movement may have influenced this response. They also suggest that the increase in cadence is due to the urgency to place the foot on the belt before the other foot completes stance phase, as a means to avoid falling off the back of the treadmill.

Murray and colleagues (1985) examined 7 individuals whilst walking at 3 different speeds (slow stroll, comfortable and fast) on the treadmill and on a walkway. No significant differences were seen in mean velocity, step length and temporal parameters; however there was a trend at all speeds for the treadmill to induce shorter step lengths, faster cadences, shorter swing phases and longer double support times. In terms of kinematic measures, there was a trend for the pelvis to have more anterior tilt on the treadmill. There was also significantly less hip extension at the end of stance phase at all 3 speeds, less dorsiflexion during stance (at slow and fast speeds) and smaller vertical excursions of the head when walking on the treadmill. No significant differences were found in knee flexion-extension; however the knee tended to be in more extension on the floor at slow and fast speeds. EMG data was also assessed in this study, with the quadriceps exhibiting significantly greater activity when walking on the treadmill at the slow and fast speeds. Although no other significant differences in EMG were seen the average EMG was greater on the treadmill for all muscles examined (erector spinae, gluteus maximus, hip abductors, hamstrings, calf and pretibial muscles) for all speeds than when walking overground. Despite these findings the authors concluded that in general walking on a treadmill does not significantly differ from walking on a level floor. More so, they attribute the changes to possible apprehension of treadmill walking. Given the amount of acclimatisation (several bouts of 30mins) completed by participants it is unlikely this is the case (as discussed in section 7.5.3).

In terms of mechanical energy, a pilot trial on 1 individual indicated similar patterns in energy curves between treadmill and overground walking (Correa et al., 2000). However, when expressed as a total change in energy there was a greater change when walking overground compared to the treadmill, suggesting the treadmill provides some energy to the system, therefore questioning whether comparing like with like. However, a few strides from one participant is not sufficient data to prove this result, and further study in the area is required. It does however offer suggestion as to the source of the increased energy cost when walking overground stated in the work by Custance (1970) above.

7.5.3 Familiarisation with treadmill gait

Walking on a treadmill presents a different environment to that normally experienced when walking overground. A set speed is introduced, with the treadmill belt moving below the individual rather than the individual propelling their body mass forward. It is therefore understandable that a degree of acclimatisation is required for individuals to become comfortable with treadmill walking. The amount of time required for an individual to gain such acclimatisation is of debate. Custance (1970) suggests a period of several days and sometimes more than a week to condition oneself. However this data was collected on a treadmill made of rollers. These types of treadmills are no longer in use, with belt treadmills being most commonly used now. In order to examine kinematic differences between treadmill and overground walking Alton et al., (1998) suggested a period of 3 minutes was sufficient time for participants to become familiar with treadmill walking. Following this they are allowed to dismount from the treadmill for 30 seconds before beginning the testing session. Matsas et al., (2000) determined an acclimatisation period of 6 minutes is required before collection of knee kinematic data is relative to overground gait. Measurements before this time were seen to be significantly different on the treadmill when walking at a self-chosen speed. This is particularly evident when measures are taken at 0 minutes just after the treadmill has been started, where most variation is seen. As mentioned previously Murray et al (1985) allowed a total of at least 30mins at various speeds on the treadmill prior to testing days in order for familiarisation to occur.

Wall and Charteris have reported studies examining short and long habituation times. Their original study in 1980 examined habituation times up to 10 minutes (quoted in (Wall & Charteris, 1981)) and determined that at this time participants had not achieved steady state in their walking gait. Therefore a further study examining the changes after training for up to 3 hours was conducted. In the first

10 minutes of walking stride lengthens and there is increased knee flexion after impact. Following this there are only slight differences in the knee response up to 2 hours as the flexion pattern decreases in single support. However these differences are deemed important, as the extent to which the knee is flexed is a good indicator of the comfort of the individual on the treadmill. Initial strides of naïve users indicate excessive flexion of the knees in order to support the body and decrease risk of falling, this decreasing as time progresses. Overall Wall and Charteris (1981) suggest a period of up to 1 hour habituation is required with no measurement during the first 2 minutes of performance. However, in a research setting this would not be practical in terms of completing data collection. Although this work suggests a period of 3 hours continuous walking has occurred, in fact this was split into 2x10min treadmill walking sessions per week for a period of 9 weeks. Angular and temporal kinematic data was only collected at elapsed times of 10, 70, 130 and 190 mins. Therefore there is no data examining the effect of walking for 15, 20 or 30 minutes continuously and whether this would serve to habituate a person in a performance session. It was made clear however that during the first 2 minutes of any of the data collected the data showed high variability and measurements in a performance setting should not be made during this time.

7.5.4 Summary

The trade off between time available for experimental work and acclimatisation of the treadmill must be taken into account. From the studies mentioned above collection of data before a period of 6 minutes may result in the data being affected by the user's initial response to the treadmill. However using large acclimatisation times such as periods of 1 hour or several 30 minute sessions as suggested by some authors may not be a viable exercise. When conducting research with the military, access to personnel can be severely constrained and conducting such acclimatisation sessions would result in other areas of experimental work having to be removed from the protocol. Issues have also been highlighted with changes in physiological and biomechanical response as a result of using treadmills in experimental work. There is some debate of the exact nature of these changes, in particular the causes of differences in response. These changes however do not rule out the use of a treadmill in order to examine gait and posture over prolonged time periods.

7.6 Subjective measures of performance

7.6.1 What is comfort?

On a daily basis every individual is striving to exist in a state of comfort, constantly trying to increase his or her comfort level. However, defining comfort is somewhat difficult as it is related individually to each situation/environment that a person may be experiencing. Slater (1985) attempts to define comfort as "a pleasant state of physiological, psychological and physical harmony between a human being and the environment". In the opposing context Kee and Karwowski (2003) associates discomfort with biomechanical changes at joints, muscles or due to pressure which produces feelings of pain, soreness and/or stiffness.

Measurement of a scale of comfort presents a problem as it is only when a person realises they are experiencing some level of discomfort they are aware they are no longer comfortable. Different levels of comfort are complex to ascertain; measurements of a scale of discomfort or changes from comfort to discomfort present less of a challenge. This is because in order for a person to be in a true state of comfort there must be a complete absence of discomfort in every possible way.

7.6.2 Measurement of comfort

Measurements of comfort are considered subjective rather than objective, such as measuring heart rate. Therefore they depend on the ability of the individual to make a decision about the level of the scale they are to report. These rating scales are used commonly in ergonomic investigations (Bryant et al., 2000; Corlett & Bishop, 1976; Kee & Karwowski, 2003; Olendorf & Drury, 2001; Wu & Chen, 2001), however are subject to unreliability if not carefully planned. Annett (2002) suggests several areas in which the reliability of results may be placed into question. The administration of scales following a test may introduce a time error, due to the individual not being able to hold the subjective response in their memory. Whilst taking measures at the time of testing may interrupt the particular test, if this is minimal then it is seen as the preferred method. The use of individuals skilled in the area being tested can also affect results. Skilled testers may have the ability to identify subtle characteristics of the object in question that an otherwise untrained individual would not. The selection of participants is dependent on the system one wishes to test.

One of the early papers considering comfort in relation to ergonomic requirements was work done by Corlett and Bishop (1976). They proposed the use of body zone discomfort (similar to Figure 7.1) as a means to validate changes in workspace design. These measures, combined with an overall body comfort rating showed significant differences in work ability with an increase in ability to work and a decrease in work load, potentially reducing costs. They also found that overall discomfort ratings were not specific to the intensity of discomfort in one zone, but rather attributed to the number of body parts in which pain is felt. The position of a joint also affects the level of discomfort that is relayed. Discomfort is seen to increase as joints deviate from their neutral position, with this increase becoming much greater as soon as the joint moves past 75% of its maximum range of movement (Kee & Karwowski, 2003).

7.6.3 Measurement scales

There are several different types of scales that may be used to evaluate the subjective response of an individual. Ordinal scales such as body part discomfort (BPD) scales rely on simple rating scales such as numbers from 1-5 or 1-7, with ratings ranging from for example very comfortable to very uncomfortable. Other rating scales include the visual analogue scale (VAS); a line with minimum at one end and maximum at the other on which a participant marks a point to show the intensity of the perception; and interval scales such as RPE (Borg, 2001).

In 1962 Gunnar Borg proposed the idea of using perceived exertion as a measure of physical stress. This scaling was developed from exercise on a cycle ergometer utilising 15 grades ranging from 6-20 (see scaling used in experimental work in Chapter 8). This range was chosen to roughly cover the similar range of heart rate 60-200 beats per minute (bpm; divided by 10) and the values have been shown to increase linearly with work load and with heart rate (Borg, 1970). Since this point in time the RPE has been adopted worldwide as a means to measure body stress during exercise and/or work. A link has been demonstrated between physiological measures and RPE when carrying loads and altering load positions (Stuempfle et al., 2004). Movement of load from a high to low position increases both the physiological cost and the RPE.

Jacobson et al. (2003) used a VAS to examine the comfort/pain in three regions of the body; lower back, shoulder and neck as well as overall comfort, whilst carrying different LCSs, one of which incorporated a shelving system in an attempt to improve distribution of the load. In all regions the experimental LCS received significantly lower ratings on the VAS suggesting that it was the least comfortable system, although the comparison of the experimental pack with each individual's preferred choice of backpack questions the validity of the research.

Olendorf and Drury (2001) assessed RPE and BPD measures over 168 body postures whilst holding a load in front of the body. He concluded what others have also concluded; that BPD is highly correlated with RPE and suggests the use of one rather than the other is possible to achieve the same results. This is particularly relevant when the physiological stress of the task is not as high as the relevant postural stress/discomfort which is being measured.

Correlations also exist between perceived discomfort and shoulder and lumbar force. As both of these forces increase, the perceived discomfort increases in a linear fashion. This is more highly correlated in the lumbar region ($r^2 = 0.81$) (Bryant et al., 2000). Shoulder discomfort was reported by 95% of soldiers when average shoulder pressure exceeded 20kPa in this study. Although this pressure is greater than the 14kPa limit that indicates blood flow occlusion, all 4 LCSs examined exceeded this value in the shoulder and upper limb regions. These ratings are therefore important to be considered. However of equal importance are performance requirements of the LCS rather than just assessing physical attributes.

7.6.4 BPD scales and LCS design

The work of Legg and colleagues (Legg et al., 1997; Legg et al., 2003) uses body mapping (see Figure 7.1) and subjective scales (Borg CR-10 scales) in the attempt to determine preferable LCS designs. This is an area that has received limited attention in backpack research, with the studies by Legg being concerned with recreational LCS design.

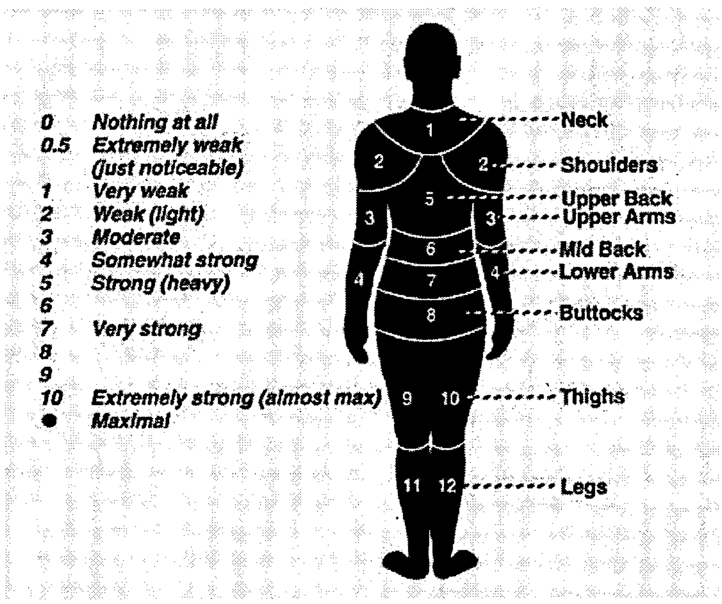


Figure 7.1: Category-ratio scale (CRS) ratings of perceived discomfort as used by Legg and associates (Legg et al., 1997; Legg et al., 2003)

By using this CRS scale Legg and co authors deviated from the previous method of assessing an overall comfort rating or using RPE to discern between designs. Rather they were attempting to identify areas of discomfort into specific body zones. Whilst changes were seen between body zones, no differences were seen between designs (Legg et al., 1997) possibly due to the similarity of the packs. These measures were taken following the period of load carriage (30 mins) possibly incurring some time error (see section 7.2.2). The authors suggest the use of questionnaire rather than post exercise rating scales is more useful in determining pack differences; however investigation whilst actually carrying the loads had not been examined. The use of such scales in the field presents a cost effective way to establish differences between systems as opposed to using expensive physiological and biomechanical methods. When taken into the field Legg et al. (2003) collected VAS comfort ratings for the shoulder, back, upper and lower legs following a 15 min outdoor carriage. Once again no difference between packs could be determined – again assumed to be a result of the similarity between the two packs. The intensity of exercise and period of load carriage may also have affected any possibility of observing differences between packs.

Madras et al., also (1998) attempted to compare different loads using RPE and physiological measures. Loads of 4.5kg placed on the back or around the waist showed no difference in RPE over the whole body. When RPE was examined relative to only the leg or the back there was still no difference seen. However at such low loads the metabolic and biomechanical differences between the two loads, combined with a sample of very similar heights would produce negligible changes between packs.

Balance, load control and shoulder/arm motion restriction have been identified as the three most important performance factors when assessing different load carriage designs (Doan et al., 1998a). These findings are based on assessment of 76 measures on nine military LCSs using a load carriage simulator and confirmed by surveys of military load carriage experts. A combination of objective (39) and subjective (37) variables were included in the 76 measures. If the goal of the study is to pinpoint differences between LCSs these variables should be given consideration.

7.7 Other considerations with prolonged load carriage

7.7.1 Balance following fatigue

Studies have been conducted in the literature analysing the effect fatigue of postural muscles, such as those supporting the neck, have on the ability of an individual to maintain their balance (Gosselin et al., 2004; Schieppati et al., 2003). Continuous contraction of neck muscles and/or an uncomfortable head position could contribute to feelings of dizziness, and lead to alterations of balance (Schieppati et al., 2003). Induced fatigue of cervical spinal musculature of 5 minutes (Schieppati et al., 2003) and 15 minutes (Gosselin et al., 2004) resulted in alterations to body sway. In both cases these measures were only significant when eyes were closed. However, in the case of the Schieppati study, in both open and closed eye conditions subjective responses indicated lower self confidence in ones balance following the fatigue protocol. Whilst load has not been carried in these studies, and the possibility of involvement of other trunk muscles has not been accounted for, it is reasonable to predict that prolonged load carriage at high loads may have a similar effect on balance of a soldier, in particular as a large amount of stress is placed on the muscles that support the neck. In addition it is possible to predict tasks which need to be completed following load carriage may also be affected.

Alteration of balance following fatiguing exercise is also confirmed by Pendergrass et al. (2003) when examining the effect of a 2-mile run at maximum speed. This test is commonly employed as part of the American biannual fitness test that all service personnel are required to undertake. A significant increase in postural sway was seen in the experimental group compared to the control (no run) following exercise. A change in muscle strength at the ankle was a suggested cause of the change in postural sway following exercise. One criticism of this study however is that the average 2 mile run time is not reported, therefore one is unable to compare results to other studies with specific exercise timings. Previous studies have reported that such changes in postural sway and therefore balance wear off after 15 minutes (Nardone et al., 1998). Therefore tasks requiring balance may not be able to be performed successfully until this time. The implications for tasks needed to be performed in the military environment is of concern here as at times this could be in life and death situations where delays are not possible.

7.7.2 Injury with prolonged load carriage

Injuries, in particular blisters, are also shown to increase over longer load carriage trials. Reynolds et al. (1999) examined injury incidence and risk factors over a 161km infantry road march, this data being collected when carrying US equipment. Thirty six percent of soldiers (n = 218) suffered one or more injuries during the course of the experiment, with 8% unable to complete the march due to these injuries. When one considers the burden, both staffing and financial, that this may have on a military operation, it is important to determine areas that are able to reduce such incidence, including changes to equipment design and implementation of adequate rest periods.

When considering lower back pain, a problem when carrying loads augmented as time of load carriage increases, an important factor is the endurance on the trunk extensor muscles. Individuals with history of lower back trouble are shown to have smaller endurance capacity than those who have never had lower back trouble (Jorgensen & Nicolaisen, 1987). The trunk extensor muscles are predominantly type I fibres (slow oxidative) and therefore have large endurance capacity. It is possible those with, or having experienced, lower back trouble have a larger proportion of type II (fast twitch) fibres. This is a consideration to take into account when examining the effect that load has on the body, particularly the trunk, over time.

Ability to complete a military task is hampered by load carriage. Knapik et al. (1992) showed that 50% of soldiers that were unable to complete a 20km walk reported problems associated with the back being the reason for non completion. These heavy loads may be a risk factor for injury and forward inclination of the trunk may be a key factor. These long marches also lead to decreases in performance in marksmanship and grenade throwing ability tasks (Knapik et al., 1991; Knapik et al., 1997).

McCraig and Gooderson (1986) completed a survey of 2000 soldiers following a 2-month mission in the Falklands in 1982. Fatigue due to the weight of the load carried was listed by 20% of the group as a significant problem that they experienced. In terms of the equipment they carried whilst undertaking this mission, the boots were the most common source of dissatisfaction (29.6%), with webbing rubbing on the legs and backache due to localised pressure from backpacks also noted as areas which amplified the problem of fatigue. The implications of these injuries and failure to complete tasks in the battle context have yet to be fully investigated.

7.8 Summary

The completion of a longer duration trial will give insight into the overall effect of carrying military loads. Although the physiology of such tasks has received attention in the past, collection of biomechanical data is somewhat limited. In particular the collection of data over the entire time period rather than pre/post test is an area that requires further attention. The combination of this data with collection of subjective information will serve to give a better overall picture of the effect of prolonged military load carriage on the body and the influence of different designs.

There are a number of variables associated with the methodology that may impact on the results achieved. Walking on a treadmill can elicit differing gait patterns when compared to walking on the ground, as gait on a treadmill is forced rather than naturally chosen. Walking either in the laboratory or on a treadmill is also very different to tackling the terrain that a soldier would encounter when on exercise or during a mission. Limitations of the motion analysis equipment mean it is not possible to examine the effect of terrain on posture and gait, but it is hoped that by examining gait and posture over a long period of time the general effects of load carriage can be explained, and these then extrapolated to what would occur in the field.

The next two chapters attempt to delve further into the examination of longer term load carriage. Chapter 8 is concerned with a 2 hour load carriage trial whilst carrying 2 different LCS designs. Measurements of a biomechanical, physiological (heart rate) and subjective nature are taken across the entire time period. As this work was conducted in the laboratory it is possible that there are differing responses seen when completing the same 2 hour load carriage in the field. Therefore chapter 9 examines the responses from 129 personnel completing a similar trial as part of their basic training. Comparisons can then be made between the two situations, including responses from specific individuals as some completed both experimental trials.

Chapter 8 – Effect of Load Carriage Duration on Gait, Posture and Subjective Comfort

8.1 Introduction

The experimental work presented in chapters 4, 5 and 6 demonstrated the effect of short term load carriage on gait and posture, in particular examining the addition of load, changes due to gender and changes seen due to carrying different load carriage systems. Whilst this information is useful as it allows a baseline to be established for British military equipment, the duration of load carriage scenarios presented to participants were well below any realistic scenario they would experience in training or combat situations. As these situations are where the predominant number of injuries occur in the military it is important they are examined. The field visits with researchers in Australia and the United States (section 7.2) highlight the worldwide interest in undertaking such research. Similar issues are being experienced by these defence forces and it is felt by gaining a better knowledge of the changes that occur as load carriage duration increases more effective training regimes may be devised, combat scenarios may be altered and in the long run injury incidence could be reduced.

In order to complete long duration trials it was important that experienced personnel were recruited. Through liaison with the MoD an opportunity was presented to attend the Land Warfare Centre Battlegroup in Warminster (Wiltshire, UK) to work with the 1st Regiment Black Watch (Royal Highland Regiment). This regiment consisted of predominantly infantryman (as with the work in Chapter 5). However due to operational commitments at the time of the experimental work and the deployment of this regiment, only the rear party were present at the barracks at the time of this experimental work. The rear party consists of those members of the regiment who are injured or have minimal experience in the field. This includes personnel recently recruited, therefore very young and mostly not ranking above the level of Private. Therefore, in order to supplement this work, further experimental testing took place at Loughborough University in the Load Carriage Laboratory with members of the East Midlands Army Officer Training Corps (EMAOTC). These individuals were of the same level of experience (if not greater) to those participants recruited from the Black Watch (BlkW). Experimental conditions and protocol for both trials were identical.

8.2 Method

Twenty male participants participated in this study (10 BlkW and 10 EMAOTC). All participants were experienced in long term load carriage as either part of their employment (BlkW) or through specific training in association with the Territorial Army (EMAOTC). Participant characteristics are presented in Table 8.1. This work was conducted following approval from LUEAC (G03/P18, R03/P98). All participants completed a health questionnaire prior to commencement of testing sessions, gave informed consent ensuring knowledge of procedures involved (see Appendices A7-A9) and in the case of Black Watch were declared physically fit for duty by their regimental commander.

In order to obtain kinematic data (as per defined in Chapter 3) the CODA Cx1 and the mpx30 were used for these experimental trials. Both camera systems were utilised in the work at Warminster (BlkW) due to restricted availability of military participants. Therefore at all times 2 participants were completing the trials at the same time, in adjacent rooms. In the case of the work completed in the Load Carriage Laboratory at Loughborough University, only the Cx1 was used to collect kinematic data. Participants also walked at a predetermined speed on a Tunturi J9F treadmill (BlkW) or Horizon Paragon CS treadmill (EMAOTC) as shown in Figure 8.1. These treadmills were chosen as they allowed minimal interference with saggital view data collection by having small (Tunturi) or removable (Horizon) side arms.

Table 8.1: Participant characteristics (mean ± SD)

Age (years)	20.15 ± 3.48
Height (cm)	176.54 ± 4.64
Body Mass (kg)	69.85 ± 7.30
Body Fat % *	12.88 ± 3.05
Greater trochanter height (cm)	91.96 ± 3.90
C7 height (cm)	153.74 ± 4.33
Back Length (cm)	61.78 ± 2.11

* Data unavailable for one individual.

It was important to replicate load carriage conditions regularly experienced by military personnel. For this reason the Standard LCS (Figure 3.16) and the Airmesh LCS (Figure 3.17) were used. Participants also wore their own standard issue boots and socks and were supplied with shorts and a Coolmax T-shirt for all experimental trials. The SA-80 rifle was carried during all experimental trials in order to replicate body posture positions normally imposed on military personnel. In the case of the work at Loughborough University this was done using the replica weapon (as per Chapter 6), to simulate the same conditions as experienced in Warminster.

8.2.1 Protocol

All participants were required to complete two testing sessions, each comprising of a 2 hour walk at set speed on the treadmill, carrying a different LCS each time. It was envisaged the protocol of this research was to replicate as closely as possible a task that members of the military are required to undertake. Upon consultation of the "Fit to Fight" Pamphlet Two (DIPT, 2002) a series of fitness tests are required to be completed by all serving members in order to ascertain general health and physical capabilities. These tests include the Basic Combat Fitness Test (BCFT), the Advanced Combat Fitness Test (ACFT) and the Basic Personal Fitness Assessment (BPFA).

Tunturi J9F Treadmill	Horizon Paragon CS Treadmill

Figure 8.1: Treadmills used for research trials

The BCFT represents the minimum standard of basic combat fitness required by all military personnel. This test is age and gender free and is designed to measure aerobic capacity using a physically demanding task in the form of a loaded march. The ACFT is designed as a specific test to account for role and operational readiness within a unit and may use task specific tests (possibly up to 20km in distance), whilst the BPFA accounts for more general fitness components associated with military task performance, maintenance of good health and the reduction of susceptibility to fatigue and psychological stress. Due to the generic nature of the BPFA and the specific nature of the ACFT, it was decided that a test modelled on the BCFT would be most effective in terms of assessing the response of an individual over time whilst carrying a military load.

The BCFT consists of a 12.8km loaded march which is to be completed in a maximum time of 2 hours but not less than 1 hour 55 minutes. Under field conditions the test must be at least ¼ off-road, with water stops along the way at the discretion of the commanding officer. The load carried is also dependent on the role of the unit, all infantry carrying a load of 25kg inclusive of personal weapon and ancillary equipment such as helmet, body armour etc. Whether helmet is worn or carried, full LCS or just Bergen (backpack) used, or whether the weapon is carried using the strap is also at the discretion of the commanding officer, as is the level of build up to combat phase that the unit is undertaking at the time.

Based on the above information, the test undertaken by all individuals in this experimental trial involved walking for 2 hours on a treadmill (Figure 8.2) at a set pace of $5.8km.h^{-1}$ ($6.4km.h^{-1}$ was determined to be too fast for participants due to age, experience and body size), whilst carrying a load of 20kg in the LCS (7kg in webbing + 13kg in Bergen) plus weapon (4.4kg). The average percentage bodyweight of the load was $28.9 \pm 3.0\%$ which is in accordance with previous research recommending loads of between 33-45% BW being the maximum carried for extended time periods (Cathcart et al., 1923; Hughes & Goldman, 1970; Knapik, 1989; Lothian, 1922; Shoenfeld et al., 1977). Participants completed this test twice; once carrying the Standard (STD) LCS and once carrying the Airmesh (AM) LCS. There was a period of one week's rest between the two trials, and both trials were conducted at the same time of day for each participant. Order of conditions was balanced between participants to ensure no effect of one LCS over the other. All testing took place with rooms heated to normal room temperature.

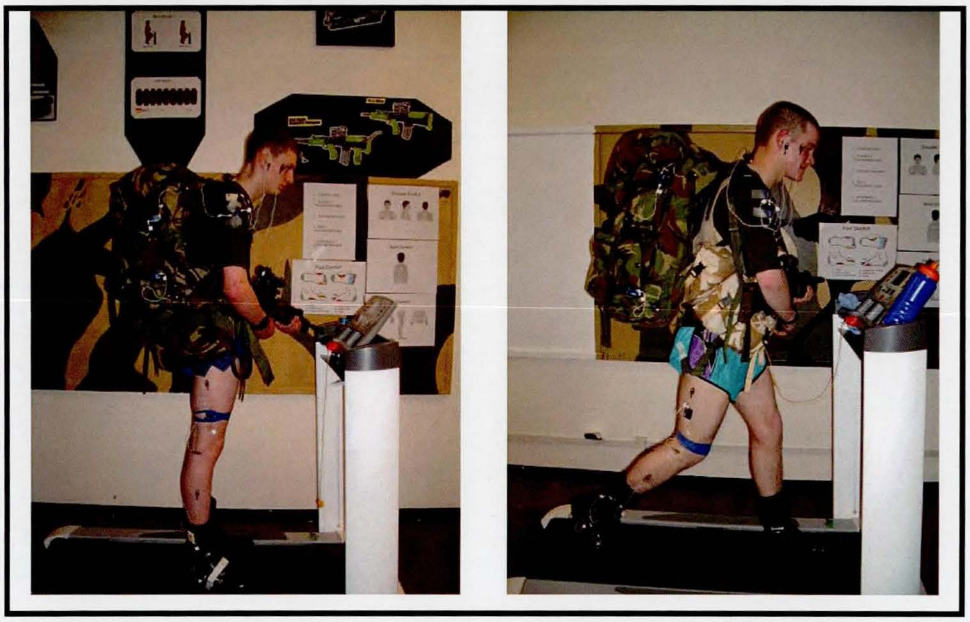


Figure 8.2: Experimental conditions carrying the STD LCS (left) and AM LCS (right)

Participants were given the right to withdraw from testing sessions at any time, supplied unlimited water and monitored by a heart rate monitor at all times to ensure safety. Should the participant heart rate have exceeded 80% of their age predicted maximum the experiment was terminated as this could have indicated overexertion (McArdle et al., 1991). An initial 3 minutes of warm up was undertaken before raising the speed to $5.8km.h^{-1}$ for the rest of the test duration. Measurements of angular data (Section 3.6), RPE, thermal and comfort ratings (Section 8.2.3) and heart rate were taken at 15 minute intervals throughout the test. Angular measures were made in the last 10 seconds before the 15 minute mark (i.e. 14 min50 sec) and all other measures taken once these were completed. This allowed the final subjective ratings data to be taken during the 5 minute cool down stage without extending the test to accommodate this piece of data collection. Prior to commencing the test baseline ratings and heart rate data were obtained and pre and post static angular data was also collected.

A simple cognitive task (Figure 8.3) was also completed both before and after the walking test to assess any decrement in cognitive performance. This type of test is commonly used in the psychology and clinical settings to assess cognitive performance. Three practice sessions of this test were completed by all participants at a briefing session prior to experiment days to ensure no learning effect occurred from pre to post test.

Subject Number   Date   Time   T1

DIGIT	1	2	3	4	5	6	7	8	9
SYMBOL	O	U	⊥	⊐	–	X	Λ	L	=

SCORE

SAMPLES

2	1	3	7	2	4	8	1	5	4	2	1	3	2	1
4	2	3	5	2	3	1	4	6	3	1	5	4	2	7
6	3	5	7	2	8	5	4	6	3	7	2	8	1	9
5	8	4	7	3	6	2	5	1	9	2	8	3	7	4
6	5	9	4	8	3	7	2	6	1	5	4	6	3	7
9	2	8	1	7	9	4	6	8	5	9	7	1	8	5
2	9	4	8	6	3	7	9	8	6					

Figure 8.3: Digit symbol test

Participants were instructed to replace the digits with the associated symbols as quickly as possible for a period of 90 seconds. Scores were calculated as total number of correct symbols. Ten different symbol combinations (T1-T10) were used to ensure no participant completed the same test twice. The order of these tests was randomised between participants.

8.2.2 Angular measurement data reduction and smoothing

The angles described in Chapter 3 were calculated from -20% to 120% stance phase, making them independent of time and walking speed (in this case constant). Observing the data in this way also ensured any anomalies around heel strike (0%) or toe off (100%) were observed and accounted for. Collection of data was for a 10 second period every 15 minutes whilst on the treadmill with 5 stance phases selected from this period for analysis at each time point.

This test was designed to replicate a fitness test which all members of serving military should be able to complete at any time. However, in the case of the Black Watch participants full completion of both LCS tests was only completed by 4 of the 10 participants. For this reason all data presented only includes those 14 participants who completed both tests. Mean angular values for these participants were calculated and to obtain a single representation of each collection time (i.e. 15 mins, 30 mins etc) the mean and 95% confidence intervals were calculated for all 14 participants. A 2 factor within-subjects ANOVA was conducted on all spatiotemporal data and maximum, minimum, mean and ROM values for all angles (significance set at $p=0.05$). Reasons for withdrawal of other participants are also presented in the results section.

8.2.3 Subjective measurements

In addition to the angular measurements, a series of subjective measures were also collected (after successful collection of each bout of angular data). In order to assess perceived exertion of the participants, the Borg CR- 20 scale was used (Borg, 1998). Participants gave a rating between 6 (no exertion at all) to 20 (maximal exertion) at each 15 minute interval (Figure 8.4). An indication of thermal comfort was also ascertained using the Ashrae Thermal Sensation Scale (cited in Parsons (2003)), ranging from 1 (cold) to 7 (hot) with data collected at each 15 minute interval (Figure 8.4). These ratings, combined with the collection of continuous heart rate data also served to allow monitoring of the individual to ensure safety.

RATE OF PERCEIVED EXERTION

6 no exertion at all
7 extremely light
8
9 very light
10
11 light
12
13 somewhat hard
14
15 hard (heavy)
16
17 very hard
18
19 extremely hard
20 maximal exertion

ASHRAE THERMAL SENSATION SCALE

During the test we want you to describe how your body temperature feels: that is, we want you to rate your thermal sensation. Don't concern yourself with any one area, such as your hands or feet, but try instead to concentrate on your total body temperature sensation.

Please rate on these scales how YOU feel NOW.

7 Hot
6 Warm
5 Slightly warm
4 Neutral
3 Slightly cool
2 Cool
1 Cold

Figure 8.4 RPE and Thermal Scales

Subjective comfort measures over a variety of body zones were also collected to ascertain any changes over time and any differences when carrying different LCSs. Body zones were explained to participants prior to commencement of the exercise trial and baseline measures were also collected. In addition an overall comfort rating was obtained. Participants were asked to give a rating of 1-5 (Figure 8.5) in all zones in the upper and lower body. The areas concentrated on were the shoulders and back (Figure 8.6) and the hips and feet (Figure 8.7). These readings were taken following collection of motion analysis data every 15 minutes throughout the trial. If participants consistently gave a rating of 5 in one zone (more than 2 times) this was a reason for discontinuing the test. A 2 factor within subjects ANOVA was conducted on all subjective ratings scores and physiological data with significance set at p=0.05.

1. COMFORTABLE
2. SLIGHTLY UNCOMFORTABLE
3. UNCOMFORTABLE
4. VERY UNCOMFORTABLE
5. EXTREMELY UNCOMFORTABLE

Figure 8.5: Comfort rating scale – as developed by Martin (2001)

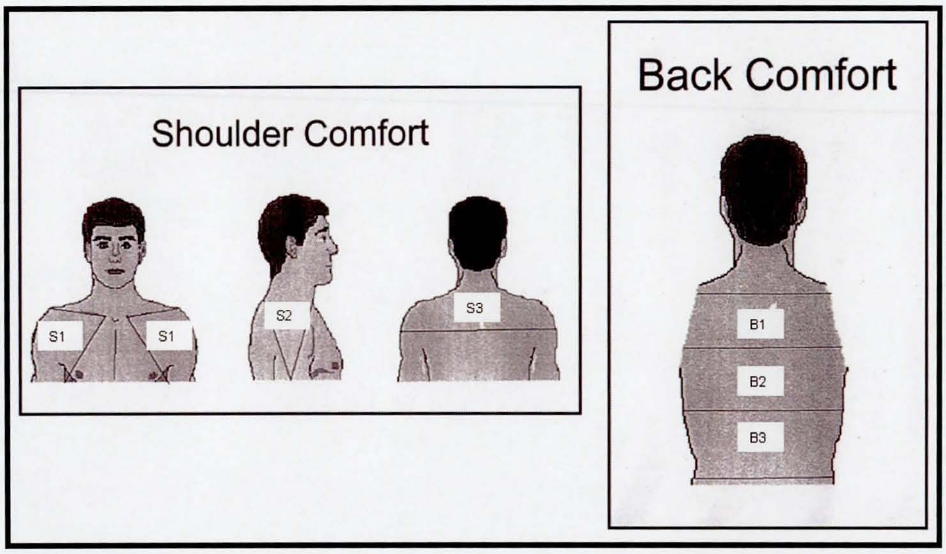


Figure 8.6: Upper body comfort zones. Shoulder zones (L to R) are zone S1, S2 and S3. Back zones (top to bottom) are B1, B2 and B3. Developed from work by Jones (2005a)

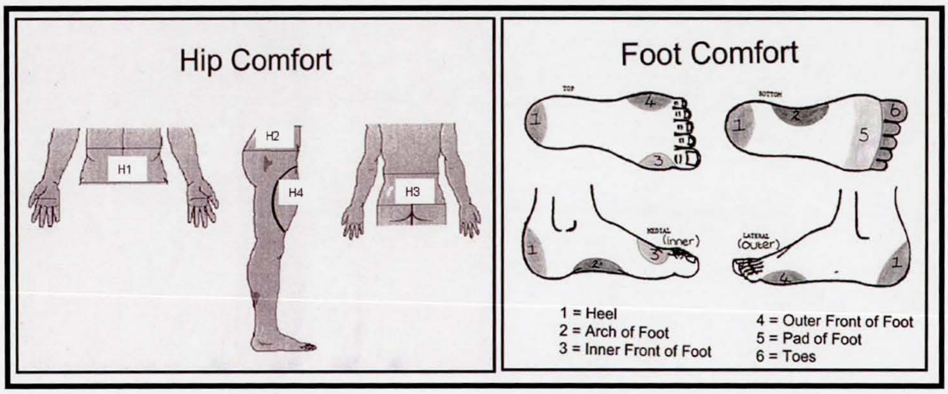


Figure 8.7: Lower body comfort zones. Hip zones (L to R) are zone H1, H2, H3 and H4 on the thigh (as developed from Jones (2005a)). Foot zones as explained in the figure range from F1-F6

8.3 Results

8.3.1 Participant characteristics

As mentioned previously, 6 participants were unable to complete the experimental trials. For this reason their data has been removed from the analysis. A test of normality was conducted on the remaining 14 participants (Kolmogorov-Smirnov). Height, weight, age and percentage body fat all fell within a normal distribution.

8.3.2 Spatiotemporal parameters

Descriptive gait characteristics were derived from heel and toe marker positioning over time. Stride Length (m) was calculated as the total distance travelled from heel strike until the following heel strike. This was calculated using the speed of the treadmill and the time between heel strikes. The stride time was then used to calculate stride frequency (strides/minute). Stance time (sec) was calculated as the period from heel strike to toe off. As all of these trials were conducted on the treadmill speed was constant at 1.61 $m.s^{-1}$. A summary of this data is indicated in Figures 8.8 (stride length), 8.9 (stride frequency) and 8.10 (stance time).

As the length of time on the treadmill increased changes were minimal in terms of these parameters. As speed was constant any change that occurred must be counteracted by an opposing change in another variable. Although no significant differences are seen over time for either SL or SF, there is a trend ($p = 0.077$) for the AM LCS to result in a greater SL than the STD LCS. As a result of this the opposite is true for stride frequency ($p = 0.063$). In the case of the STD LCS a marked change is noted at the 90 minute mark in both SL and SF whereas when carrying the AM LCS a similar change occurs at the 60 minute mark (Figures 8.8 and 8.9). In terms of stance time (Figure 8.10) there is a trend for an increase over time ($p = 0.065$). This is more so evident in the AM LCS than the STD LCS. The AM LCS also has consistently longer stance time (apart from 15 mins) than the STD, although not significant ($p = 0.214$).

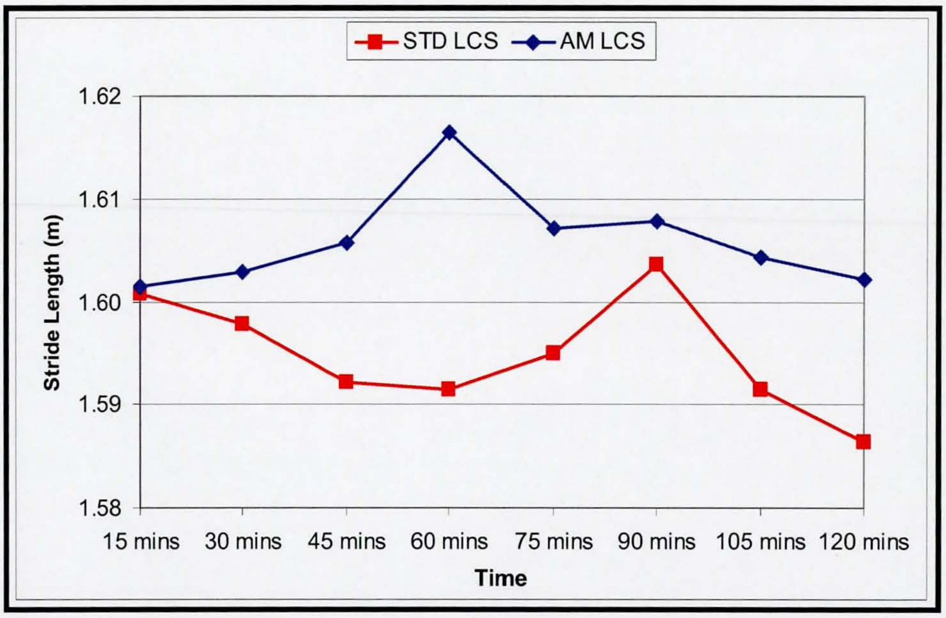


Figure 8.8: Stride length over time. Mean values for STD LCS (■) and AM LCS (◆)

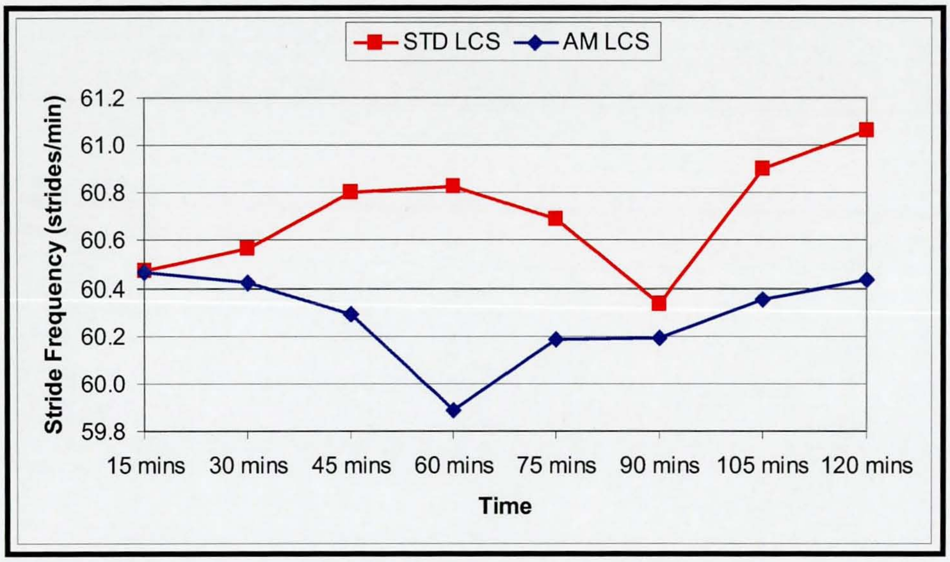


Figure 8.9: Stride frequency over time. Mean values for STD LCS (■) and AM LCS (◆)

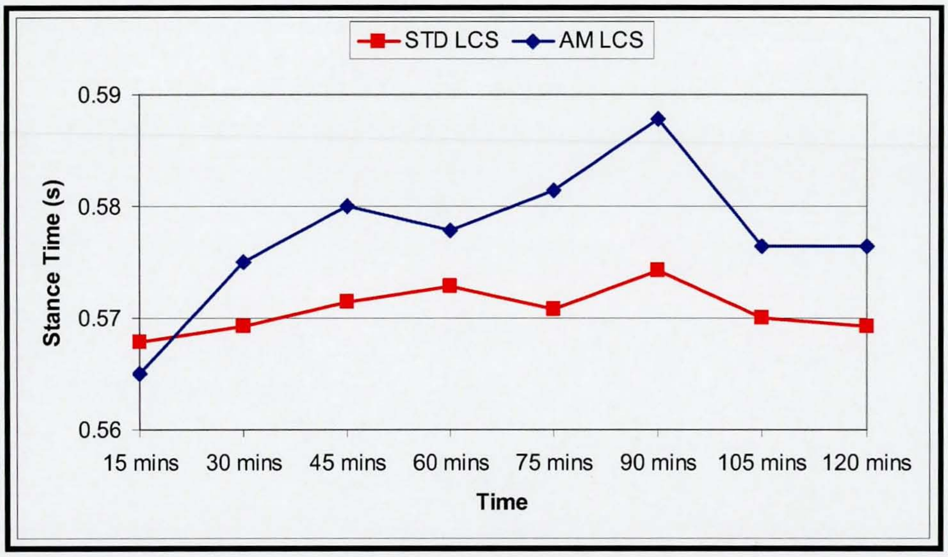


Figure 8.10: Stance time over time. Mean values for STD LCS (■) and AM LCS (◆)

8.3.3 Lower limb angular data

The movement of the lower limb through stance is described in section 5.3.2. The work in chapters 5 and 6 has examined angular data at different load variations or between LCS conditions. In this case data will only be represented as a consequence of time or as the difference between the two LCSs carried. Over the three lower limb angles some changes over time were indicated in the knee and femur, and in all cases there is a distinct difference between LCSs. Lower limb data from all 14 participants were combined by taking an overall average of the experimental data for all time points (Figure 8.11). Very narrow confidence intervals (± 95% CI) indicate this data shows minimal change over time (as shown in Figure 8.11), however closer examination of knee and femur angles does indicate a main effect for time – particularly in terms of maximum angle (Figure 8.12) and therefore ROM. Table 8.2 contains statistical output data (p values) from the within subjects ANOVA conducted on the lower limb angular data.

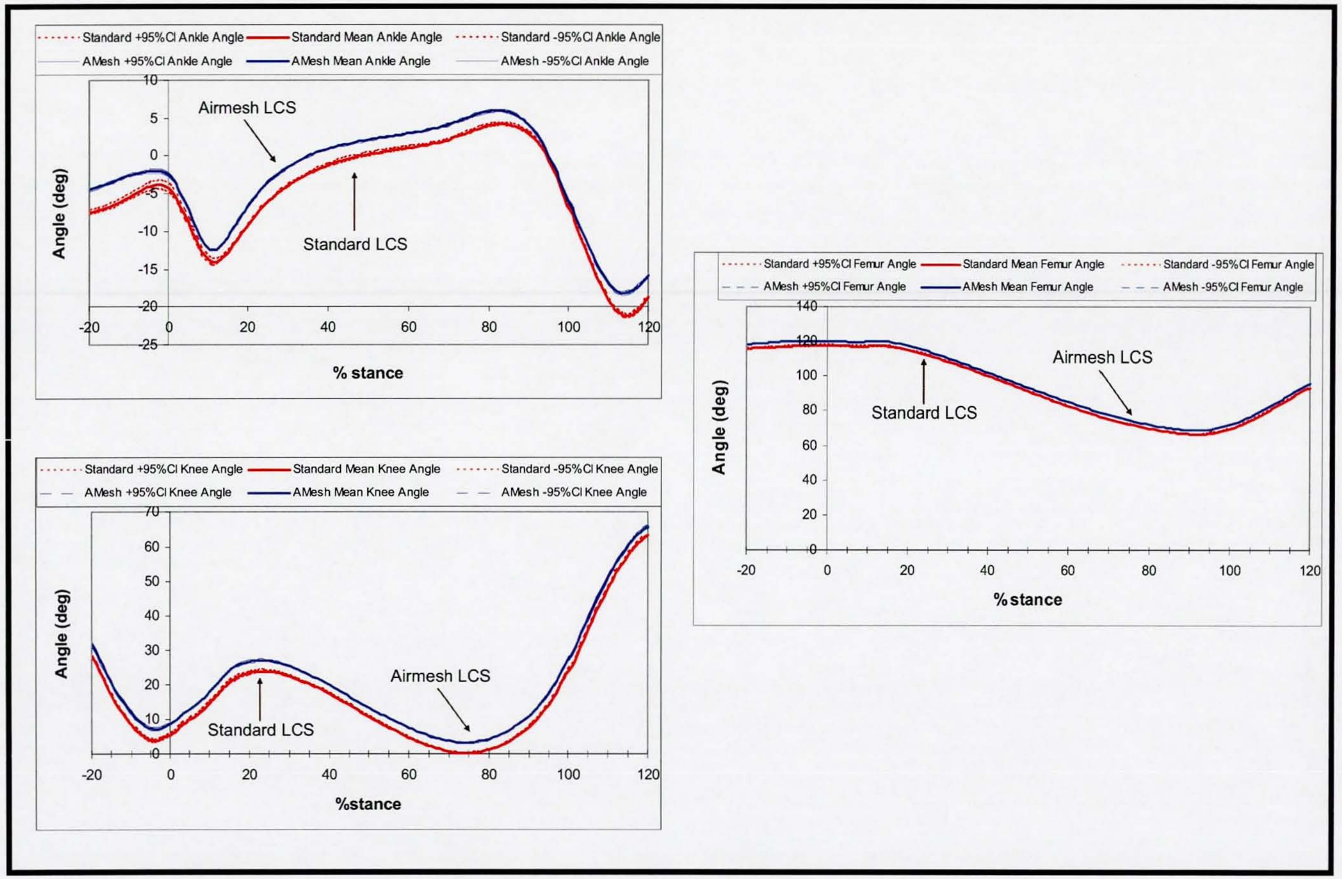


Figure 8.11: Ankle (top left), knee (bottom left) and femur (right) angles as a percentage of stance. Average data from all participants and all time samples. STD LCS and AM LCS represented as indicated on figure

Table 8.2: Statistical output for lower limb angular data. Significant effects of Time or Pack indicated in **BOLD**. Comments indicate nature of significant response seen

		Time	Pack	Comments
Ankle	Max	0.129	0.077	
	Mean	0.579	**0.043**	AM>STD
	Min	0.152	0.301	
	ROM	**0.001**	0.276	↑ over time
Knee	Max	**0.001**	**0.001**	↑ over time, AM>STD
	Mean	**0.003**	**0.008**	↑ over time, AM>STD
	Min	0.389	**0.008**	AM>STD
	ROM	**0.002**	0.213	↑ over time
Femur	Max	**0.000**	**0.001**	↑ over time, AM>STD
	Mean	**0.001**	**0.012**	↑ over time, AM>STD
	Min	0.243	0.100	
	ROM	**0.001**	0.429	↑ over time

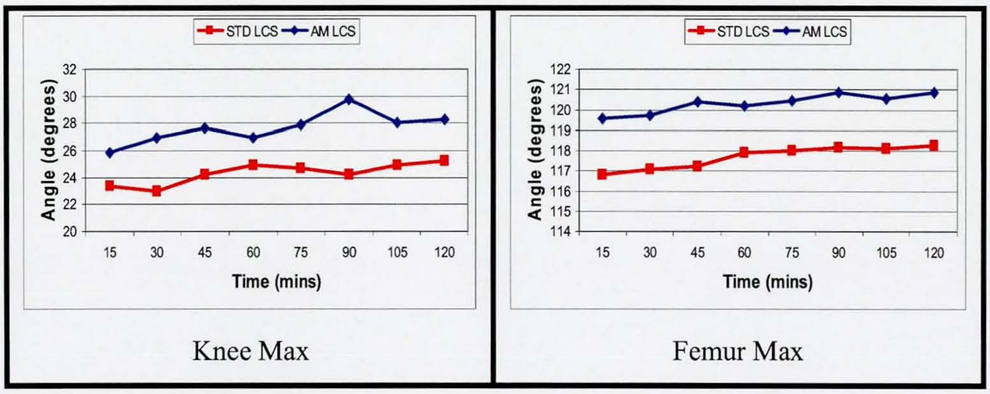


Figure 8.12: Knee (left), and Femur (right) maximum angle values over time. STD LCS (■) and AM LCS (◆)

8.3.4 Upper body segment movement

Measurement of the trunk and head allow an overall indication of the body posture response to carrying loads. As with the lower limb angular data, narrow confidence intervals are seen in trunk data when all time data is combined (Figure 8.13), however significant differences are seen in maximum (Figure 8.14), mean and minimum values ($p < 0.01$ in all cases). These values all decrease over time, indicating a greater forward lean as time increases. What is also indicated by Figure 8.13 and 8.14 is the greater ROM experienced by the trunk segment when carrying the AM LCS ($p < 0.01$). There is a change in the amount of forward lean, with the AM LCS producing a more upright position in the first 50% of stance, then moving to a greater forward lean as individuals move towards toe off (100% stance).

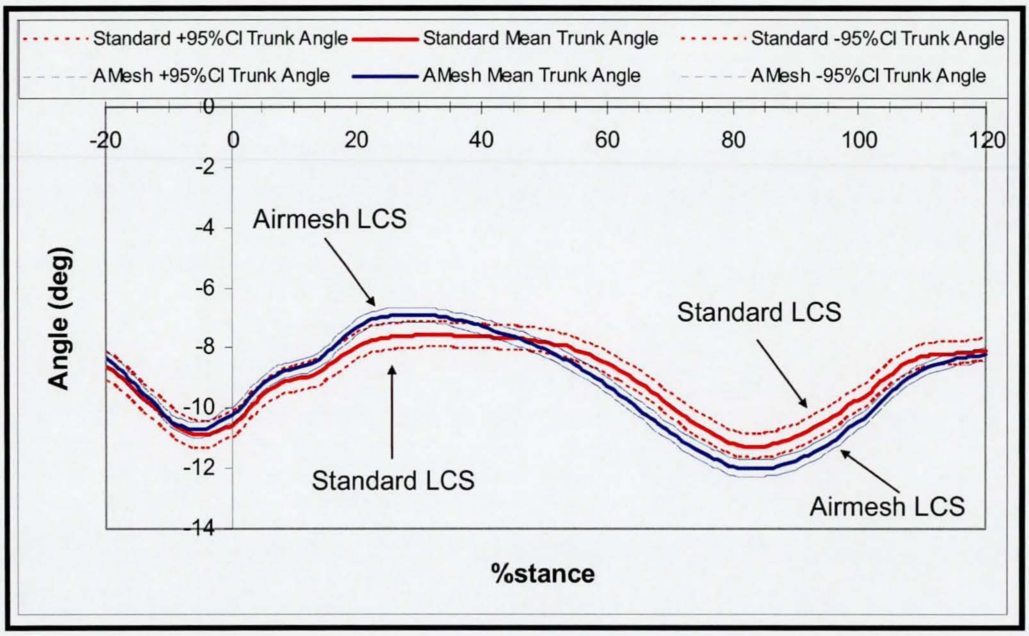


Figure 8.13: Trunk angle as a percentage of stance time. STD LCS and AM LCS represented as indicated on figure

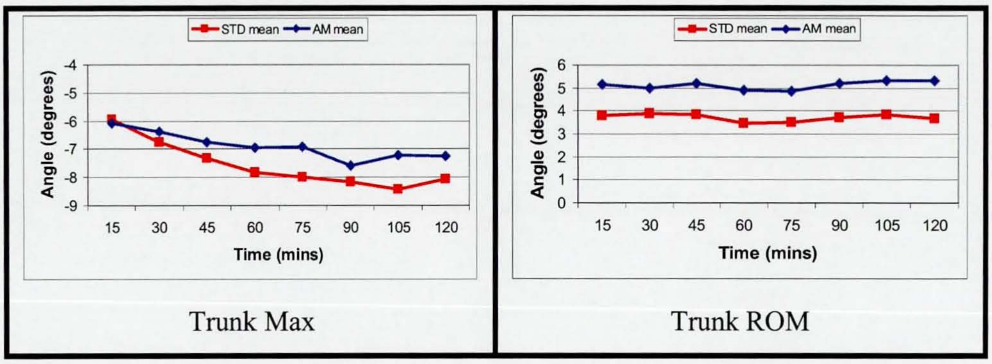


Figure 8.14: Trunk Max (left) and Trunk ROM (right) over time. STD LCS (■) and AM LCS (◆)

In terms of head posture measures, changes over time are not seen; with the exception of craniohorizontal (CH) ROM. This angle shows a significant increase ($p = 0.01$) over time (Figure 8.15). Trends are also seen for the AM LCS to have a higher (therefore more upright) mean and minimum value than when carrying the STD LCS (Figure 8.16). In the case of the craniovertebral angle (Figure 8.16) no significant differences were seen in any of the variables measured, although a trend for a decrease (Figure 8.17) was noted in the minimum value as time increased ($p = 0.096$).

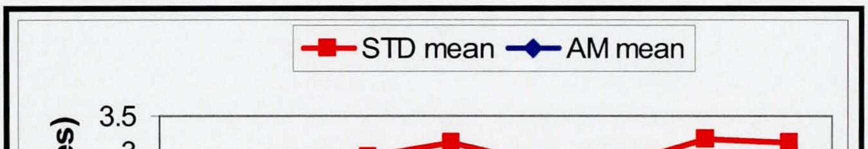


Figure 8.15: Craniohorizontal ROM over time. STD LCS (■) and AM LCS (◆)

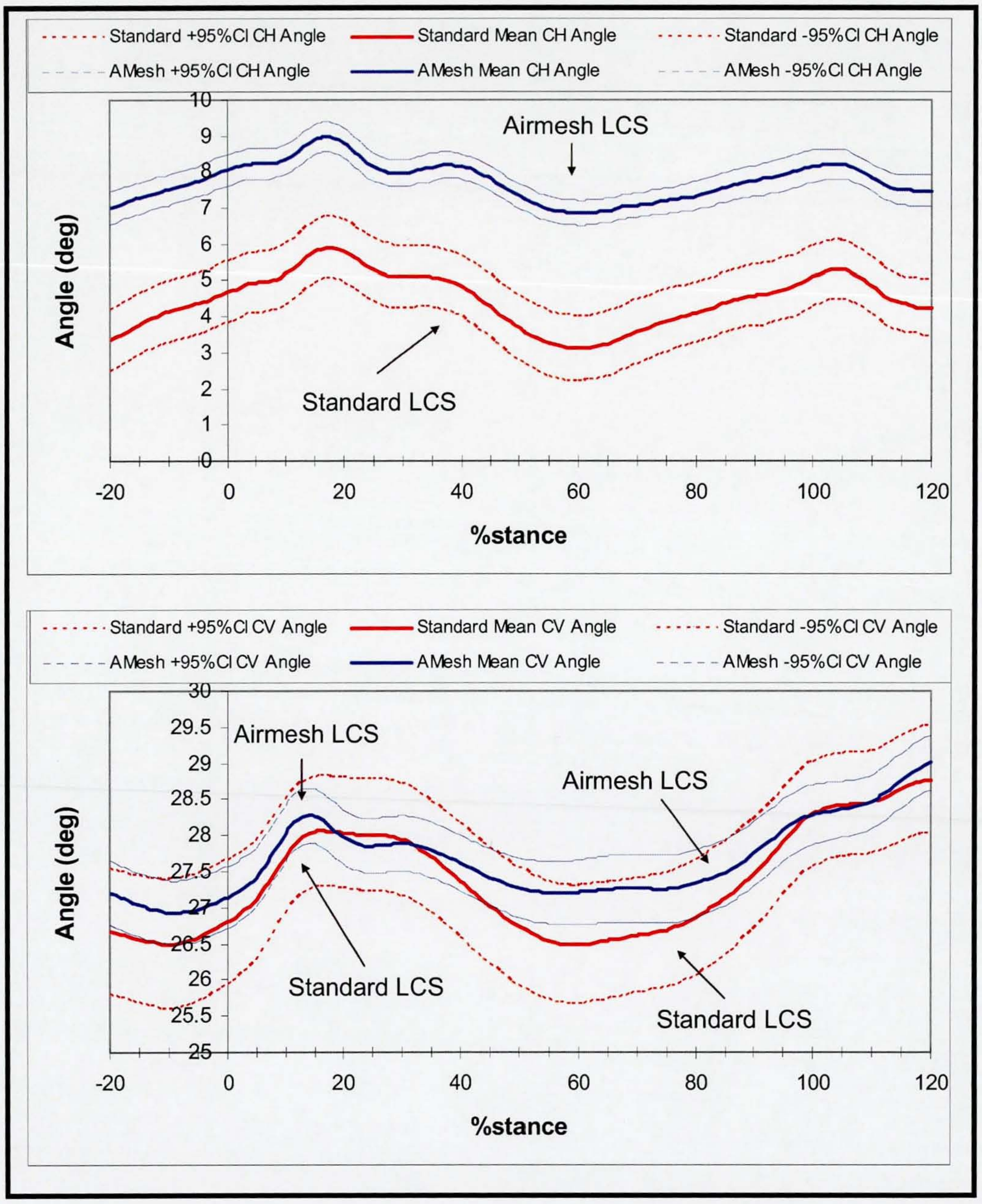


Figure 8.16: Craniohorizontal (top) and Craniovertebral (bottom) angles as a percentage of stance time. STD LCS and AM LCS represented as indicated on figure

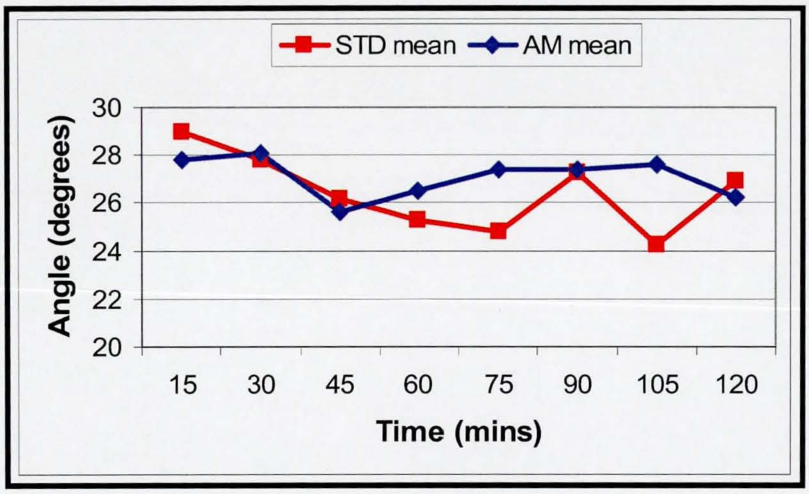


Figure 8.17: Craniovertebral Min over time. STD LCS (■) and AM LCS (◆)

8.3.5 Physiological parameters and comfort response

Both physiological and subjective comfort information were collected following each kinematic data collection. Data collected at baseline was not included in any statistical analysis. Physiological data comprised of heart rate, RPE and thermal ratings, which all increased significantly over time ($p<0.05$). Heart rate response (Figure 8.18) was similar for both LCS with a levelling off at approximately 15 minutes as the participant entered steady state exercise. There was also a slight drift upwards towards the end of the exercise period. Heart rate was measured continuously throughout the testing session (for safety reasons) so Figure 8.18 represents all time points rather than just the 15 minute intervals.

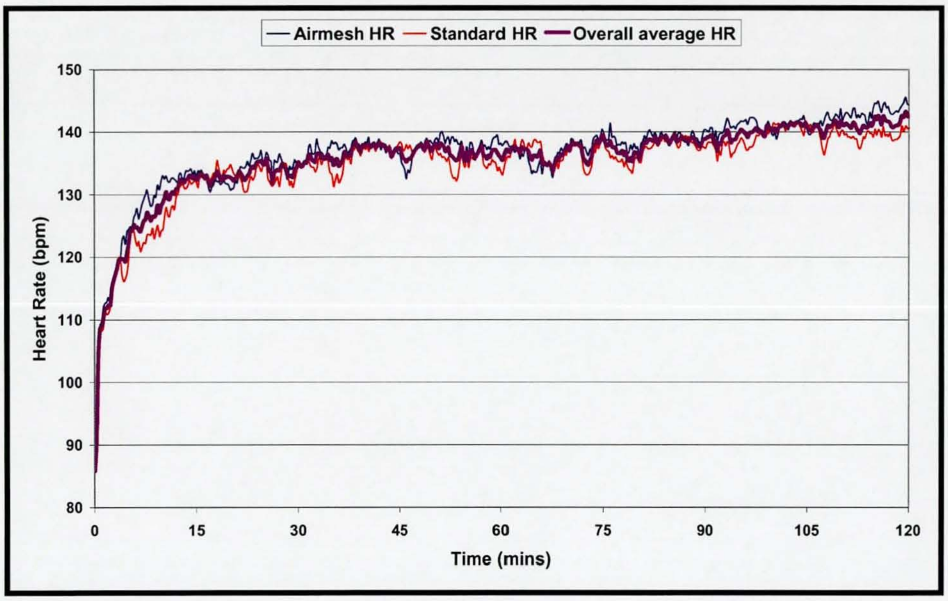


Figure 8.18: Heart rate response over time

Following the trend of heart rate, both RPE and thermal comfort ratings remained relatively constant throughout the testing session (Figure 8.19). A slightly higher RPE was noted when carrying the Airmesh LCS until 90 minutes, when a cross over of the systems occurred, resulting in the significant interaction for Time*Pack ($p<0.05$). Thermal response was similar between both LCSs, although there was an indication that the AM LCS produced a higher thermal response between 60-90 minutes.

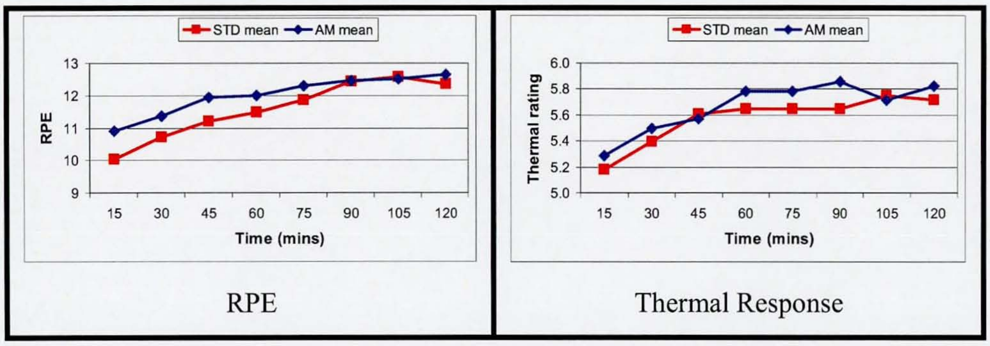


Figure 8.19: RPE (left), and Thermal (right) response over time. STD LCS (■) and AM LCS (◆)

Subjective measures of comfort were taken in the shoulder, back, hip and foot regions. A summary of the results of the repeated measures ANOVA are presented in Table 8.3. Significant increases in a number of variables were seen over time. These indicate that the participants were experiencing greater discomfort as time increased (see scale in Figure 8.5) In particular, all areas of the shoulders indicated significant increases over time, as did all areas of the foot (with the exception of zone F2).

Shoulder responses for the 3 zones and a combined data set to represent the entire shoulder region are indicated in Figure 8.20. All scales on the graphs within the figure are kept identical in order that magnitude of response can be observed. This figure indicates the zone S1 (front of the shoulder) resulted in greater discomfort with the AM LCS, whereas zones S2 and S3 (significant at $p < 0.05$) resulted in greater discomfort when carrying the STD LCS. From the overall figure, it is indicated that until 90 minutes the STD LCS results in slightly more discomfort than the AM LCS.

Table 8.3: Statistical output for subjective comfort data. Significant effects of Time or Pack indicated in **BOLD**. Trends indicated in *italics*. Comments indicate nature of significant response seen

	Time	Pack	Time*Pack	Comments
Shoulder 1	**0.006**	0.132	**0.015**	↑ over time
Shoulder 2	**0.002**	0.562	0.190	↑ over time
Shoulder 3	**0.002**	**0.031**	**0.043**	↑ over time STD > AM
Back 1	**0.039**	0.247	0.769	↑ over time
Back 2	0.608	0.189	0.608	
Back 3	0.301	1.000	0.736	
Hip 1	1.000	1.000	1.000	
Hip 2	0.190	*0.085*	0.190	STD > AM
Hip 3	1.000	1.000	1.000	
Hip 4	0.437	0.336	0.437	
Foot 1	**0.003**	0.409	0.705	↑ over time
Foot 2	0.182	0.588	0.321	
Foot 3	**0.004**	*0.066*	0.107	↑ over time AM > STD
Foot 4	**0.041**	0.373	0.455	↑ over time
Foot 5	**0.001**	0.674	0.543	↑ over time
Foot 6	**0.048**	0.374	0.466	↑ over time

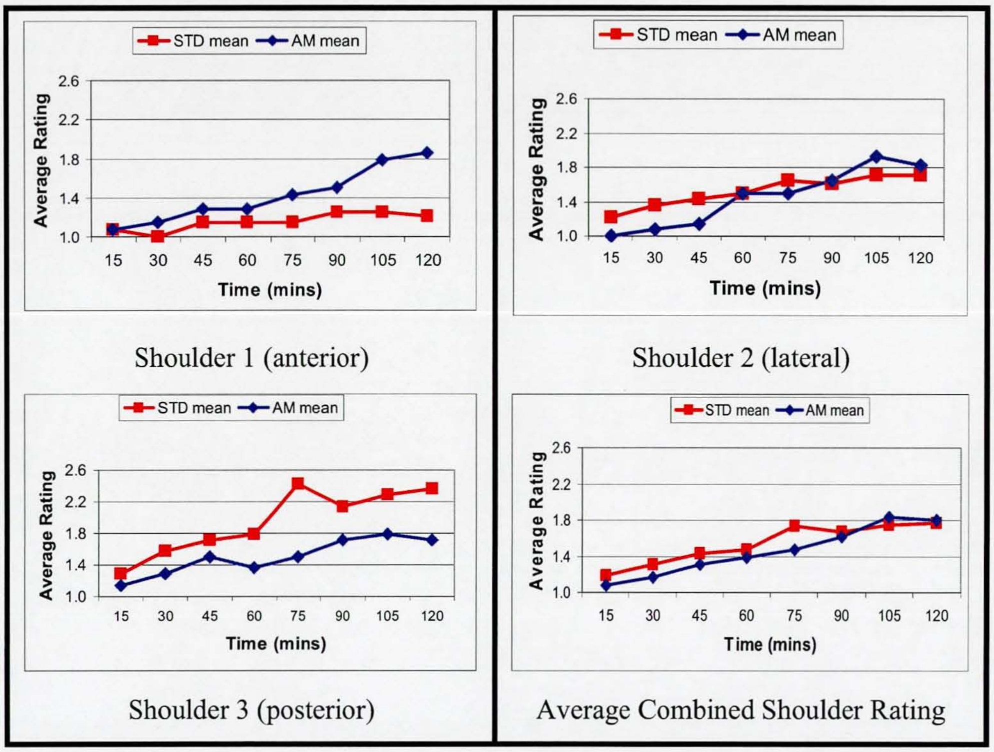


Figure 8.20: Shoulder region comfort ratings over time. STD LCS (■) and AM LCS (◆). 1 = comfortable, 5 = extremely uncomfortable

In terms of the response of the feet, again this data is presented for each individual zone and for the entire region of the foot and all scales are the same on the graphs within the figure (Figure 8.21). Significant increases ($p<0.05$) were seen for all of these zones with the exception of F2. No significant differences between LCSs were noted, although a trend was seen for the AM LCS to induce greater discomfort in zone F3 ($p=0.066$). The greatest discomfort rating is noted in zone F1 which corresponds to the heel, an area prone for blisters. In general with all zones in the feet, a gradual increase is seen in the response when carrying the STD LCS, whereas when carrying the AM LCS a sharp increase is seen around 75-90 minutes, which then plateaus off towards the end of the test.

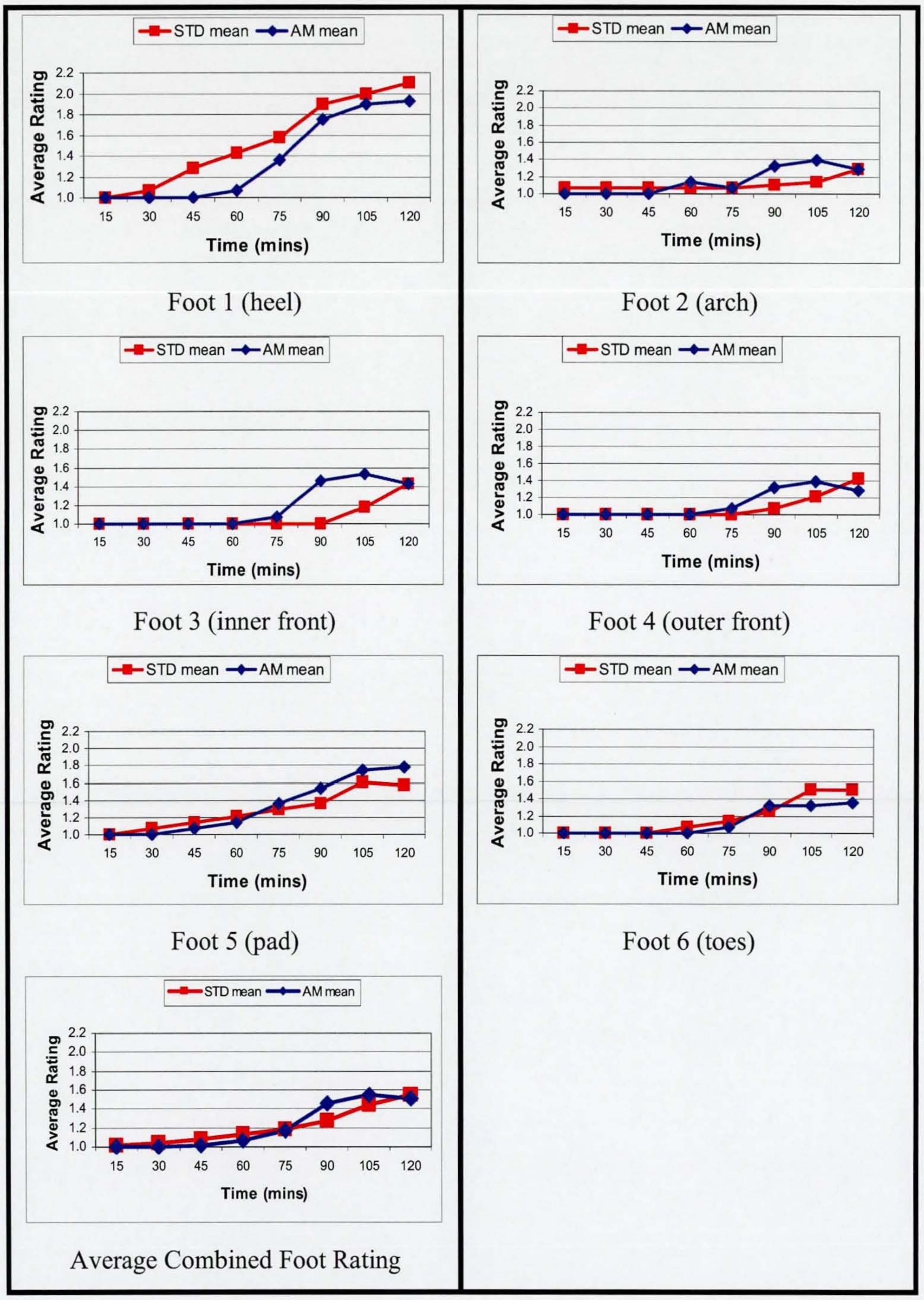


Figure 8.21: Foot region comfort ratings over time. STD LCS (■) and AM LCS (◆).1 = comfortable, 5 = extremely uncomfortable

It is pertinent to mention here the other 6 participants (from the Black Watch Regiment) who for one reason or another did not complete both LCS trials. Two participants were unable to start one of their trials (DNS) due to work commitments within the regiment at the time of the experimental work, and 1 participant did not start in the 2nd week due to a broken foot. However of the remaining trials that were completed it was evident that comfort levels (i.e. extreme discomfort) were the reasons for ceasing the tests (Table 8.4), with once again the concentration being on the shoulder and foot zones. Of those tests that were completed (n=14), several participants did reach ratings of 5 (extreme discomfort) in one or more zones, but were still able to complete the test.

Table 8.4: Subjective response in participants who did not complete experimental trials

Participant	Standard LCS	Airmesh LCS
BlkW 3	Complete	Withdrew due to foot pain (zones 2,3,4) at level 5
BlkW 4	DNS	Complete
BlkW 5	Complete	DNS
BlkW 6	Withdrew due to shoulder (all zones), back (zone 3), hips (zone 1,2) and foot (zone 1,5) at level 5	Withdrew due to shoulder (all zones), back (zone 1) and feet (zone 5,6) at level 5
BlkW 8	DNS (broken foot)	Complete
BlkW 9	Withdrew due to shoulder pain (zones 1,2) at level 5	Withdrew due to shoulder pain (all zones) at level 5

8.3.6 Cognitive tests

Prior to starting the 2 hour load carriage trial and immediately after it was completed (or when the participant withdrew for one reason or another) a simple cognitive test (Figure 8.22) was completed. Results obtained are indicated in Figure 8.22. In general a decrease in score was seen following the trial, average results plotted as the end bars on these graphs. No significant change in performance was seen pre-post for either LCS (paired t-test). The STD LCS pre-post decrement (average for all participants) was 1.50 (p=0.09) and the AM LCS pre-post decrement (average for all participants) was 1.68 (p=0.17). Areas on Figure 8.22 where no data is reported are for those trials in which the participant did not start the trial (as mentioned above). It was important however to include all other participants that did start, but did not complete, the tests here, as in a field situation not being able to complete a mission does not mean an individual would not be required to make decisions.

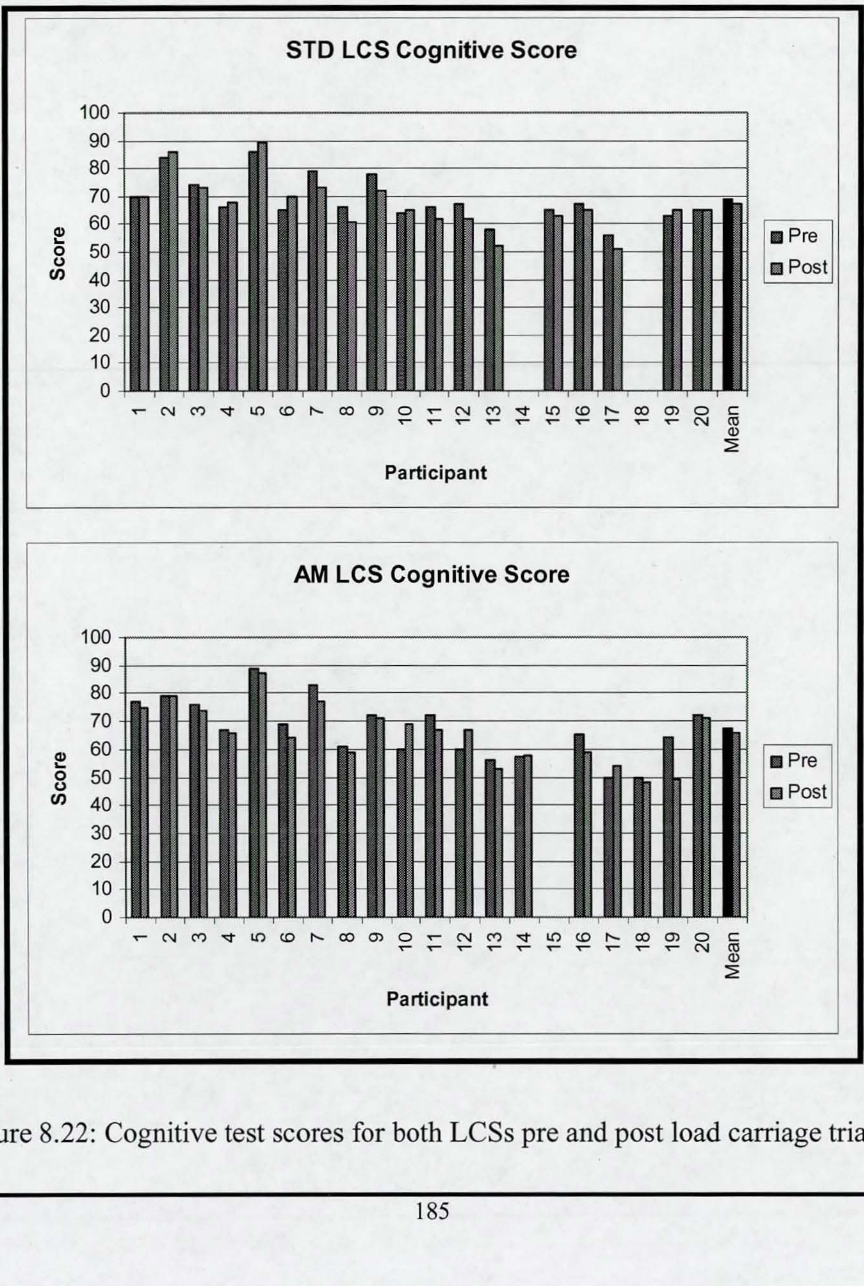


Figure 8.22: Cognitive test scores for both LCSs pre and post load carriage trial

8.4 Discussion

The carriage of load is an important component of any military training or exercise. Previous research in this thesis and within the literature has concentrated on measures taken during short duration periods of load carriage or pre-post longer duration carriage. In the military environment it is quite common for an individual to be required to carry a load for a substantial time period. Therefore the importance of examining the response of the body over such a time period is highlighted.

8.4.1 Lower limb kinematic, spatiotemporal and comfort response

Studies examining set speed walking (such as when walking on a treadmill), have indicated that as load is increased a decrease in SL is seen in order to increase the period of double support (i.e. both feet on the ground). A uniform load was used in the current study, with minimal change seen over time for most variables, the exception being a trend for an increase in stance time. The two LCSs behave differently, with the AM LCS resulting in greater SL and therefore lower SF than the STD LCS.

Other treadmill based military load carriage work has also compared SL and SF at 4, 11 and 18 minutes (Martin et al., 1982a). No change was seen between 11 and 18 minutes and the differences found at 4 minutes were attributed to treadmill acclimatisation rather than the effect of carrying load. This suggests that a period longer than 18 minutes is required before seeing any change in spatiotemporal parameters when walking on a treadmill. However, from the current data there is the suggestion there is no change at all over time. This however may be dependent on the weight of the load that is carried. Work conducted with the Australian Army as per the field visit discussed in section 7.2, indicated a trend towards increased SF and decreased step length as time increased (M. Jaffrey, personal email communication, October 18^{th} 2005), which conforms to the expected outcome as mentioned above. The loads carried by the Australian personnel were double that carried in the present study.

In work conducted overground (rather than on a treadmill), Frykman et al., (1994) noted decreased SL and stride time post 20km military load carriage march. Orloff and Warren (2003) found no changes in SL or SF over time (4-6kg load carried for 600m walk) when examining school children, whereas Yoshino et al., (2004) reported that 67% of participants increased their mean gait cycle time (reciprocal of stride rate/SF) from 90 minutes onwards when walking for 3 hours at a self selected pace. This was associated with decreased activity of the tibialis anterior, which could possibly affect ankle movement. This decrease in activity may also serve to explain the change in behaviour in terms of spatiotemporal data at 90 minutes for the STD LCS. It may be possible that due to the different configuration of the load when carrying the AM LCS that such a response occurs earlier.

Changes in the spatiotemporal response may be related to a protective response of the body as the muscles of the lower limb begin to fatigue. As muscles fatigue increased motor neuron recruitment is required in order to facilitate movement. Decreased activity of peroneal and triceps serae musculature has been noted post 2km march suggestive of fatigue and reduced ability to plantarflex and evert the foot (Gefen, 2002). Triceps serae is also involved in the absorption of ground reaction forces, which are increased when carrying military loads (Birrell & Hooper, 2005a) and may be related to increased metatarsal stress in the foot (Kinoshita, 1985). These forces have also been shown to increase carrying 20kg for 1 hour; this moderate fatigue being sufficient to increase local bone deformation in the foot (Arndt et al., 2002). These changes in the ability to ameliorate force may be responsible for the increase in foot discomfort seen over time (Figure 8.21).

Foot discomfort was a major concern for several of the participants, particularly those who were unable to complete the task (Table 8.4). Continuation of such stresses placed on the foot may result in metatarsalgia or stress fractures. In the more immediate term blisters are the predominant source of foot pain. An example of a blister which occurred in zone F1 is indicated in Figure 8.23 below. This zone was the zone of greatest discomfort in the foot (Figure 8.21). It is not uncommon that such discomfort is seen in the foot region, with previous research examining long term marches whilst carrying loads confirming these results. Johnson et al., (1995) notes during a 20km with 3 different loads and 2 different pack arrangements that at all times the most predominant rating of discomfort was in the legs/feet. Similarly Vaananen et al., (1997) showed that most of the pain felt in the feet following a 4 day march was due to abrasions and blisters and McGraig and Gooderson (1986) found from questionnaires following a 5 day land campaign that the most common source of dissatisfaction in the troops related to the state of their feet, and the performance of their boots.

Figure 8.23: Blister on zone F1 following carriage of STD LCS

Range of motion of lower limb angular data indicated significant increases over time for all 3 angles measured. In terms of the knee and femur angles this was brought about by the significant increase in the maximum angle. Maximum values of knee and femur response occur during the flexion phase following heel strike. This is where most shock absorption occurs due to the ground reaction force experienced. As mentioned above decreased anterior tibialis activity is noted over time. As a result the musculature of the upper leg may be required to be recruited in order to absorb the forces moving through the leg. This will result in the upper leg moving through greater ROM. This is a similar response as seen when load is increased. Kinoshita (1985) notes an increased dorsiflexion of the foot as load increases, which in turn results in increased knee ROM. A similar change in knee ROM and hip ROM is noted by Harman et al., (2000a) when adding loads, with increased flexion around heel strike.

Significant differences between LCSs carried were also noted when examining the lower limb. In all cases the AM LCS resulted in a more upright walking posture, in agreement with results seen in a similar study comparing backpack to a double pack design (Johnson et al., 2000). The authors suggested a more upright knee angle is indicative of normal gait, also confirmed by another double pack study by Kinoshita (1985). This is due to a greater pelvic rotation when carrying the load on the back alone, associated with a greater forward lean. Quesada et al., (2000) notes a decrease in knee moment over time, again associated with a change in the loading pattern of the body, due to fatigue of the quadriceps musculature and an increase in ROM of the lower limb. This increase in ROM is further corroborated by Frykman et al., (1994).

8.4.2 Upper body kinematic and comfort response

The location of the load when carrying the STD LCS is predominantly on the back, whereas in the case of the AM LCS the distribution of the webbing part of the load is moved forward on the body. Whilst this type of distribution is not a double pack design per se, it is comparable. Previous military load carriage work has concentrated on the examination of a double pack design in order to move the load closer to the body's centre of mass to facilitate ease of movement (Frykman et al., 1994; Harman et al., 1994; Johnson et al., 2000; Johnson et al., 1995; Knapik et al., 1997). Subjective ratings have been unable to distinguish between pack designs, but a consistent trend of greater thermal stress has been noted when carrying load in a double pack design, due to a greater covering of the body surface by the load. Whilst an increase in thermal discomfort over time is noted in the current study, no significant difference between LCSs is seen (Figure 8.19). There was however an indication that the AM design resulted in greater thermal stress from the period of 60-90 minutes.

As with this data (Table 8.3/Figure 8.20) changes in the zones of discomfort are also seen when comparing LCSs. Knapik et al., (1997) noted more prominent hip discomfort when carrying a load similar to the STD LCS design, and greater shoulder/neck (zone S3) discomfort with the double pack design. Work by Legg and Mahanty (1985) showed similar trends with STD LCSs causing discomfort in the mid trunk and upper legs, whereas the double pack design affected the shoulders and the neck. Whilst a trend for the increased hip pain was noted in zone H2 when carrying the STD LCS, the position of the shoulder discomfort is different to that which the literature suggests. A significantly greater discomfort was seen in the zone S3 when carrying the STD LCS. Alternatively the zone S1 resulted in a trend for greater discomfort with the AM LCS. The disparity between the current results and that presented in the literature above may be due to the differences in design of a double pack as opposed to the AM LCS.

The changes in load distribution also have a clear effect on the movement of the trunk. Over time, a significant decrease in trunk angle (i.e. greater forward lean) is noted for both LCSs. This greater lean places increased stress on the musculature supporting the load, in particular the neck and lower back. A more upright posture is more efficient in terms of ambulation (Madras 1998), however forward lean is used to facilitate the movement of the centre of mass of the body (including that of the LCS) forward through the base of support. In the AM LCS design, part of the load is already forward on the body, suggesting a decreased need to lean as far forward to progress the body. Less forward lean is seen in the first 50% of stance when carrying the AM LCS, but the trunk moves through a greater ROM. Data collected with no load (Chapter 6) indicates an average trunk ROM of 3.78°, which is similar to that represented by the STD LCS over time (3.72°). In contrast the AM LCS results in a trunk ROM of 5.12°; this increased trunk ROM possibly impacting on physiological cost. Frykman et al., (1994) indicated that even though a double pack design gave a more upright posture it did not change the effects of fatigue on posture. There was still an increase in forward lean over time (as seen with the current data) and a change in hip angle occurred (linked to trunk via angular definition). The data presented by Frykman included carrying loads of the magnitude of 47kg and collected data pre and post marching 20km. We see the same effect for much lighter loads carried for significantly shorter time periods.

The greater forward lean over time (Figure 8.14) and accompanying more forward head posture (Figure 8.16) with the STD LCS may have implications due to the stresses placed on the small supporting muscles of the neck. Increased forward heads position over time has been seen with loads as low as 11.4kg over 3.8km distances (Orloff et al., 1999). This is due to the need to counterbalance the load with the head. Fatigue of this neck musculature may lead to disturbance of balance (Gosselin et al., 2004), dizziness (Schieppati et al., 2003) and decrement in performance on military tasks such as marksmanship (Knapik et al., 1997). However, a more upright posture may not allow counterbalance of the backpack, resulting in an increase in spinal curvature (Orloff & Rapp, 2004). Initial investigations with low loads suggest this is an area where future interest may lie, as up until this point the trunk has been treated as a segment and spinal curvature not examined due to difficulties associated with measurements whilst wearing backpacks. Orloff and Rapp have devised a method of measurement of spinal curvature (Figure 8.24) using a data recorder within an instrumented backpack. This type of methodology warrants further investigation with heavier military loads. In addition greater forward lean may contribute to decreased stability in the foot as mentioned previously. If the hips/lower back experience fatigue they may not be able to support and control the head-arms-trunk segments of the body as effectively as when not fatigued, resulting in changes to stability of the lower limb (Gefen, 2002). Changes in trunk movement over time may serve to indicate this.

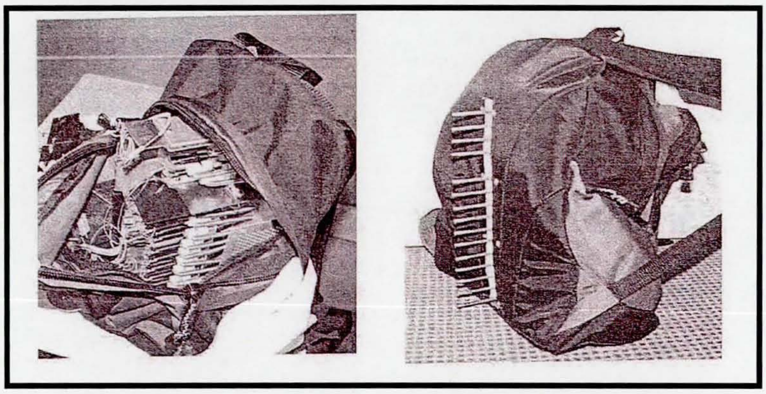


Figure 8.24: Instrumented backpack (left) with protruding rods (right) to measure spinal curvature whilst load carrying (Orloff & Rapp, 2004)

8.4.3 Physiological, comfort and cognitive response

An important part of this investigation lies with the collection of subjective data whilst the participant is carrying the load. In the past researchers have concentrated on overall body comfort rather than specific body zones, and have taken measurements following a test rather than during the test – possibly subjecting this data to a time delay effect (Johnson et al., 1995; Legg et al., 1997; Legg et al., 2003). Physiological data collected in the form of heart rate indicated a significant increase over time (Figure 8.18), as noted by other military load carriage studies (Daley et al., 1996; Reading et al., 1996; Warber et al., 2000). Other physiological examinations when carrying military loads have indicated a relatively consistent level of exertion over time (Epstein et al., 1988; Kirk & Schneider, 1992; Knapik et al., 1997; Sagiv et al., 2000; Scott & Ramabhai, 2000). Whilst a significant increase in heart rate was seen, it was not considered dangerous to the participant, anywhere near maximum heart rate values or a reason for stopping the experimental trial. However, even those these values, and RPE, remained relatively stable, ratings of discomfort continued to increase and were the reason for several of the participants failing to complete the trial. A similar protocol to the BCFT using loads of 5.2, 31.2 and 49.4kg also resulted in participants failing to complete due to discomfort (Patton et al., 1991). Scott and Ramabhai (2000) also noted a change over time for the areas of most discomfort, with the first hour during load carriage having discomfort concentrated at the shoulder, but by the third hour the feet were the predominant area. Increases over time in shoulder discomfort with no change in heart rate were also seen by Kirk and Schneider (1992). The feet are of importance in determining an individual's ability to complete work whilst carrying military loads and their ability to perform once the load carriage task is complete. These studies and the study presented in this chapter indicate fatigue is localised in the area of the backpack and the load bearing zones rather than contributing to an overall body fatigue. Implications arising from localised fatigue may include rucksack palsy (compression of nerves in the brachial plexus), or in the case of the feet blisters, which may result in a decreased ability to perform military tasks post load carriage.

An attempt to indicate a decrement in performance post load carriage was also demonstrated using the simple cognitive skills test as shown in Figure 8.3. In general, regardless of the LCS carried, a decrement was seen from pre-post test (Figure 8.22). Sufficient practice of these tests was given to participants prior to undertaking the load carriage trial in order to ensure a learning effect did not occur. This type of test has been used to measure effects of fatigue in many psychological studies including accident analysis (Williamson et al., 2001). Whilst not a specific military task, any decrement in cognitive performance could have possible implications on ability to read map coordinates, decision making including who to fire upon, and on ability to take appropriate cover in a battle situation. Whilst this outcome is not suggested by the cognitive task data presented here, it does highlight the possible impacts that decrements in cognitive performance may have.

8.5 Limitations

Due to the constraints of military personnel availability for this experimental work, the military experience of the participants who undertook this study was limited to only a few years (max age = 23). It is possible that different outcomes may be displayed when level of training or experience is taken into account. As with other physical tasks, training results in the development of strategies by the body in response to the exercise it is undertaking. Unfortunately, access to individuals with a greater level of experience with load carriage and other military tasks is a rarity. Conducting future research in this area would be beneficial as it may allow recommendations for load carriage scenarios to be made.

Another consideration is the surface on which the experimental work was conducted. Walking on a treadmill represents a smooth, uniform surface, very different from that one may encounter when load carrying outdoors. It is possible a potential contributor to fatigue is the effort required to maintain lateral stability; a factor which may have been minimised during these treadmill trials. Assessing all three movement planes, rather than just the saggital plane as examined here, may be of interest when carrying loads on a non uniform surface.

8.6 Chapter summary and conclusions

Completion of a modified Basic Combat Fitness Test on a treadmill gave opportunity to examine changes in gait, posture and subjective response over time whilst carrying military loads. These changes indicate alterations to gait patterns which may be attributed to fatigue and could possibly cause injury. Measures of subjective comfort gave insight into what is occurring at the LCS/body interface. From this work, it may be concluded that a change in load position due to carrying a different LCS alters the position of the stress on the body, but does not remove the stress all together. Differences are noted in the positioning of discomfort in the shoulder region, but of greater concern are the high levels of discomfort observed in the foot zones. These values suggest that the ability to perform the task may be limited by the extreme discomfort, possibly resulting in changes to gait patterns, and ultimately having to discontinue due to blisters or other injuries that may occur. This outcome warrants further investigation, including examination of different types of military boots.

Comparison of different LCS designs in the form of the STD LCS and AM LCS indicate differing responses as a result of load positioning. The AM LCS design behaves in a similar manner to that of a double pack design due to weight being redistributed to the front of the body. Less forward lean (during first 50% of stance) and a more upright posture is indicated, however no consideration of the true thermal effect due to having the chest covered, or the effect of this design on soldier profile have taken place. Subjective responses were unable to distinguish between packs, with the exception of shoulder discomfort.

This experimental work serves as a useful baseline in examining the response of soldiers carrying British military equipment. By investigating the response over time rather than pre-post load carriage, changes that occur may be more closely pinpointed to time of load carriage. In particular subjective discomfort measures appear to increase more rapidly following 60 minutes of load carriage; possibly suggesting that rest periods around these times should be observed. Further research examining the effect of heavier loads, such as those that would be carried in a battle scenario (similar to those seen in Chapter 5), and the effect of military training will give added insight into the response over time and may allow definitive work/rest ratios to be devised. The inexperience of the participants recruited for this study may have impacted on results obtained and may not be indicative of the response of a more experienced soldier or of members of the defence force in general.

Chapter 9 – Longer Duration Load Carriage Subjective Response

9.1 Introduction

The experimental work presented thus far has been conducted within a laboratory environment. This is due to motion analysis equipment capabilities; i.e. it may not be used outdoors. Also, conducting work in the laboratory allows a controlled environment to be maintained. Realistically though, load carriage in the military would never occur under such scenarios. Until a validated method for monitoring biomechanics of human movement in the field is developed, work based in the laboratory environment will continue to be required.

The work by Jones (2005a) examining pressure measurements in the field is an example where load carriage data has been collected over a variety of terrains, carrying loads in realistic situations. Legg and colleagues (2003) also consider the attainment of field data very important when assessing different backpack designs. In both these cases the collection of subjective comfort data has been employed similar to that presented in the previous chapter.

So the question remains; how do individuals carrying heavy military loads respond in the field? In order to provide an initial insight into subjective response due to load carriage, a field trial was conducted with the East Midlands Army Officer Training Corps at Fremington Training Camp, Devon UK. The camp was attended by all members of the Corps as part of their summer training programme and included a variety of activities related to military combat, such as field infiltration exercises, drill competitions, inter-platoon march and shoot competitions and patrols. In addition at some point during the two week camp all members were required to pass a Combat Fitness Test (CFT). This test is similar to that described in the previous chapter (BCFT), except that the distance/time over which it is conducted is halved (due to these personnel only being reservists). Through consultation with the commanding officer, collection of subjective comfort data occurred for all participants completing the CFT.

9.2 Method

All individuals at the Fremington camp were split into 2 platoons for the purpose of the CFT. These platoons were "A" Company (advanced) and "B" Company (basic). In general those in A Company had been members of the Corps longer, with more field and training experience. Details of the two groups are shown in Table 9.1.

Table 9.1: Participant characteristics (mean ± SD)

	"A" Company		"B" Company		Total
	Male	Female	Male	Female	
Participants (n)	38	10	62	19	129
Age (years)	21.5 ± 4.1	20.8 ± 1.1	20.1 ± 1.5	20.2 ± 1.1	20.6 ± 2.6
Experience (years)	3.0 ± 3.9	2.5 ± 1.1	1.5 ± 1.3	1.5 ± 1.2	2.0 ± 2.4
Weight carried (kg)	25.0	25.0	25.0	16.0	22.75
Wearing own boots	18.4 %	30 %	17.7 %	5.1 %	17.1 %
Backpack Carried					
Day sack	5.3 %	10.0 %	4.8 %	0.0 %	4.7 %
Long back	44.7 %	80.0 %	25.8 %	68.4 %	41.9 %
Short back	42.1 %	10.0 %	67.7 %	31.6 %	50.4 %

All participants completed a one hour CFT carrying a load of 25kg (with the exception of B company females who carried 16kg). The course was designed so that a distance of four miles was covered within the hour with all participants marching together as a group (Figure 9.1). It was conducted on a predominantly sealed flat surface, with a compulsory water break taken half way through the test.

In all cases webbing and a backpack (type indicated in Table 9.1) were carried, helmets were not worn but were included within the pack weight, and a rifle was carried (Figure 9.2). All participants had the weight of their equipment confirmed prior to commencement of the test.

Figure 9.1: CFT march formation (note rifles carried)

Figure 9.2: Webbing and backpacks carried on CFT

Throughout the test, rear markers were placed with each platoon in order to assist any members who were struggling to complete and to transport any individuals who injured themselves during the test. With the exception of one female in A company, all participants completed the CFT. This individual pulled out due to heat related stress which was associated with a previous exercise she had been involved with. On return to the start point a cool down/stretching routine was followed, (Figure 9.3) and then a full inspection was completed – including examining feet for blisters. During this time participants filled in a subjective comfort questionnaire (Figure 9.4). Details of the questionnaire are indicated in the panels of Figure 9.5.

Of those participants that completed this field trial, 6 were also participants in the laboratory work presented in Chapter 8. Comparisons for data at the 1 hour point were made for these participants. In addition all data from this field trial was combined to obtain an overall view of level of discomfort experienced by participants when carrying military loads.

Figure 9.3: Cool down/stretching routine

Figure 9.4: Inspection and completion of questionnaire

Comfort questionnaire

Loughborough University work with the MoD looking at military equipment. We ask that you please fill in this form to let us know how you feel following your CFT. All forms should be returned to your PSR or member of Loughborough University on site. Any questions you have may be directed to Renee Attwells (R.L.Attwells@lboro.ac.uk) or Stewart Birrell (S.A.Birrell@lboro.ac.uk). We have asked for your details should we need to contact you at a later date or when we are doing further research.

Disclaimer

I understand what I have been asked to do and am aware I may ask any questions or withdraw at any time

Name.. Sex M / F

Signature......................................

Contact Details: (Ph)......................... and/or (Email) ....

Date of Birth......................... Time in Army/OTC.........yrs.........months

Boots worn on CFT (please circle) Issued / Own

Weight carried (circle) 35lb (~16kg) / 55lb (~25kg) / Other (please specify)..........

Webbing used Belt Order / Vest webbing

Backpack carried? Y/N If yes then Day Sack / Short back / Long back / Other

Have you used Zinc Oxide tape? Y/N If so where...

PLEASE COMPLETE BOTH SIDES OF THE FOLLOWING SHEETS

Figure 9.5: Questionnaire – Panel 1

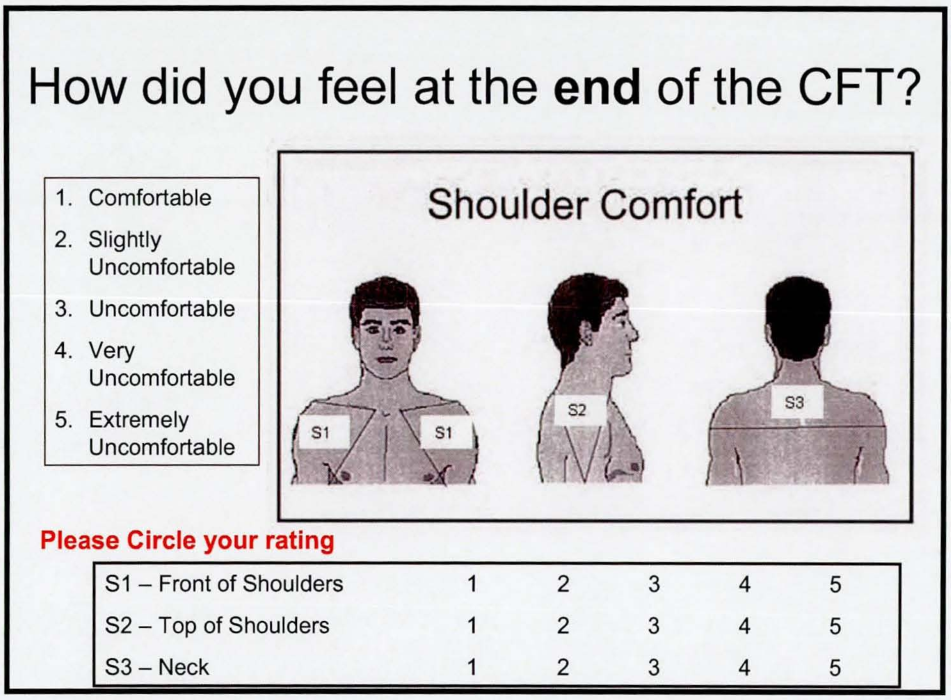


Figure 9.5: Questionnaire – Panel 2

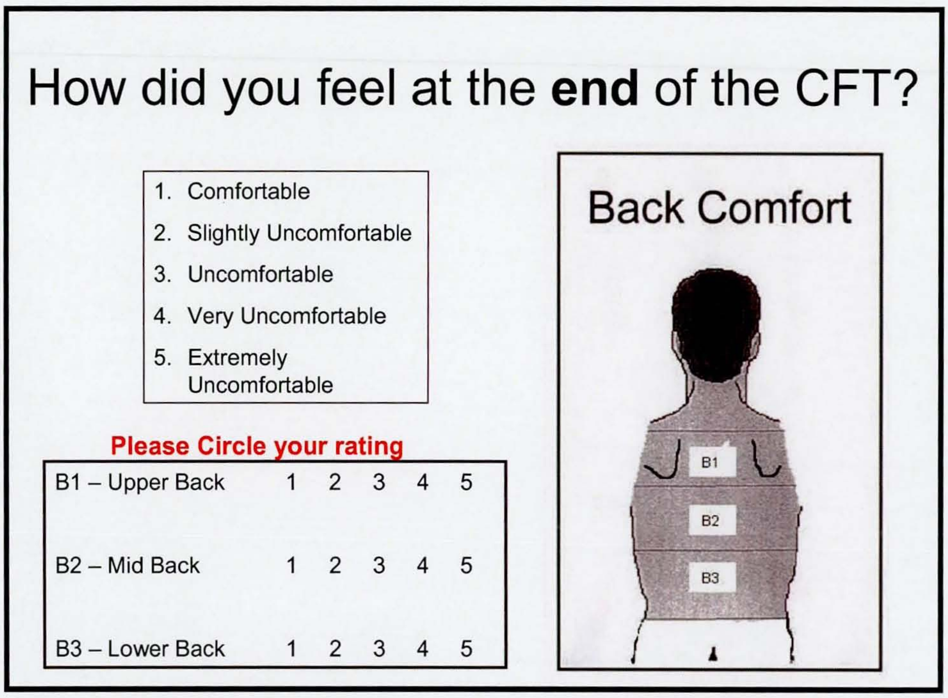
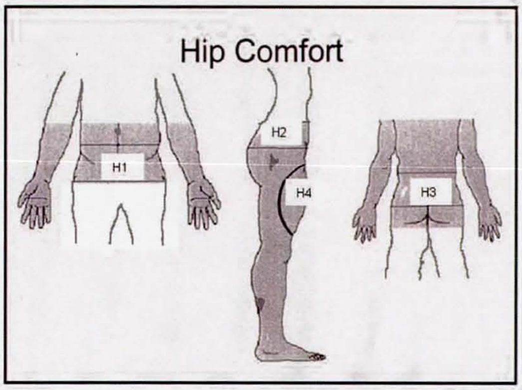


Figure 9.5: Questionnaire – Panel 3

How did you feel at the **end** of the CFT?

1. Comfortable
2. Slightly Uncomfortable
3. Uncomfortable
4. Very Uncomfortable
5. Extremely Uncomfortable



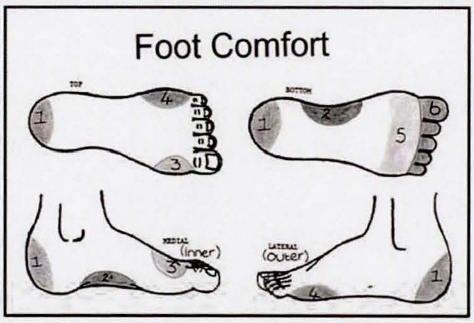
Please Circle your rating

H1 – Front of Hips	1	2	3	4	5
H2 – Side of Hips	1	2	3	4	5
H3 – Top of backside	1	2	3	4	5
H4 – Thigh	1	2	3	4	5

Figure 9.5: Questionnaire – Panel 4

How did you feel at the **end** of the CFT?

1. Comfortable
2. Slightly Uncomfortable
3. Uncomfortable
4. Very Uncomfortable
5. Extremely Uncomfortable



Please Circle your rating

1 – Heel	1	2	3	4	5
2 – Arch of foot	1	2	3	4	5
3 – Inner side of Big Toe	1	2	3	4	5
4 – Outer side of little toe	1	2	3	4	5
5 – Balls of feet	1	2	3	4	5
6 – Underneath Toes	1	2	3	4	5

Figure 9.5: Questionnaire – Panel 5

9.3 Results

All 129 individuals who participated in the field trial completed the questionnaires. Figure 9.6 indicates the combined response of all individuals, with all zones combined (i.e. Average Shoulder = average (S1+S2+S3)). Each bar represents the percentage response for each zone. The area in which the most comfort was experienced was the hips, followed by the back, feet and then shoulders. These regions are then broken down into their individual zones (still combining data from all participants). Figure 9.7 represents all 3 shoulder zones as separate entities. Zones S2 and S3 reported the greatest values of discomfort, with a small percentage of participants reaching "extremely uncomfortable" in these zones. A further breakdown of zone S3 is shown in Figure 9.8. A greater level of extreme discomfort was experienced in this zone by those in "B" company. In terms of the back most of the higher ratings came from zone B1 (upper back) and on the hips the distribution was spread fairly evenly across all zones. Foot data again showed higher levels of discomfort (Figure 9.9). This was concentrated in zones F1 (heel) and F5 (balls of feet).

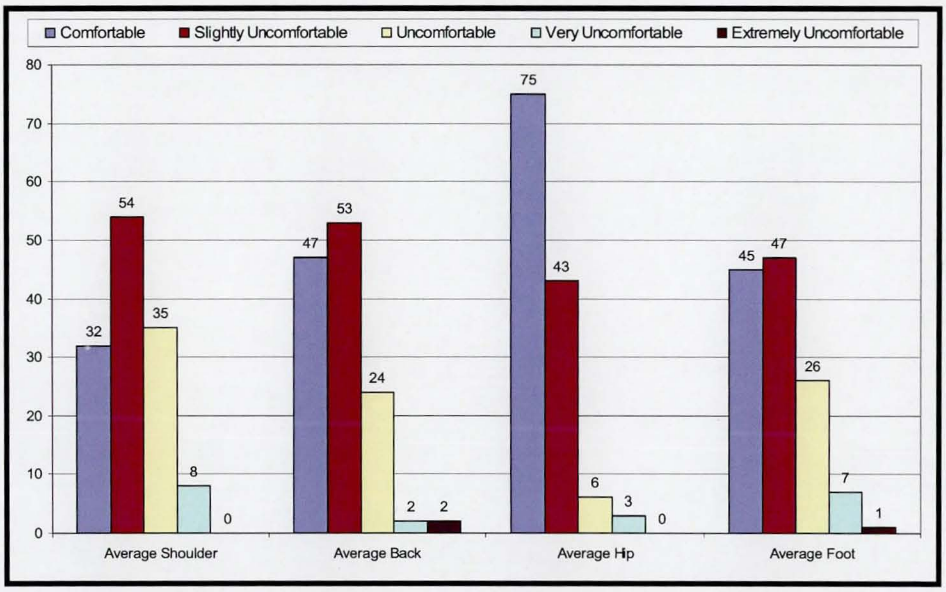


Figure 9.6: Combined comfort ratings (%) following field trial

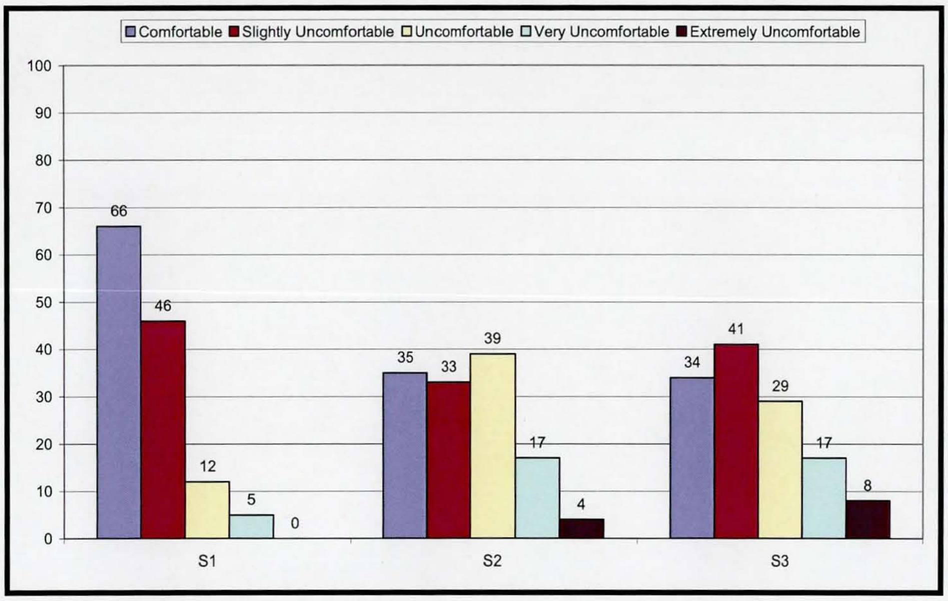


Figure 9.7: Shoulder comfort ratings (%) following field trial

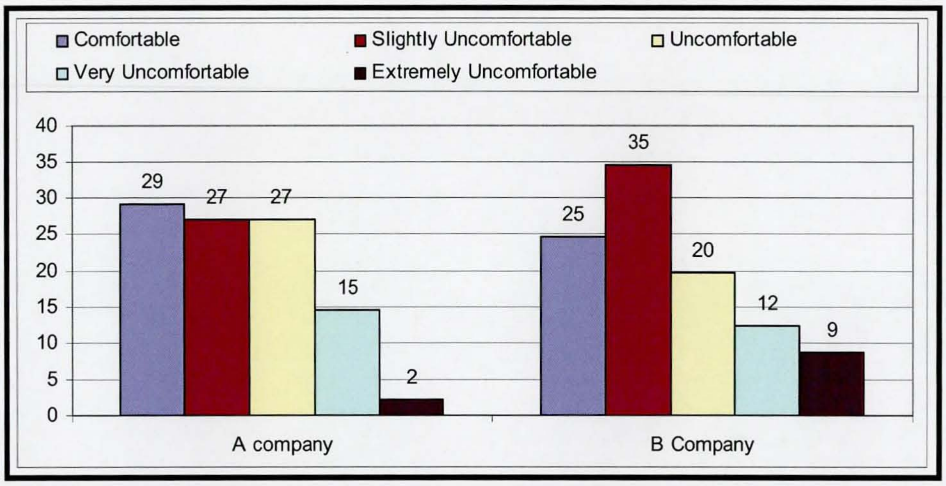


Figure 9.8: Shoulder zone S3 ratings (%) split between "A" and "B" company following field trial

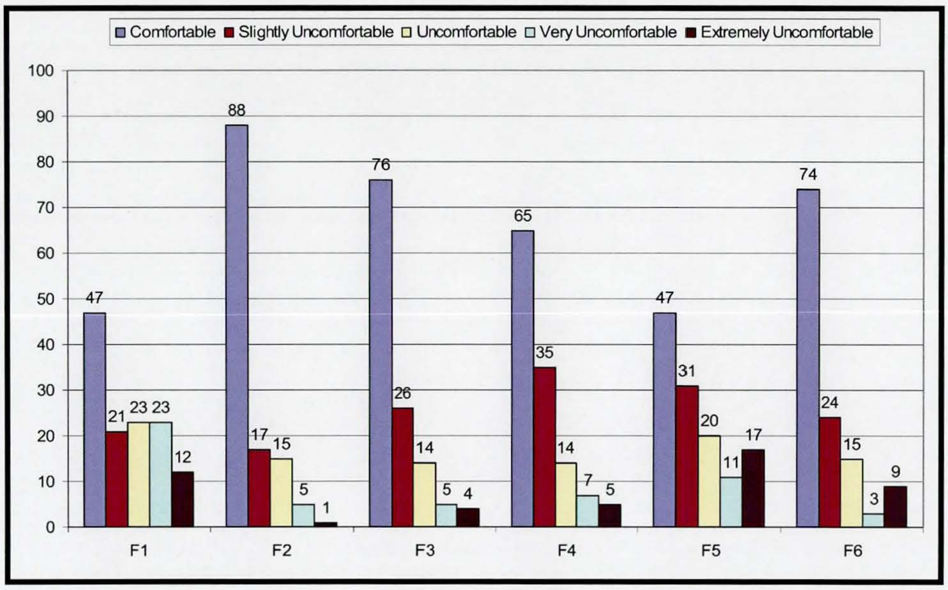


Figure 9.9: Foot comfort ratings (%) following field trial

Data collected in the field trial was able to be compared to data collected in the laboratory (Chapter 8) for 6 participants. This data is presented Figure 9.10. Data is compared for the 1 hour time point in the laboratory trial. Subjective responses gathered in the field are generally similar to those collected in the laboratory. Where discrepancies are noted, in most cases it is the value obtained in the field trial which represents greater discomfort. Half of these participants (1, 2 and 5) carried a short back Bergen – as carried in the laboratory trial, and the other half a long back Bergen. Differences between these types of backpack are as the name suggests; the short back has a shorter back length than the long back.

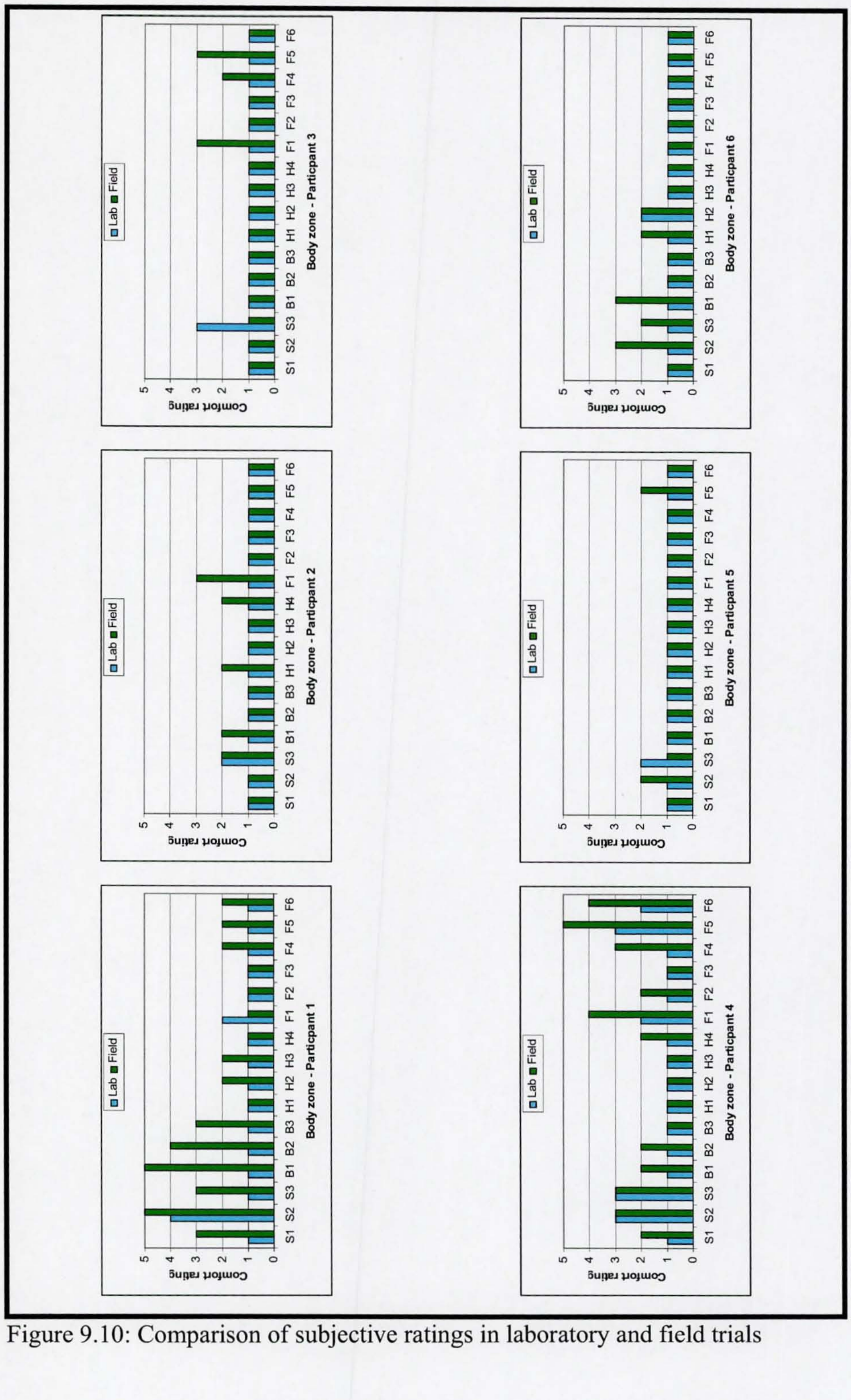


Figure 9.10: Comparison of subjective ratings in laboratory and field trials

9.4 Discussion

The data collected in this chapter begins to explore the response of individuals in the field. By using a comfort scale and body map, a cost effective and simple manner of collecting data concerning load carriage has been achieved. This moves away from the laboratory based assessments which may not be indicative of the true conditions experienced when carrying military loads. By associating with a large group of individuals, collection of a variety of responses is obtained, rather than the limited research work which can take place in the laboratory.

The ratings obtained from this study confirm the data in Chapter 8. Again the areas of the greatest discomfort are the load bearing structures; i.e. the shoulders and the lower limb. When examining the shoulders, it is the zones S2 and more so S3 in which most discomfort occurs. Zone S3 resulted in significantly greater discomfort when carrying the STD LCS design in the work in Chapter 8. The design of the standard LCS results in most of the load being placed on the back and supported by the shoulders. The main load bearing points are concentrated over the clavicles and across the back of the shoulders (Figure 9.11). The positioning of the Bergen on top of the webbing in this LCS design (Figure 3.16) may contribute here. It results in a poor fit (more evident when a long back Bergen is carried) around the shoulder interface, with reduced contact with the scapula region. In comparison the AM LCS (Figure 3.17) results in a close fit across the entire shoulder zone, transporting some of the load to the front of the shoulders. This is further demonstrated by the difference in redness and abrasions following a load carriage trial (Figure 9.12). The AM LCS also moves the loading on the front of the body across to the area around the armpit. It is possible that the plastic inserts which are placed within the strap contribute to this.

Figure 9.11: Main load bearing zones following load carriage with STD LCS

Figure 9.12: Main load bearing zones following load carriage with AM LCS

Jones (2005a) also highlights the issue of poor fit, suggesting as a consequence individuals increase the tension on the shoulder straps to gain a more secure fit of the backpack (STD), which in turn increases the peak pressure placed on the bony landmarks such as the clavicles and scapulae. This highlights the importance of each individual being supplied with the correct back length Bergen. In practise most individuals are initially issued with long back Bergens (personal communication, 2RRF and Black Watch (military field trials)). As a result, alterations to such packs occur, or commercial backpacks are purchased (Jones, 2005a). In a questionnaire with 100 participants ranging in experience from 1-20 years, 55% of individuals used an adapted or alternative pack when completing military tasks. This suggests that the present design is not suitable and should be further investigated with alternative options available to current serving members.

The levels of discomfort recorded in the shoulder region have also been associated with the shoulder strap design of the LCS. The above mentioned survey by Jones (2005a) stated the most negative aspect of the STD LCS design were the shoulder straps, with the main concerns being that the straps are too thin, do not contain enough padding, and are generally uncomfortable. A typical alteration to the straps is to reinforce them with duct tape. This is to reduce the creasing of the straps and to increase the surface contact area at the interface. Inserts placed within these straps to increase their rigidity is a possible solution here, and is part of the design of the AM LCS.

Features crucial in determining good civilian backpack design include stability, comfortable lumbar pad support, firm fitting harness with smooth, wide, well padded shoulder straps and a well balanced weight distribution (Legg et al., 2003). At present the current military LCS has no padded lumbar support at all, and as mentioned above, padding of the shoulder straps is a cause of concern. Many commercial backpack designs include a functioning hip belt, the ability to alter back length, and numerous adjustments for tension across the lower back and shoulders. Incorporating some of these factors into military LCS design may assist in alleviating some of the discomfort experienced. However, the issue of functionality is also extremely important to any designs that may be considered. The military LCS exists to play a part in assisting the soldier to complete their mission. Altering the design to ensure the most comfortable system is worn is only useful if the practicality of use remains.

In addition to the issues surrounding the shoulder region, again a large amount of discomfort is experienced in the feet. This is particularly the case in the zones of the heels and under the balls of the feet. As mentioned in Chapter 7 (section 7.7.2), injury incidence is high following prolonged load carriage, with blisters on the feet being a leading cause of concern. Friction between the socks and the boots causes these blisters to develop, with time of load carriage increasing the risk for them to occur. As load carriage is a weight bearing exercise, foot comfort is the limiting issue. If an individual cannot walk then they will be unable to complete the task at hand. Therefore again the trade-off between comfort and practicality comes into play. The design of the current boots used by the infantry needs to be assessed more closely, to highlight possible areas in which comfort may be increased and injury reduced. As with the choice of backpacks worn, 17.1% of the participants in this field trial chose to wear their own boots rather than those supplied by the military. This is again a high percentage and warrants examination of a change in design.

The comparison between the data collected in the laboratory trial in Chapter 8 and that presented here confirms the ability to collect similar subjective data in the field, but also confirms that in the case of this particular study, the replication of conditions in the laboratory was very close to that which would be normally experienced. Conducting work on the treadmill was of concern because of the associated alteration of gait (section 7.5). Changes here may have resulted in different foot comfort values being observed, more likely being greater discomfort due to the forced nature of treadmill gait. However, exercises conducted in the field are predominantly conducted at set pace in the military environment and this may serve to explain why similar results were obtained here. In addition in the current field trial most of the CFT was conducted on flat paved ground. In most situations these tests are conducted on differing terrain. The BCFT mentioned in chapter 8 requires that at least 37.5% of the test is conducted off road (DIPT, 2002). Further examination of subjective response during load carriage tasks which encompass different terrains and environments will provide additional knowledge in this area and may be important for assessing injury risk.

9.5 Conclusion

The work presented in this chapter gives initial insight into the response when carrying military loads during a "live" military task. Collection of data occurred at the end of a 60 minute fitness test and the data obtained replicates closely that collected in the laboratory trial conducted in Chapter 8. Most discomfort is experienced in the load bearing zones of the body – shoulders and feet - with the areas of the back of the shoulders, heels and balls of feet being the primary discomfort locations when carrying the standard LCS.

These findings support the notion that the currently issued military LCS and footwear need to be examined closer. Possible changes in design are required to ensure all military personnel continue to use the issued equipment rather than making alterations or purchasing commercial systems. It also combines with Chapter 8 to highlight the importance of collecting subjective information whilst military tasks are taking place. Further collection of data including the examination of effects of terrain and environmental change may allow recommendations on load carriage timings and rest periods to be devised and as a result a reduction in injury may occur. This in turn would increase the effectiveness of a military unit, provide a better working environment for the infantry soldier and reduce overall costs due to rehabilitation and illness for the Ministry of Defence.

Chapter 10 – Final Discussion

10.1 Introduction

Load carriage is a necessity with in the Defence working environment. Load carriage tasks occur as components of both training and operational activities and the loads carried on the body sometimes amount to a large percentage (between 60-80%) of the carrier's bodyweight. The recommended maximum amount of load to be carried during military operations is between 33-45% bodyweight (see Section 2.6). Therefore, as these load limits are usually exceeded the predisposition of the individual to injury is heightened. The greater the load carried, or the increased duration over which it is carried, further increases this injury risk. For this reason the examination of the body's response to military loads is important. Gaining an increased understanding in this area, through examination of biomechanical and comfort measures, as in the case of this thesis work, allows recommendations on load carriage practices to be made and comments on the quality of new load carriage system designs to be fed back to governing military organisations.

Through the use of CODA™ motion analysis and individuals experienced in load carriage, the work presented in this thesis has examined the effect of military loads on gait, posture and subjective comfort response. Using the protocol developed (Chapter 3) several different components of load carriage have been investigated. Chapter 4 examined the response of the lower limb when wearing military boots and indicated the restricted movement patterns these boots place on the ankle. Chapter 5 showed increases in ROM of lower limb angular response are seen with increases in load, as is an increase in forward lean. Gender differences in these variables are also noted (Chapter 6) with females compensating more when carrying loads. Further examination linked all lower limb differences to body size rather than gender per se. Relocation of load via the use of different load carriage system designs also results in changes to posture variables, with a more upright posture noted when load is located closer to the body's centre of mass. The later work (Chapter 8) is the first to assess changes to biomechanics over time. Subjective and biomechanical response over a 2 hour load carriage task indicated the subjective comfort of an individual may be the limiting factor in the ability to complete a load carriage task rather than any of the biomechanical variables previously examined. This was particularly evident once 1 hour of load carriage had elapsed. Subjective comfort response was further examined in a large field trial during a specific military activity (Chapter 9).

Critical to all work conducted within this thesis has been the use of a load carriage system rather than a backpack alone. Most previous work has concentrated on singular components of military equipment rather than considering the entire system the soldier is required to carry. This chapter presents a discussion of the main findings of the experimental work, linking these into design concepts and injury mechanisms.

10.2 Lower limb

The assessment of gait biomechanics over the kinematic experimental trials has allowed examination of the movement of the lower limb in the saggital plane. Most notably affected during all experimental trials was the range of movement through which the limbs progressed. Increases in load (Chapter 5) and increases in load carriage time (Chapter 8) resulted in greater ROM of all lower limb angles measured.

A load increase of 42kg resulted in significant increases in knee (4.5°) and femur (8.9°) ROM. When carrying a load of 25kg, the increase in ROM over time was less than when heavier loads (42kg) were carried for a short time period. Knee ROM increased by 1.3° when carrying the Standard LCS and femur ROM increased by 1.5°. In addition an increase in ankle ROM of 2.7° was seen over the 2 hour time period. Whilst individually these increases are small, when combined together it is possible they would influence the physiological response of the individual carrying the load. It is reasonable to suggest that if the heavier military loads examined in Chapter 5 were carried for an extended time period then at least the change seen when carrying a 25kg load would be experienced. It is more likely that a greater change in ROM of the lower limb would be noted, further impacting the ability of the individual to continue to carry the load. These heavier loads are those which are used in military operational activities. During these times the ability of the soldier to perform is a crucial requirement and any decrement in performance may increase the possibility that injury could occur.

Body size of the individual also impacted on the ROM of the lower limb (Chapter 6). Smaller participants indicated a trend for greater ROM of the ankle and femur when carrying load. This was offset by a smaller knee ROM in these participants. This suggests that in individuals of smaller body size, it is the ankle and hip regions which respond to the load being carried, but as body size increases it is the knee which takes over this response.

Any increase in ROM of the body brings an associated greater energy cost. The nature of a load carriage task means the physiological cost is already high, with any addition to this cost being undesirable. A certain ROM of the lower limb is important in order to progress the body forward, but any additional non required change may result in fatigue occurring earlier when carrying loads; possibly compromising the soldier. In addition, changes in design of military equipment concentrate on assisting the soldier in making load carriage tasks as efficient as possible. The target is to decrease the physiological cost. This may also be achieved by correct training techniques prior to carrying such loads, concentrating on both the cardiovascular system and the muscular system which must support the load.

Increases in ROM may also be associated with the ground reaction forces experienced by the individual carrying the load. Whilst walking unloaded these peak forces are approximately 1.2 times body weight. As load is increased, a proportional increase occurs, with a load of 40kg resulting in a peak force of 1.8

times body weight when carrying British military loads (Birrell & Hooper, 2005b). Frequent exposure to these high forces is a major risk factor for injury, in particular overuse injuries such as stress fractures and increased incidence of blisters (Kinoshita, 1985). This is due to the musculature of the lower limb having an inability to attenuate these elevated forces, resulting in the skeletal structures having to take the load.

Of equal concern is the duration of load carriage. As time is increased changes in lower limb mechanics take place; as indicated in Chapter 8. Increases in ROM of the ankle, knee and femur angles occur as time increases. As the smaller muscles of the lower limb musculature fatigue alternative movement strategies must occur. This also results in changes to spatiotemporal parameters of gait, with a trend for the SL to decrease over time and SF to increase over time when carrying the standard LCS.

Local deformation of the foot has been shown to change after fatigue or with the addition of a 20kg load. This change in deformation has been linked to a decreased ability to attenuate force. When the foot becomes fatigued compressive strain on the bones increases, but the tensile unloading mechanism that normally occurs in a non fatigued foot decreases. Combined with the fatigue of the supporting musculature of the foot, this results in an increased deformation of the foot and increased localised stress on the skeletal system (Arndt et al., 2002). Work examining running and fatigue shows a significant increase in the dynamic loading experienced by the body with fatigue (Voloshin et al., 1998). As a result the body inherently makes alterations to the running pattern to reduce the impact on higher parts of the skeleton such as the spine and the head as a protective mechanism. Although running was not examined in the current work, as load has been added to the body similar levels of ground reaction forces may possibly be experienced. The ability to attenuate this shock over time is extremely important in order to keep injury incidence minimised. Training may have an impact on the ability of the individual, as would appropriate footwear. Yet to be examined is the shock attenuating characteristics of military boots over time. If, in addition to the changes that occur in the body, there are changes occurring in the ability of the footwear to assist with this force dissipation then injury risk may be at a premium. This is an area of work which requires greater attention. Unfortunately due to the experimental equipment available in the current work force data was not examined. A treadmill with embedded force plates would be extremely useful in examining the changes to such forces over time.

In summary, when examining the response of the lower limb whilst carrying military loads, the important factors to consider are the weight of the load carried, the amount of time that the load must be carried, and the size of the individual carrying it. It is possible that certain individuals should be restricted from carrying loads (as is the current situation with front line troops) in order to ensure that the risk to injury is kept at a minimum. Examination over time of the heavier loads carried in the experimental work presented in Chapter 5 may allow recommendations of time of load carriage in true military scenarios to be made. From the work conducted at lower loads, changes in lower limb mechanics do occur over time, but in a gradual manner. It is only the sharp increases in discomfort which may indicate rest periods should occur after one hour of load carriage. Work completed in this thesis has also been conducted on level, uniform surfaces. It is possible that uneven terrain may further influence these results.

10.3 Upper body

Body posture, both in terms of the trunk and the head, has also been a concentration of the work presented in this thesis. It was demonstrated that changes occur as a result of load weight, load carriage time and gender. The consideration of these variables is important as the load is predominantly supported by the trunk, and its encompassing musculature. Also, in order to counterbalance the load that is placed on the back, a more forward head posture is adopted, which in turn places possible stresses on the supporting small musculature. Stress on these muscles has been associated with neck ache, dizziness and loss of balance, exacerbated when longer term stress is applied (Chansirinukor et al., 2001; Raine & Twomey, 1997).

As load is increased a greater forward lean is seen. An increase in load from 8kg to 50kg resulted in 20° more forward lean when carrying the standard LCS. No changes were seen in the ROM of the trunk during this increase. An increase in forward lean as load is increased is the most commonly reported biomechanical response when examining military loads (Filaire et al., 2001; Goh et al., 1998; Harman et al., 2000a; Kinoshita, 1985; Martin & Nelson, 1986; Pascoe et al., 1997). The response occurs in order to balance the effect of having the load concentrated on the rear of the body, behind the centre of gravity. Moving some of the load to the front of the body, such as when carrying the AM LCS, results in a more upright posture. However, the AM LCS results in a greater ROM when carried for longer durations. As with the lower limb, in these situations a large body mass must be moved by the musculature. Any increase in ROM is again associated with an increased physiological cost, which, when combined with possible increases in energy cost related to the lower limb, may result in a much more rapid progression to fatigue. Some forward lean is essential for progression of the body forward, but excessive forward lean places increased stresses on the supporting skeleton and musculature, predisposing the load carrier to injury. Carrying loads for extended periods in such a posture further increases this injury risk and should be avoided if possible.

When gender differences were examined, females were shown to respond differently to males in terms of response of the trunk. When no load was carried they were in a more upright position, but once a load of 40% BW was added they moved to a position of greater forward lean than the male participants (Chapter 6). A difference in ROM of the trunk was also seen, with females exhibiting greater ROM than males. Unlike the lower limb, in the case of the trunk the gender difference was not linked to any anthropometric measures of the participants. Therefore it is suggested that females respond differently in terms of body posture when exposed to military loads. Whether this small difference may have an impact on the ability to perform a load carriage task is not known. The data collected was over a short time period, with long term load carriage only considered with male participants in this thesis (Chapter 8). Male participants showed an increase in forward lean over the 2 hour load carriage period. Given females showed a greater response in terms of forward lean when carrying loads for a short time period, it may be expected that their increase in forward lean is greater than their male counterparts when they carry similar loads over a more extensive time period. Therefore there may be some suggestion for different load carriage practices for males and females when considering the response of the trunk. However, all lower limb gender differences are linked to body size, and trunk response is only one component of the whole body system response. Consideration of the overall body response is the most important factor in determining whether changes to load carriage practices should occur.

Previously the examination of head posture measures has been confined to static measures or, when dynamic movement is occurring, low loads have been carried (Chansirinukor et al., 2001; Raine & Twomey, 1997). In terms of military research this is the first known work to examine such angular data. When load is increased a more forward head position is noted, in order to counterbalance the load. A greater ROM of the head is also noted in terms of the craniohorizontal angle over time. As a more forward head position is linked to illness and injury, such as neck ache, dizziness and loss of balance, these results are of concern and need to be examined further. Closer investigation of the changes that occur to muscle activation of the neck and shoulders during such load carriage tasks may prove valuable. By collecting information on muscle firing patterns and levels of recruitment, possible predictors to fatigue in this region may be quantified. It is expected these patterns of recruitment would be linked closely to the levels of discomfort experienced by individuals as discussed in Section 10.5.

10.4 Equipment

Military personnel are required to wear and carry specific equipment whilst they carry out military tasks. As part of the work presented in this thesis two components of this equipment have been examined: boots and load carriage systems. Both biomechanical and subjective comfort information have been collected for participants using this equipment, with possible implications for design being highlighted.

10.4.1 Military boots

As mentioned in Chapter 4, the most commonly worn boots by military personnel are the "assault" boots. Their function is to provide a stable and protective environment in which the soldier may complete their daily activities. This function is of extreme importance; however the cost at which this occurs, in terms if injury occurring due to wearing such footwear, is bought into question. It is essential that the boots have steel caps, rigid soles, and are affordable for the military to purchase, but the human cost and financial cost of individuals not performing when wearing them must also be taken into consideration.

The rigidity of the boot system results in significant decreases in range of motion of the ankle joint. As a result other parts of the body must compensate to ensure the individual is able to move freely across the ground. The rigidity also plays a predominant role in the incidence of blisters that occur when wearing such footwear. The most commonly reported injuries when completing military tasks occur in the lower limb, with blisters showing the highest incidence (Knapik et al., 1992). This is further supported by the subjective data collected in Chapters 8 and 9 that highlight the discomfort experienced by the foot, particularly in the heel area. In some cases individuals were unable to complete the task set for them, or did complete, but at a level of extreme discomfort. The debilitating nature of this type of injury results in the soldier being unable to complete their objectives and possibly being removed from duty in the following days. Cost ramifications are high, an issue which all defence agencies are constantly attempting to reduce. Prior to the work conducted here, assessment of comfort, if included at all, has concentrated on the upper body – particularly when carrying loads. Closer assessment of different zones of the feet is important in order to understand the areas where alterations to the footwear may be required. Those zones that are placed under the highest levels of stress may require increased padding, or alteration to the shape of the boots. Consideration of the shock attenuation characteristics are also important (Section 10.2) as these may further contribute to lower limb injuries and stress fractures.

Development of boot design has received less attention than increases in technology, which has been of primary importance for the UK military in recent years. However, if unable to walk due to wearing such boots, then the advantages gained from these increases in technology could be compromised. Whilst examination of different types of boots has not occurred as part of this thesis work, the impression that individuals are not content with the current design is reinforced by the number who choose to wear their own commercially purchased boots; further reinforced from the questionnaires conducted by Jones (2005a). It is essential that a large scale study examining different styles of boots is conducted in order to increase compliance with design, reduce the injuries that occur and continue to supply the functionality that is essential for everyday military use.

10.4.2 Load Carriage System design

The currently issued LCS used by the British military has been in use since 1990. Although many developments have occurred with commercial backpack systems during the last 15 years, no major changes have taken place with the military equipment. Developments have occurred however in the technology which a soldier is required to carry, generally at a cost of increased weight. When a load carriage task needs to be completed, the essential items such as food, water, clothing and ammunition may not be left behind to make room for this new technology. Therefore the implication is the load will continue to increase.

Current war and peacekeeping activities result in a large proportion of motorised transport, but there are still situations where long duration load carriage tasks must take place. It is during these times that design and training are the most important in ensuring a large number of injuries do not occur. As part of the work presented in this thesis the examination of a prototype design has taken place. The Airmesh

LCS is a completely different design to that seen in the current issued STD LCS. The Bergen (backpack) component has a fully functional hip belt, plastic inserts placed within the straps to ensure crumpling does not occur, and integrates well with the vest webbing, worn on the chest. This highlights the importance of considering these systems as a whole. Use of the AM Bergen with the STD webbing would not be possible as the hip belt would not be able to be used. Likewise, integration of the STD Bergen with the vest webbing would result in the entire load being placed on the shoulders – a feature which is undesirable.

Several advantages have been noted with carrying the AM LCS. The work in Chapter 6 indicated a more upright walking posture, due to redistribution of some of the load to the front of the body, and a reduction in trunk ROM when carrying the AM compared to the STD system. When carried during the longer term load carriage trials (Chapter 8), the AM LCS resulted in a more upright position in terms of the lower limb but a greater ROM of the trunk. There are also several issues associated with this design that have not been examined as part of this work. Although thermal comfort ratings were taken in the longer term trials, with the AM system indicating a slightly higher thermal stress, this has not been properly examined. By covering the front of the body with the vest arrangement there is a restriction in the area of which sweat evaporation can occur and during hot and humid environments this may cause problems with heat related injuries. Another consideration is the profile of the soldier. With part of the load placed on the front of the body the soldier's profile is increased. As a result there is a larger target for the enemy should the system be worn in a hostile situation. It may also present problems when carrying or attempting to fire a weapon, and may cause injury when a soldier has to go to ground.

The list of assessments that must be made before a specific design may be recommended is not limited just to those of a physiological or biomechanical nature, although these factors are important. The functionality of the system, level of comfort experienced and injury causing mechanisms should be fully examined before any such recommendations take place. At this time, there are elements of the AM LCS design which are recommended, in particular the use of a hip belt to move some of the weight off the shoulders. Also, the use of inserts within the shoulder straps has been shown to disperse the pressure experienced over a greater area (Jones 2005a), which may explain increased comfort seen in 2 of the 3 shoulder zones examined in this work. However, most important is that the LCS is treated as a whole and that any changes that occur to the backpack element must be able to integrate with the type of webbing carried as this is carried at all times.

10.5 Subjective comfort

The work presented in the latter half of the thesis highlights the continued importance of subjective comfort data collection, in line with the work by Jones (2005a) and that of Legg and colleagues (Legg et al., 1997; Legg et al., 2003). Collection of data whilst the exercise is taking place is important. This allows an indication of possible timings when discomfort exceeds tolerable levels, making the individual more prone to injury or unable to complete the task at hand. In order not to distract from the task at hand a simple method of collecting data, such as that presented in Chapter 8, should be used. This scale allows data to be collected quickly and accurately for a variety of body zones which are important to the user of the load carriage device.

Similar methodology is used in other ergonomic assessment work related to the military. Work conducted by BAE Systems in the UK uses the Instantaneous Self Assessment (ISA) tool to assess workload on a variety of military tasks (Leggatt, 2005; Sturrock & Fairburn, 2005). The tool involves a box with 5 buttons ranging in workload from very low to very high, which prompts the user to make a selection at predetermined time points. This data is automatically recorded and displayed to the researchers (without knowledge of the participant). It also has the ability to be used by multiple users simultaneously. At present this tool is used as part of a cockpit design (Sturrock & Fairburn, 2005) or similar; i.e. must be fixed and hardwired. Development of such a tool into a lightweight device which may be worn by an individual in a manner similar to a wrist watch would be extremely useful for examining field data whilst carrying military loads. This would allow a variety of terrains to be examined and the effect of some of the extremely long load carriage scenarios (e.g., 20km march) to be observed.

From the data presented in chapters 8 and 9 it is evident that the shoulders and the feet are the primary sources of discomfort to the load carrier. A gradual increase in discomfort of the shoulder region is seen over 2 hours, whereas with the feet it appears that a period of greater than 60 minutes load carriage results in increases in discomfort. Through use of a simple monitoring device as suggested above, one could determine a critical level for discomfort and once this has been reached, periods of rest must be observed. This would serve to allow the discomfort to dissipate and increase the effectiveness of a military unit by decreasing injury incidence. Monitoring of individuals during training exercises will allow recommendations for safe practice during operational activities.

Chapter 11 – Summary and Conclusions

11.1 Summary

The work presented in this thesis represents the examination of various factors which may alter an individual's ability to carry military loads. It presents a biomechanical assessment of the current UK military load carriage system, which has not been completed in the past. Previous concentration has been on individual pieces of military equipment rather than considering the whole entity. Through development of the protocol, the final trial (Chapter 8 – Effect of Load Carriage Duration on Gait, Posture and Subjective Comfort) also presents novel work. The value of subjective data collection has also been highlighted, with specific attention given to the shoulders and feet. These measures should be included in all future load carriage work to allow possible changes in design and reduction in injury to occur.

The objectives of this thesis work have been met.

1. A protocol for the examination of the effect of the military LCS on gait and posture was developed. A CODA™ motion analysis was chosen to collect such data due to its portability, ease of use, as well as representing an accurate measurement system for the collection of biomechanical data. The alignment of the system was validated, and reliability of marker placement and number of gait trials required was assessed. Marker placement allowed examination of saggital plane biomechanical information for both the lower limb and upper body. Collection of subjective comfort data was also crucial to obtaining the overall response of the individual when carrying military loads.

2. Changes in gait and posture in response to military boots, alterations in load weight, load position (via use of different LCS designs), gender and duration of load carriage were examined with military personnel or experienced backpackers. This was completed by conducting 5 experimental trials both at military bases and with members of local military units near to Loughborough University. At all times participants carried the total LCS rather than concentration on backpack carriage alone which has been the emphasis of previous work. Military boots were also always worn and all participants always carried a rifle to replicate as closely as possible a realistic military load carriage scenario.

3. Possible contributors to good LCS design were highlighted following conducting experimental work with appropriate end users. The relocation of load to the front of the body represents a change in the body response when carrying loads. The examination of subjective comfort data was also crucial in determining these factors, with different systems concentrating the level of discomfort experienced into different body zones.

11.2 Overall conclusions

1. Development of the current protocol has allowed the biomechanical response of carrying military loads using the military load carriage systems to be examined. At all times the load carriage system rather than separate components has been investigated. Also, the systems have been examined using members of military personnel or experienced backpackers.

2. Load carriage results in alteration to the lower limb response in terms of range of motion through which the body moves. This is linked to the physiological cost that the individual experiences when carrying loads. It may also be linked to injury that an individual may experience.

3. The trunk and head regions of the body respond to load carriage by working to offset the change to the body's centre of gravity. This results in a greater forward lean and more forward head posture, in order to offset the load placed on the rear of the body (in most cases). The stresses associated with maintaining such a posture over a long time period need to be further examined, but predisposition of injury due to continuing to maintain such a body posture is high.

4. The first known examination of biomechanics over an extended time period has been conducted. This allowed time points to be highlighted where the greatest change in response to load is seen. This type of experimental trial is also currently listed as a priority in other military establishments worldwide.

5. The importance of collection of subjective comfort data has been highlighted. This is particularly pertinent in terms of the response of the feet and shoulders when carrying military loads. This type of data has been collected both within the laboratory and during a large military training operation.

6. Changes in load carriage system design have been examined. Whilst a more upright posture and changes to lower limb biomechanics may have been noted in one system versus another, the most crucial determinant of the ability to carry the load is the comfort of the individual undertaking the load carriage task. Reaching levels of extreme discomfort results in individuals unable to complete the task at hand, and in severe cases may be removed from duty due to injury. This is an area which requires further attention to ensure individuals never reach such a level of discomfort.

7. As a final note, overall ergonomic assessment with actual end users is important. Designs of equipment used by the military should be proactive, not reactive to high rates of injury or similar issues. Practicality of use must also be examined closely as the most important factor is to maintain the functionality of this equipment.

Chapter 12 – Suggestions for Further Work

12.1 Recommendations

Throughout the course of this thesis a number of areas of work have been highlighted that would be of value in the area, but could not be completed due to constraints of time, equipment and restricted availability of military personnel. These and other possible areas of interest are listed below.

1. **Three dimensional biomechanical analysis of gait whilst carrying LCSs:** This will allow other planes of motion to be examined, as it may be possible that these planes contribute more to the cause of injury, or influence fatigue. Also, the pelvis is important in this type of data collection, so a method of measuring movement of this area whilst still wearing the webbing component of the LCS needs to be developed. At present no such methodology exists, and 3-dimensional analysis has only been conducted when wearing a backpack alone. Once such a methodology has been developed the examination of longer duration load carriage should take place.

2. **Bipedal gait:** Data should be collected on both lower limbs rather than concentrating on one side of the body as has occurred here. This will allow closer examination of factors such as double support and other spatiotemporal data. It will also serve to examine the contribution of the pelvis to movement more closely. Using a motion analysis system that can surround the individual, such as 2-3 banks of CODA™ cameras is required so that both sides of the body may be observed.

3. **Changes in ground reaction forces:** Examination of these forces, particularly over time should be observed. In particular changes to the shock attenuation characteristics of gait should be given close attention as these may highlight injury mechanisms, in particular with issues such as stress fractures. Changes in the location of the GRF as it passes through the lower limb can demonstrate indicators for injury. If the GRF is, for example, consistently passing medially to the knee, the greater stress is placed on the inner side of the knee than normally experienced when walking. As the structures here are not designed to absorb all of the GRF the body experiences there is an increased susceptibility for injury in this region. This is further exacerbated by carrying loads as the GRF experienced is increased.

4. **Orloff and Rapp (2004) spinal curvature methodology:** Further development of the methodology undertaken by Orloff and Rapp (2004) related to the examination of spinal curvature whilst carrying loads should take place. At present this technology has only examined light loads placed on the back. It provides a novel methodology that solves the issue of treating the trunk as a total segment. It may also highlight specific areas of the spine where most loading occurs, allowing changes in design to address redistribution of this load more evenly over the entire load carrying surface.

5. **Terrain:** The effect of terrain is important to consider. All work conducted in this thesis has been on flat uniform surfaces, with realistic military scenarios unlikely to occur on such surfaces. Terrain may cause changes to posture response, and may influence levels of subjective comfort/discomfort experienced. In terms of subjective data response, data on terrain effects could be collected in the field by placing checkpoints following different terrain environments over a course designed by experimenters. Using a specific training exercise which military personnel must complete would facilitate in collecting such data, and the emphasis should be placed on collecting data when loads have been carried for more

than a short time period. Collecting biomechanical data related to terrain presents a more difficult scenario, as at present such systems are unable to be used in the field. A series of different terrain environments could be created in the laboratory to simulate those experienced outside and data collected in this manner.

6. **Field subjective data:** In line with recommendation 5, the measurement of subjective data in the field is important as the response of individuals when placed in a laboratory environment may not fully replicate that experienced in the field. The field work in Chapter 9 did indicate similar results to that of the laboratory, with reasons for this discussed. A further in-field assessment should include different environmental scenarios, with different load carriage tasks taking place.

7. **Training:** Military training is an important consideration. The work presented here concentrates on military personnel with limited field experience. It is possible that those with extensive training may have adapted differently to load carriage tasks and may elicit different responses. Members of different military units also have different load carrying capabilities required of them. For example, members of the Special Forces are required to carry higher loads for longer periods than any other military unit within the Army. Obtaining knowledge on how such individuals respond may prove useful in training individuals with less experience.

8. **Consumer backpack designs:** Incorporation of some of the advances in consumer backpack design, such as hip belts and adjustable back and strapping systems, into the military backpack design may allow redistribution of load on the body, resulting in more efficient and injury free load carriage. This will only be useful if the functionality of the military LCS is maintained. The AM Bergen/backpack has attempted to use such design components, but at present is not designed to work in a load carriage system (i.e. including the webbing) that can be used by all

military personnel. Concentration on these design components within the LCS design is crucial to achieving any benefit that may occur.

9. **Military footwear:** The examination of the footwear worn by military personnel warrants closer attention. The level of discomfort and injury in this area is high. The functionality of the current boot design results in restricted movement of the lower limb, with many individuals choosing to purchase their own commercial footwear instead. Changes to the design of this footwear would assist in injury reduction and increase compliance.

10. **Cognitive performance:** An initial experiment examining cognitive performance following load carriage was presented in Chapter 8. This simple test indicated decrements in cognitive performance do occur following longer term load carriage. At present the majority of research has concentrated on examining the physical changes (whether they are physiological or biomechanical in nature) that occur as a result of load carriage. However, the cognitive performance of the soldier following a period of load carriage is also extremely important. It is during these times of fatigue that crucial operational decisions are sometimes made, therefore ensuring cognitive performance is at a premium is imperative. Design of a simple field test which can be completed by individuals whilst out on training exercises is a methodology which would serve to assist in collection of such data. Again it is important that these issues are examined in the field rather than the laboratory environment.

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Research Dissemination

Journal Publications

1. Attwells, R. L., Birrell, S. A., Hooper, R. H., & Mansfield, N. J. (2006). Influence of carrying heavy loads on soldiers' posture, movements and gait. *Ergonomics 49(14) pp 1527-1537*

2. Attwells, R.L., Birrell, S.A., Hamilton, S.L., Hooper, R.H., Mansfield, N.J. (2006). The effect of gender on gait and posture whilst carrying military loads. *Gait & Posture – under review*

Conference Proceedings

1. Attwells, R. L., Birrell, S. A., Hooper, R. H., & Mansfield, N. J. (2003a). *Influence of carrying heavy loads on soldiers' dynamic trunk and head posture.* Paper presented at the Fifth International Conference on Sport, Leisure and Ergonomics (Nov 19th-21st), Burton Manor, The Wirral, UK.

2. Attwells, R. L., Birrell, S. A., Hooper, R. H., & Mansfield, N. J. (2004b, June 18 – 21). *Effect of Design Changes of Military Load Carriage Systems on Gait and Posture: A Case Study.* Paper presented at the XVth Congress of the International Society of Electrophysiology and Kinesiology, Boston University, Boston, Massachusetts, USA.

3. Attwells, R. L., & Hooper, R. H. (2005a). Gender differences in military load carriage. In *Contemporary Ergonomics* (pp. 151-156): Taylor & Francis.

4. Attwells, R. L., & Hooper, R. H. (2005b). Biomechanical examination of British prototype load carriage systems. In *Contemporary Ergonomics* (pp. 157-160): Taylor & Francis.

Appendices

List of Appendices

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A1

Loughborough University

Influence of carrying heavy loads on soldiers' body posture, movements and gait: A preliminary investigation at two speeds.

INFORMED CONSENT FORM
(to be completed after Participant Information Sheet has been read)

The purpose and details of this study have been explained to me.

I have read and understood the information sheet and this consent form.

I have had an opportunity to ask questions about my participation.

I understand that I am under no obligation to take part in the study.

I understand that I have the right to withdraw from this study at any stage for any reason, and that I will not be required to explain my reasons for withdrawing.

I understand that all the information I provide will be treated in strict confidence.

I agree to participate in this study.

Your name ____________________

Your signature ____________________

Signature of investigator ____________________

Date ____________________

A2

Loughborough University

HEALTH SCREEN FOR STUDY VOLUNTEERS **Name or Number** ....

It is important that volunteers participating in research studies are currently in good health and have had no significant medical problems in the past. This is to ensure (i) their own continuing well-being and (ii) to avoid the possibility of individual health issues confounding study outcomes.

Please complete this brief questionnaire to confirm fitness to participate:

1. **At present,** do you have any of the following health problems or are you receiving treatment for:
   - (a) back and/or shoulder pain.. Yes ☐ No ☐
   - (b) knee and/or foot injuries.. Yes ☐ No ☐
   - (c) any other muscle injuries .... Yes ☐ No ☐
2. **In the past two years,** have you had any illness which require you to:
   - (a) any serious injuries or illnesses that have caused you to have time off duty .... Yes ☐ No ☐
3. **Have you ever** had any of the following:
   - (a) pathological/atypical gait patterns..................................... Yes ☐ No ☐
   - (b) surgery that altered your gait pattern................................. Yes ☐ No ☐
   - (c) Problems with bones or joints .... Yes ☐ No ☐
   - (d) Disturbance of balance/coordination................................. Yes ☐ No ☐
   - (e) Numbness in hands or feet .... Yes ☐ No ☐
   - (f) Disturbance of vision... Yes ☐ No ☐
   - (g) Ear / hearing problems .... Yes ☐ No ☐
   - (h) Allergy to plasters or sticking tape.................................... Yes ☐ No ☐
4. **Are you** classified FIT FOR DUTY at present? Yes ☐ No ☐

If YES to any question (or "NO" to question 4), please describe briefly if you wish (e.g. to confirm problem was/is short-lived, insignificant or well controlled.)

....

....

Thank you for your cooperation!

Loughborough University

A3

Loughborough University

Influence of carrying heavy loads on soldiers' body posture, movements and gait: A preliminary investigation at two speeds.

PARTICIPANT INFORMATION SHEET

The purpose of this study is to look at the effect the loads carried by the military have on the posture and gait (walking patterns) of individuals. It is hoped that results from the study will assist in design of future equipment.

During the study you will be asked to walk at a patrol pace under 4 conditions;

1. Wearing PT uniform, boots, helmet and assault rifle (unloaded).
2. Addition of webbing, packed for full marching order
3. Addition of rucksack, packed for full marching order
4. Addition of LAW (unloaded)

In addition during the first two conditions you will also be required to move at assault speed.

In order for measurement to be made sensors will be placed over key body positions. These will be attached by double sided tape and mostly placed on your skin or over the top of your uniform. These sensors emit an infrared signal to the infrared cameras that allow the position of the body to be monitored. Video recording of testing sessions will also take place. This is to allow further analysis and the identity of participants will be kept confidential at all times.

Each testing session will require you to move between a 5-metre distance in front of the cameras at the assigned speed and condition for a total of 10 trials of each condition. Before the trials with the rucksack on you will also be given 10 minutes to walk around with the pack on and adjust for comfort. Testing time is expected to take a maximum time of three hours.

You are able to withdraw from the study at any time for any reason, and you will not be required to explain your reasoning. Please feel free to ask questions at any time.

Thank you for your participation.

A4

Loughborough University

Influence of carrying backpack loads on body posture, movements and gait. Differences in response due to gender.

INFORMED CONSENT FORM
(to be completed after Participant Information Sheet has been read)

The purpose and details of this study have been explained to me.

I have read and understood the information sheet and this consent form.

I have had an opportunity to ask questions about my participation.

I understand that I am under no obligation to take part in the study.

I understand that I have the right to withdraw from this study at any stage for any reason, and that I will not be required to explain my reasons for withdrawing.

I understand that all the information I provide will be treated in strict confidence.

I agree to participate in this study.

Your name ______________________________

Your signature ______________________________

Signature of investigator ______________________________

Date ______________________________

A5

Loughborough University

HEALTH SCREEN FOR STUDY VOLUNTEERS **Name or Number** ....

It is important that volunteers participating in research studies are currently in good health and have had no significant medical problems in the past. This is to ensure (i) their own continuing well-being and (ii) to avoid the possibility of individual health issues confounding study outcomes.

Please complete this brief questionnaire to confirm fitness to participate:

1. **At present,** do you have any health problem for which you are:
   - (a) on medication, prescribed or otherwise .... Yes ☐ No ☐
   - (b) attending your general practitioner.................................. Yes ☐ No ☐
   - (c) on a hospital waiting list .... Yes ☐ No ☐
2. **At present,** do you have any of the following health problems or are you receiving treatment for:
   - (a) back and/or shoulder pain.. Yes ☐ No ☐
   - (b) knee and/or foot injuries.. Yes ☐ No ☐
   - (c) any other muscle injuries .... Yes ☐ No ☐
3. **In the past two years,** have you had any illness which require you to:
   - (b) any serious injuries or illnesses that have caused you to attend a hospital or hospital outpatient department.................... Yes ☐ No ☐
3. **Have you ever** had any of the following:
   - (a) pathological/atypical gait patterns..................................... Yes ☐ No ☐
   - (b) surgery that altered your gait pattern................................ Yes ☐ No ☐
   - (c) Problems with bones or joints .... Yes ☐ No ☐
   - (d) Disturbance of balance/coordination................................ Yes ☐ No ☐
   - (e) Numbness in hands or feet .... Yes ☐ No ☐
   - (f) Disturbance of vision.. Yes ☐ No ☐
   - (g) Ear / hearing problems .... Yes ☐ No ☐
   - (h) Allergy to plasters or sticking tape.................................... Yes ☐ No ☐
   - (i) Convulsions/epilepsy.. Yes ☐ No ☐
   - (j) Heart, circulation and/or respiratory problems.................. Yes ☐ No ☐

4. **Do you** consider yourself to being in good health at present? Yes ☐ No ☐

If YES to any question (or "NO" to question 4), please describe briefly if you wish (e.g. to confirm problem was/is short-lived, insignificant or well controlled.)

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....

Additional question for female participants

(a) could you be or are you pregnant? .... Yes ☐ No ☐

5. Please tell us about any exercise you take

Type of exercise	How often each week	Approx. how long each time

Thank you for your cooperation!

Loughborough University

A6

Loughborough University

Influence of carrying backpack loads on body posture, movements and gait. Differences in response due to gender.

PARTICIPANT INFORMATION SHEET

The purpose of this study is to look at the effect backpack loads have on the posture and gait (walking patterns) of individuals and if there are any gender differences in these responses. The results from the study will assist in design of future equipment.

During the study you will be asked to walk at a self selected pace under 4 conditions;

1. Wearing shorts and t-shirt and walking barefoot whilst carrying a replica rifle.
2. Wearing shorts and t-shirt, military boots (provided by researchers), and carrying a replica rifle.
3. Addition of webbing, load to maximum 7% body weight. (x2)
4. Addition of backpack, loaded to maximum 33% body weight (x2)

In order for measurement to be made sensors will be placed over key body positions. These will be attached by double sided tape and mostly placed on your skin or on your clothing or shoes. These sensors emit an infrared signal to the infrared cameras that allow the position of the body to be monitored. Force data will also be collected. Video recording of testing sessions will also take place. This is to allow further analysis. The identity of participants will be kept confidential at all times.

Each testing session will require you to move between a 10-metre distance in front of the cameras and over the force plate at the assigned speed and condition for a total of 10 trials of each condition. Before the trials with the rucksack on you will also be given 10 minutes to walk around with the pack on and adjust for comfort. Testing time is expected to take a maximum of three hours.

To ensure that there are no risks from load carriage you will be asked to complete a health screen questionnaire. If you have lower back pain, gait, joint or muscular discomfort or disease you will not be able to participate. Likewise you will not be able to participate if you suffer from diagnosed respiratory, circulatory or blood pressure difficulties or are receiving medication acutely or profilactically.

Any load carriage may include some discomfort at the interface between the pack and the body, so there is the possibility of discomfort. It should not be of any large magnitude but you are able to withdraw from the study at any time for any reason, and you will not be required to explain your reasoning. Please feel free to ask questions at any time.

Thank you for your participation.

Renee Attwells

A7

Loughborough University

Effect of fatigue on body posture, movements and gait whilst carrying military loads.

INFORMED CONSENT FORM
(to be completed after Participant Information Sheet has been read)

The purpose and details of this study have been explained to me.

I have read and understood the information sheet and this consent form.

I have had an opportunity to ask questions about my participation.

I understand that I am under no obligation to take part in the study.

I understand that I have the right to withdraw from this study at any stage for any reason, and that I will not be required to explain my reasons for withdrawing.

I understand that all the information I provide will be treated in strict confidence.

I understand I have the right to refuse the collection of visual material such as videotaping and photographs.

I agree to participate in this study.

Your name ______________________________

Your signature ______________________________

Signature of investigator ______________________________

Date ______________________________

A8

Loughborough University

HEALTH SCREEN FOR STUDY VOLUNTEERS **Name or Number** ....

It is important that volunteers participating in research studies are currently in good health and have had no significant medical problems in the past. This is to ensure (i) their own continuing well-being and (ii) to avoid the possibility of individual health issues confounding study outcomes.

Please complete this brief questionnaire to confirm fitness to participate:

1. **At present,** do you have any health problem for which you are:
   - (a) on medication, prescribed or otherwise .... Yes ☐ No ☐
   - (b) attending your general practitioner .... Yes ☐ No ☐
   - (c) on a hospital waiting list .... Yes ☐ No ☐
2. **At present,** do you have any of the following health problems or are you receiving treatment for:
   - (a) back and/or shoulder pain .... Yes ☐ No ☐
   - (b) knee and/or foot injuries .... Yes ☐ No ☐
   - (c) any other muscle injuries .... Yes ☐ No ☐
3. **In the past two years,** have you had any illness which require you to:
   - (c) any serious injuries or illnesses that have caused you to attend a hospital or hospital outpatient department .... Yes ☐ No ☐
3. **Have you ever** had any of the following:
   - (a) pathological/atypical gait patterns .... Yes ☐ No ☐
   - (b) surgery that altered your gait pattern .... Yes ☐ No ☐
   - (c) Problems with bones or joints .... Yes ☐ No ☐
   - (d) Disturbance of balance/coordination .... Yes ☐ No ☐
   - (e) Numbness in hands or feet .... Yes ☐ No ☐
   - (f) Disturbance of vision .... Yes ☐ No ☐
   - (g) Ear / hearing problems .... Yes ☐ No ☐
   - (h) Allergy to plasters or sticking tape .... Yes ☐ No ☐
   - (i) Convulsions/epilepsy .... Yes ☐ No ☐
   - (j) Heart, circulation and/or respiratory problems .... Yes ☐ No ☐

4. **Do you** consider yourself to being in good health at present? Yes ☐ No ☐

If YES to any question (or "NO" to question 4), please describe briefly if you wish (e.g. to confirm problem was/is short-lived, insignificant or well controlled.)

....

....

....

5. Please tell us about any exercise you take

Type of exercise	How often each week	Approx. how long each time

Thank you for your cooperation! Loughborough University

A9

Loughborough University

Effect of fatigue on body posture, movements and gait whilst carrying military loads.

PARTICIPANT INFORMATION SHEET

The purpose of this study is to look at the effect backpack loads have on the posture and gait (walking patterns) of individuals and also the effect that carrying time has on these responses. It is hoped that results from the study will assist in design of future equipment.

During the study you will be asked to walk on a treadmill for a period of 2 hours. This will be at a pace of 6.4 km/h (4 miles/hour) and will involve carrying a military load of 20kg (consisting of webbing and a backpack). You will also wear military boots and carry rifle (replica in the case of non military participants).

In order for measurement to be made sensors will be placed over key body positions. These will be attached by double sided tape/soluble body glue and mostly placed on your skin or over the top of your clothing or shoes. These sensors emit an infrared signal to the infrared cameras that allow the position of the body to be monitored. Video recording of testing sessions will also take place. This is to allow further analysis and the identity of participants will be kept confidential at all times. Photographs may also be taken.

In order to ensure your safety an acclimatisation session on the treadmill will be given if you are an inexperienced user. Also, during all trials a heart rate monitor will be worn and should your heart rate exceed 80% of you predicted maximum the experiment will be stopped.

To ensure that there are no risks from load carriage you will be asked to complete a health screen questionnaire. If you have lower back pain, gait, joint or muscular discomfort or disease you will not be able to participate. Likewise you will not be able to participate if you suffer from diagnosed respiratory, circulatory or blood pressure difficulties or are receiving medication acutely or profilactically.

Any load carriage may include some discomfort at the interface between the pack and the body, so there is the possibility of discomfort. It should not be of any large magnitude but you are able to withdraw from the study at any time for any reason, and you will not be required to explain your reasoning. Please feel free to ask questions at any time. Thank you for your participation.

Renee Attwells