LABORATORY INVESTIGATION OF A LOAD CARRIAGE TASK OBSERVED IN FORESTRY

BY

SHEENA ELIZABETH FURNEY

THESIS

Submitted in fulfilment of the requirements for the Degree Master of Science

Department of Human Kinetics and Ergonomics

Rhodes University, 2007

Grahamstown, South Africa

ABSTRACT

The objective of the present study was to investigate and compare the human responses to two load carriage tasks performed with three different load masses and on three different gradients.

The task of carrying hydrogel in one hand was observed in a silviculture industry and crude physiological and perceptual responses were measured. This task was simulated in a laboratory setting together with a suggested intervention of backpack carriage. Eighteen conditions were established which consisted of the two modes of carriage and a combination of three load masses (9kg, 12kg and 15kg) and three gradients (5%, 10% and 15%). Twenty eight Rhodes University female students comprised the sample and the experimental procedures were conducted on a Quinton treadmill. Each participant was required to complete nine of the eighteen conditions which were each four minutes in duration. Postural changes were assessed using lateral and posterior digital images taken at the second and fourth minute and compression and shearing forces were estimated with the *ErgoImager*^{TM}. Physiological responses (heart rate, ventilation and metabolic responses) were measured continuously with the Quark b^2 and perceptual responses ('central' and 'local' RPE) were measured every minute during the experimentation and body discomfort was rated at the completion of each condition.

Overall responses revealed that hand carriage (146 $bt.min^{-1}$, 25.09 $mlO_2.kg^{-1}.min^{-1}$) was generally found to be more physiologically stressful than backpack carriage (130 $bt.min^{-1}$, 22.15 $mlO_2.kg^{-1}.min^{-1}$) independent of load mass and gradient. Physiological responses were higher (113 $bt.min^{-1}$ to 174 $bt.min^{-1}$) in responses to increasing gradient as opposed to increasing load mass (104 $bt.min^{-1}$ to 153 $bt.min^{-1}$) for both backpack and hand carriage. Categorisation using the guidelines of Sanders and McCormick (1993) allowed for classification of conditions, with respect to physiological responses, into 'moderate', 'heavy' and 'very heavy' stress. For almost all of the physiological responses the majority of conditions which were classified as 'moderate' were backpack carriage conditions and the conditions classified as 'very heavy' were mostly hand carriage conditions. In terms of postural responses hand carriage resulted in more strain and greater compression and shearing forces on the spine. In terms of the compression forces increasing gradient had a greater affect on backpack carriage (681N to 935 N) compared to hand carriage (570N to 793N). In contrast, increasing load mass had a larger affect on hand carriage postures and compression forces (751N to 935N) in comparison to backpack carriage (723N to 780N). Shearing forces were found to be worse in hand carriage conditions overall. Although participants generally underrated perceived exertion in relation to cardiorespiratory responses, these perceptions revealed that backpack carriage, with a mean 'central' RPE of 12 compared to 11 for hand carriage, was somewhat preferred to hand carriage and that increasing gradient was perceived to be marginally more straining than increasing load mass.

DEDICATION

I dedicate this thesis to my Lord and Saviour who has provided me with all that I have needed in order to get to this place and complete this work. As well as to my parents for their unconditional and constant love and support and for believing in me even when I did not.

ACKNOWLEDGEMENTS

To my supervisor Dr. Candice Christie for her constant effort and invaluable guidance throughout my academic career and particularly in this endeavour and for maturing me as a student.

To Professor Pat Scott for her constant guidance and tireless effort, throughout my time at Rhodes University, in always pushing me to do better and for being instrumental in the development of this project.

To Miriam Mattison for her willingness to help at any time and the support given throughout the project. In particular, for her assistance with the postural analyses.

To Andrew Todd for invaluable knowledge and help in the conceptualising of experimental procedures.

To my fellow Masters for their support and help, particularly to Andrew Elliott for his untiring assistance in the experimental procedures.

To all the willing and patient participants who made this project possible.

TABLE OF CONTENTS

PAGE

PAGE

PAGE

LIST OF TABLES

LIST OF FIGURES

FIGURE **PAGE**

CHAPTER ONE
INTRODUCTION

BACKGROUND TO THE STUDY

Manual Materials Handling (MMH) tasks predispose industrial workers to injuries which result in costs to both industries and the society as a whole (Ayoub and Mital, 1989; Melhorn, 1998). Physical stresses experienced by the operators executing these manual tasks are generally manifested as strains on the musculoskeletal and cardiovascular systems (Dempsey, 1998), and Marras (2000) maintains that in Industrially Advanced Countries (IACs) musculoskeletal disorders (MSDs) are considered a severe problem. If this is true in countries where arguably technology dominates work, in all probability the problem will be greatly intensified in developing countries like South Africa (SA) where the predominant form of work is manual labour and disproportionately more materials are moved manually on a daily basis (O'Neill, 2000). O'Neill (2005) later stated that in addition labour forces in developing countries are at a higher risk of suffering from MSDs because a vast majority of the working conditions are suboptimal (Scott, 1999; Christie, 2001). This situation is exacerbated by the fact that the majority of the manual labour force in SA is living in poverty with associated undernourishment and poor health status (Scott and Christie, 2004b).

The World Health Organisation (WHO) asserts that one of the principal solutions to the problems associated with manual labour in developing countries is the incorporation of ergonomic concepts and interventions (Urlings **et al.**, 1990). Ergonomics is a relatively new discipline within SA, a rapidly developing country, but is essential in creating a positive ethos throughout the industrial sector (Scott, 1993). Kumar **et al.** (1995) contend that it is prudent to design work that optimises productivity without jeopardising the workers' safety, which can be effectively done through the discipline of ergonomics. Although there is an abundance of manual work in SA, the country is also undergoing some rapid development. This is creating unique problems due to the incorporation of advanced technology within a country that can still be considered developing, and where most of the new technology is designed for different population groups and for more educated and skilled workers which are, as a generalisation, the minority in the South African manual labour force. Because ergonomics research has been limited in SA there is a need to investigate the compatibility between workers and their tasks (Wisner, 1985; Shahnavaz, 1987; Scott, 1993; Koradecka, 1997) in various industrial sectors within the country. The premise of the current research project was based on tasks observed within the silviculture sector of the forestry industry in SA.

Engelbrecht and Manyuchi (2001) contend that there is approximately 1.4 million hectares of available land in South Africa, of which about 1.2% is used for forest plantations. These plantations produce about 16 million tons of wood per year. The forestry industry is predominantly manual labour (Hagen **et al.**, 1998; Wästerlund **et al.**, 2004), and is further recognised as one of the most hazardous industries in which to be employed (Lilley **et al.**, 2002). The industry is sub-divided in to many sectors, and Parker and Kirk (1994) argue that planting, along with logging and pruning, are the highest physiological workload tasks in the forestry work sector. It is well accepted that the task of harvesting is considered particularly hazardous (Manyuchi **et al.**, 2003; Christie and Scott, 2005; Halkett, 2006) and as such this area is also where the most research has been conducted, particularly in SA. Despite these reports, Roberts (2003) contended that the most vigorous work in forestry is the silviculture operations, which although not as hazardous as harvesting, requires high levels of human effort. Silviculture is the agriculture of trees and involves many operations such as nursery work, planting, releasing, "thinning to waste", pruning and forest maintenance (Ashby and Parker, 2003). Silvicultural treatments are becoming increasingly important to cope with the future needs for wood and for obtaining good quality products (Apud, 1995).

Planting work, the task focused on in this research, is also generally carried out by female workers (Giguère **et al.**, 1993; Blombäck and Poschen, 2003) who are not as physically robust as males (Singleton, 1986; Kumar **et al.**, 1995). Females, in addition to meeting the physical demand of their work shifts, are also expected to carry out their household, family and community duties (Tucker and Sanjur, 1988; Lukmanji, 1992; Attanapola, 2004), all of which will exacerbate the strain placed on them and they are therefore highly likely to suffer from local muscular fatigue resulting in the prevalence of MSDs in general (Dahlberg **et al.**, 2004). Tree planting, which has been found to be the most physically taxing of all the silviculture operations (Giguère **et al.**, 1993; Apud, 1995; Sullman and Byers, 2000; Lyons, 2001), is divided up into many subtasks, all of which are particularly difficult and straining on the workers. One of these subtasks is a load carriage task (see Figure 1 below) requiring a worker to carry a 20L barrel, filled by the worker with up to 18kg of hydrogel, which decreases as it is used. Hydrogel is a water based thick liquid, which is poured into the 'pits' (holes for planting) before the seedlings are planted. The barrel is often carried for long distances because the drum where the hydrogel is mixed and kept remains in a central place while the worker moves away from it. These areas can be hundreds of square metres in size and are often on sloped terrain, with left-over debris or 'slash' lying on the ground, as seen in Figure 1. These barrels are carried in one hand, while the other arm is used for balance and stability as the worker clambers over branches and broken wood, often up steep gradients. This subtask of asymmetrical hand carriage and the physical responses it elicits was the primary focus of the current research project.

Figure 1: The subtask of carrying barrels of hydrogel for tree planting.

Load carriage over unpredictable terrain for long distances is an integral part of many tasks, varying from household and recreational activities to occupational tasks (Bhambani **et al.**, 1997; Stuempfle **et al.**, 2004). Despite this there has been limited research conducted on this task, particularly within the industrial sector (Laurensen **et al.**, 2000). In the USA only 15.7% of research was conducted on carrying as compared to 39.9% for lifting tasks, and yet carrying is regularly performed in many industries due to the need for faster distribution of products (Padula and Coury, 2003). The research that has been conducted on load carriage has focused mainly on the use of backpacks in carrying loads (Gordon **et al.**, 1983; Legg **et al.**, 1992; Sagiv **et al.**, 1994) while very limited research has investigated carrying loads in one hand.

One of the primary factors affecting load carriage is the method of carriage, which affects the posture adopted by the individual (Patla, 1980), places strain on the musculoskeletal system and causes stress to the physiological systems of the body (Knapik **et al.**, 2004). The closer the load is carried to the trunk of the body, the less straining on the body (Charteris **et al.**, 1989; Soule **et al.,** 1978; Martin and Nelson, 1986; Haisman, 1988; Knapik **et al.**, 2004). The factor of load mass is a contentious one and thus an optimal mass for load carriage has not been determined, even after years of investigation by various researchers (Carre, 1908; Pierrynowski **et al.**, 1981; Laurensen **et al.**, 2000). It is, however, universally agreed that an increase in mass will cause an increased strain on the musculoskeletal system and a concomitant increase in physiological responses (Soule and Goldman, 1969; Winsman and Goldman, 1976; Soule **et al.** 1978; Keren **et al.**, 1981; Gordon **et al.**, 1983; Martin and Nelson, 1986; Christie and Scott, 2005). Another aggravating factor in load carriage is the gradient that a worker traverses while carrying loads as this affects the locomotor system and posture adopted (Vogt and Banzer, 1999) and further strains the physiological systems of the body (Laurensen **et al.**, 2000). The study of asymmetrical load carriage is therefore a complex issue depending on characteristics both intrinsic to the task and the environment as well as the capabilities of the worker. The research question addressed in this project therefore was to assess the postural, physiological and perceptual responses of females comparing asymmetrical and backpack load carriage. A secondary aspect of the study was to assess these same responses to changes in load mass and gradient, the overall objective being to make sound scientific suggestions to the industry in order to assist in minimising the risks placed on the workers.

STATEMENT OF THE PROBLEM

It is universally known that manual materials handling tasks, comprising of lifting and lowering, and more recently pushing, pulling and carrying form a large area of work in developing countries, and that these tasks are a risk factor for occupational injuries and disorders. The task of carrying has been less well researched than the others, particularly one-handed carrying. This is despite the fact that it is a task that is often observed in industry. The main problem addressed in this study was to compare the postural, physiological and perceptual responses to two methods of load carriage, one-hand carriage and backpack, with various load masses at a variety of gradients.

RESEARCH HYPOTHESIS

It is expected that load carriage with a backpack will be less straining for a worker than one-handed load carriage, independent of the load mass and gradient. It is anticipated that increases in load mass and increases in gradient will attenuate the spinal kinematics and the physiological and perceptual responses of the participants independent of the method of carriage.

STATISTICAL HYPOTHESES

1A. The null hypothesis proposed is that physiological responses remain unchanged with:

i) Different modes of carriage

$H_o: \mu_{PHYSIO(HC)} = \mu_{PHYSIO(BP)}$

$H_a: \mu_{PHYSIO(HC)} \neq \mu_{PHYSIO(BP)}$

ii) Increasing load mass

$H_o: \mu_{PHYSIO(9kg)} = \mu_{PHYSIO(12kg)} = \mu_{PHYSIO(15kg)}$

$H_a: \mu_{PHYSIO(9kg)} \neq \mu_{PHYSIO(12kg)} \neq \mu_{PHYSIO(15kg)}$

iii) Increasing gradient

$H_o: \mu_{PHYSIO(5\%)} = \mu_{PHYSIO(10\%)} = \mu_{PHYSIO(15\%)}$

$H_a: \mu_{PHYSIO(5\%)} \neq \mu_{PHYSIO(10\%)} \neq \mu_{PHYSIO(15\%)}$

1B. It is further hypothesised that the perceptual responses ('central' and 'local') remain unchanged with:

i) Different modes of carriage

$H_o: \mu_{RPE(HC)} = \mu_{RPE(BP)}$

H_a: $\mu_{RPE(HC)} \neq \mu_{RPE(BP)}$

ii) Increasing load mass

H_o: $\mu_{RPE(9kg)} = \mu_{RPE(12kg)} = \mu_{RPE(15kg)}$

H_a: $\mu_{RPE(9kg)} \neq \mu_{RPE(12kg)} \neq \mu_{RPE(15kg)}$

iii) Increasing gradient

H_o: $\mu_{RPE(5\%)} = \mu_{RPE(10\%)} = \mu_{RPE(15\%)}$

H_a: $\mu_{RPE(5\%)} \neq \mu_{RPE(10\%)} \neq \mu_{RPE(15\%)}$

2A. The second null hypothesis proposed is that the physiological responses will remain unchanged across conditions

i) H_o: $\mu_{C(A1)} = \mu_{C(A2)} = \mu_{C(B1)} = \mu_{C(B2)} = \ldots\ \mu_{C(I1)} = \mu_{C(I2)}$

H_a: $\mu_{C(A1)} \neq \mu_{C(A2)} \neq \mu_{C(B1)} \neq \mu_{C(B2)} \neq \ldots\ \mu_{C(I1)} \neq \mu_{C(I2)}$

ii) H_o: $\mu_{VO2(A1)} = \mu_{VO2(A2)} = \mu_{VO2(B1)} = \mu_{VO2(B2)} = \ldots\ \mu_{VO2(I1)} = \mu_{VO2(I2)}$

H_a: $\mu_{VO2(A1)} \neq \mu_{VO2(A2)} \neq \mu_{VO2(B1)} \neq \mu_{VO2(B2)} \neq \ldots\ \mu_{VO2(I1)} \neq \mu_{VO2(I2)}$

iii) H_o: $\mu_{EE(A1)} = \mu_{EE(A2)} = \mu_{EE(B1)} = \mu_{EE(B2)} = \ldots\ \mu_{EE(I1)} = \mu_{EE(I2)}$

H_a: $\mu_{EE(A1)} \neq \mu_{EE(A2)} \neq \mu_{EE(B1)} \neq \mu_{EE(B2)} \neq \ldots\ \mu_{EE(I1)} \neq \mu_{EE(I2)}$

2B. Perceptual responses ('central' and 'local') remain unchanged across conditions

H_o: $\mu_{RPE(A1)} = \mu_{RPE(A2)} = \mu_{RPE(B1)} = \mu_{RPE(B2)} = \ldots\ \mu_{RPE(I1)} = \mu_{RPE(I2)}$

H_a: $\mu_{RPE(A1)} \neq \mu_{RPE(A2)} \neq \mu_{RPE(B1)} \neq \mu_{RPE(B2)} \neq \ldots\ \mu_{RPE(I1)} \neq \mu_{RPE(I2)}$

* PHYSIO = PHYSIOLOGICAL RESPONSES
HC = HAND CARRIAGE
BP = BACKPACK
RPE = 'CENTRAL' AND 'LOCAL' RPE
C= CARDIOVASCULAR RESPONSES
VO_2 = OXYGEN CONSUMPTION
EE = ENERGY EXPENDITURE
A_1, A_2, B_1, B_2.....I_1, I_2 refers to the various combinations of mode, mass and gradient described on page 45

DELIMITATIONS

The experimentation phase of this study was delimited to the responses of 28 healthy, female Rhodes University students, all of whom were volunteers, within the stature range of 1640mm to 1750mm. The volunteers all reported having no musculoskeletal injuries. In order to establish the experimental phase a task within the sector of tree planting in a South African forestry company was observed. Basic physiological and perceptual responses were obtained during two work shifts on a sample of female workers. A subtask was then simulated in a laboratory setting where more in-depth analyses of the spinal kinematics, physiological and perceptual responses were measured. An appropriate intervention was also analysed using the same holistic approach. Two methods of load carriage (one-hand carriage and backpack load carriage) with varying masses and gradients were compared. This resulted in 18 combinations of the two modes of carrying with varying load masses (9kg, 12kg, 15kg) and gradients (5%, 10%, 15%). Each volunteer completed nine of the eighteen conditions. The independent variables were delimited to the three masses, which fell within the range of the mass observed in the field, and which were considered ethical for subjects to carry. The gradients were also delimited to degrees that were within the range observed in the field. Digital photographs were utilised to crudely analyse the spinal kinematics and to determine the likely stress placed on the musculature and joints of the body, specifically the back. The dependent variables were delimited to heart rate, breathing frequency, tidal volume, minute ventilation, oxygen consumption, carbon dioxide production, respiratory quotient and energy expenditure, which indicated the physiological strain experienced by the participants. Ratings of perceived exertion and body discomfort were selected to reflect the perceptual strain experienced by the volunteers. The volunteers were divided into two equal groups and each volunteer completed half of the 18 conditions. Every participant came in for three sessions; the first was an introductory session which included habituation and the measuring of anthropometric data. In this same session subjects completed three of the nine conditions. In the second session another three conditions were completed and during the last session the last three conditions were completed.

LIMITATIONS

An investigation that assesses individualised responses creates difficulty in controlling all impinging variables, due to the network causality of such experimentation. Although every effort was made to rigorously control all factors, the following variables were limiting to the research:

Due to time constraints, the sample was one of convenience. Volunteers were not randomly selected from a homogenous sample similar to that found in industry; they comprised a South African student sample, which is in all probability different to rural South African workers. Every effort was made to standardise the physical nature of the subjects.

Although strict guidelines and requests to not eat before experimentation were given, compliance could not be completely ensured. The same is true of physical activities that volunteers participated in before coming in for testing. Although the researcher requested they refrain from heavy training of any sort before experimentation, this could not be completely controlled.

Due to there being three separate sessions, sometimes up to two weeks apart, the results may have been affected by volunteers feeling different, physically and emotionally, in each session. Circadian rhythms were accounted for by ensuring that the participants came at the same time of day for each session, but having three sessions on different days may still have elicited different responses.

The experimental procedures were conducted in a laboratory setting as this allows for more rigorous control of variables. However, the results cannot be easily extrapolated into industrial situations due to factors which may not be accounted for in the laboratory. One specific factor is that of the experimentation being completed in the cold months of the year, whereas in industry the work is generally completed in the hot months, which adds to the difficulty of the extrapolation of the results into the field.

CHAPTER TWO
REVIEW OF RELATED LITERATURE

INTRODUCTION

The physically taxing nature of carrying loads within an industrial setting is well accepted as it is a form of manual effort which is known to increase the physical stresses placed on the human body (Knapik **et al.**, 1996). The key factors of load carriage which need to be considered include the mode or method of carriage, the mass of the load and the gradient to be transgressed, to name a few. During the task of tree planting in silviculture in South Africa, female workers are required to carry barrels of varying load masses unilaterally across a variety of terrains with fluctuating gradients. It is expected that the musculoskeletal and cardiovascular systems of these workers will be stressed, although within the South African work context the extent of this stress has not been assessed.

It is well known that carrying loads closer to the centre of the body is the most optimal method of carriage (Winsmann and Goldman, 1976). It is further acknowledged that carrying loads up steep gradients will aggravate physical responses (Laurensen **et al.,** 2000). Most well known is the fact that as the mass of the load carried increases so too do the responses of the human operator (Soule and Goldman, 1969; Soule **et al.** 1978; Keren **et al.**, 1981; Gordon **et al.**, 1983; Abe **et al.,** 2004). Despite this extensive research, it has not been translated to the forestry industry in South Africa (SA). The injury occurrence rate in tree planting is high in South Africa and many other countries (Robinson **et al.**, 1993; Sullman and Byers, 2000; Giguère **et al.,** 1993; Ashby and Parker, 2003) yet alternative methods of conducting the task have not been thoroughly researched. Thus despite the widespread research of different aspects of load carriage, little account has been taken of the actual requirements of the task of tree planting and the relationship between the confounding variables associated with the carrying of hydrogel in the field.

FORESTRY INDUSTRY

The forestry sector is a major trade industry, especially in South Africa, and is characterised by a combination of difficult natural and material conditions, which create risks for the safety and health of forestry workers. The terrain is generally rough and uneven, the climate harsh, the work physically demanding and the tools used are often dangerous (Manyuchi **et al.**, 2003; Bentley **et al.**, 2002). Forestry work also tends to have a low status, be poorly paid and has a higher accident frequency rate than most industrial sectors (Bentley **et al.**, 2002). Workers often live far from where they are working and thus have great distances to travel, often on foot, before even beginning their work shift (Trites **et al.**, 1993; Christie, 2002). Closely linked to these unsatisfactory conditions are poor productivity and poor sustainability. Although more mechanisation has been implemented into forestry work, the industry is still predominantly manual in nature (Giguère **et al.**, 1993; Hagen **et al.**, 1998; Wästerlund **et al.**, 2004). The most common complaints from workers in the forestry industry are musculoskeletal disorders (Davis **et al.**, 2000; Forsman **et al.**, 2002), as well as the exacerbation of cardiorespiratory complaints (Wästerlund **et al.**, 2004).

The health and safety of workers in forestry is a critical ethical matter and a major cost factor (Engelbrecht and Manyuchi, 2001). Thus safety is not only a matter of looking after the workforce, but it also makes economic sense as there are not only direct costs due to accidents and injuries, but there are also many indirect costs. Worker compensation claims are a specific direct cost to excessive task demands, but indirectly the workers' efficiency and productivity will be greatly affected. In 2001 in South Africa 1.4 million hectares of land were forestry plantations, with forestry and forest products making about R6.65 billion in exports (Engelbrecht and Manyuchi, 2001). Manyuchi **et al.** (2003) report that accident and injury reporting within forestry is not very sound or reliable and it is difficult to determine the extent of the problem in the forestry industry in South Africa. As it is a particularly hazardous industry internationally (Bentley **et al.**, 2002), it is likely that developing countries will be affected to a greater extent particularly because of low worker capacity. Thus with an industry of this magnitude, and its importance to the economy of the country, it is crucial that the workers are efficient and productive. An unsuitable workforce will be less proficient, resulting in more occupational injuries and accidents which negatively impact productivity, resulting in higher costs to the company and industry. It is also important as Robinson **et al.** (1993) contends that a stable workforce is required in the industry due to the operations being predominantly manual in nature and particularly taxing to the workers, who are mostly female. Ergonomics, which looks at the compatibility of the worker to their task and the environment, addresses these problems of poor productivity and worker health and safety and therefore could play a crucial role in effecting change and improvement in an industry where much still needs to be done.

In South Africa the main source of forestry work is commercial forestry, which comprises silviculture, harvesting and processing. All three of these sectors have varying degrees of physically taxing work. The primary sector, which has been the focus of recent research in South Africa, is harvesting (Scott and Christie, 2004a), which has been identified as an exceedingly dangerous type of work, not only in South Africa (Manyuchi **et al.**, 2003, Scott and Christie, 2004a) but universally (Halkett, 2006). In contrast there has been limited ergonomics research conducted on silviculture work (Slappendel **et al.**, 1993) particularly in the South African context. Although arguably silviculture is not considered as "heavy" as harvesting, most of the tasks necessitate a high level of muscular work and place high demands on workers (Apud, 1995).

Silviculture

The silviculture sector involves the agriculture of trees and includes operations of nursery work, planting, releasing, "thinning to waste", pruning and forest maintenance (Ashby and Parker, 2003). Giguère **et al.** (1993) reported tree planting as a seasonal activity depending on rainy and cool weather, and in Canada a season lasts approximately 30-90 days. In Chile, planting takes place in the winter months (Apud, 1995) while in other countries it takes place during summer (Hagen **et al.**, 1998). In South Africa, at the Mondi Forests where the present research was conducted, planting takes place from September to March, which are the warmer months and which are selected according to the fire and rainy seasons. Apud (1995) noted that in Chile planters usually work in a team of 10 to 15 workers, working in rows. In South Africa, and in particular in KwaZulu-Natal, where the field observation of this research took place, the planters work in teams of two or three.

Although not the case in South Africa, the preparation of sites in many other countries is often mechanised. Seedlings or bare-rooted larger plants are planted. In Canada, and other countries, the seedlings vary in height from 250mm to 500mm and can be bare-rooted or grown in containers (Giguère **et al.**, 1993). In South Africa the process of planting begins with a team of workers coming onto the site to prepare it by clearing away debris and 'slash'. Once the area is clear enough, which means that there is space for pits to be created (Figure 2), workers come and perforate the ground, creating pits, using a hoe and/or pick-axe (Apud, 1995; Sullman and Byers, 2000); the pit is required to be 25cm deep and 25cm wide. Planting, which follows this, in general requires several subtasks (Giguère **et al.**, 1993). The three primary subtasks are 1) the hoeing of the pit in order to open the ground up again, 2) the carrying and placing of hydrogel to keep the seedling roots moist, and 3) the actual placing and covering of the plant in the gel-filled pit (Figure 3). All these activities are particularly strenuous and taxing to the workers and require substantial effort.

Figure 2: An example of cleared sites where planting usually takes place.

The pit is made before by pitters and it is the job of the hoer to just remove any debris that has settled over, or in the pit. The carrier, the focus of this study, then carries the hydrogel in cut-off barrels to the pit and pours two cupfuls into the pit. Following this the planter removes a seedling from the box, protecting the roots, and inserts the plant into the cavity. The soil is then compacted around the seedling to ensure that no air can get to the roots and dry them; this must be done carefully to ensure no damage is done to the roots (Apud, 1995). The next micro-site is usually approximately two long steps away, and the same process is repeated throughout the work shift for each seedling, or until a site is completed, when the team will move to the next site.

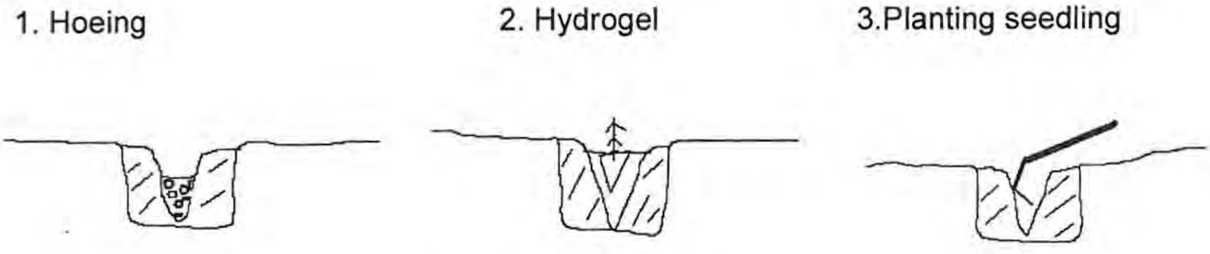


Figure 3: **The three subtasks of the tree planting process.**
(adapted from Mondi Forests Silviculture operating procedures).

The task of carrying requires workers to fill 20L barrels with hydrogel of up to approximately 18kg in mass and to carry this load across an area of land where planting is taking place. The barrel is filled at a main drum placed as centrally as possible in the area, which can be as large as a few square kilometres in area. The worker carries the hydrogel to the pits in one hand and then either bends forward or stands upright, according to personal preference, to pour the hydrogel in before moving onto the next pit. Although the load does decrease in mass as the hydrogel is poured into pits, it is still an extremely stressful task as the ground the worker walks on is covered with debris or 'slash', which can be seen in Figure 2. This makes the surface area difficult to traverse and slip, trip and fall accidents are likely to occur, particularly while they are carrying heavy barrels. The loose debris also makes it difficult for the workers to find the pit, which adds to the already stressful nature of the job. The gradient is often steep, resulting in additional stress being placed on the worker.

The Workers' Compensation Board of British Columbia (1996) stated that depending on the terrain, 100-200 trees can be planted an hour, or up to 1600 trees per day. The contractors in Mondi Forests stated that up to 1000 seedlings per shift can be the required rate, depending on the demand, although during observation it was found that a daily target of between 512-640 seedlings was planted at that particular time. About 15-17 pits can be filled by one barrel and this takes approximately three minutes. The carrier is therefore refilling the barrel with hydrogel approximately every five minutes depending on the size of the area. This means that the carrier would need to refill the barrel between 30 to 43 times per shift. This is high frequency work, which is exacerbated further by the hot and humid temperatures that are experienced in the forest areas of South Africa.

Injury occurrence rate

The Center for Human Factors and Ergonomics (COHFE) in New Zealand found that between 2000 and 2002 injury reports by silviculture workers increased by almost double, demonstrating that this is a growing concern in the silviculture industry and needs to be addressed (Ashby and Parker, 2003). Giguère **et al.** (1993) found that the most commonly reported occupational pains were reported in the hands, wrists and the lower extremities, while other researches report that another common complaint in silviculture workers is lower back pain (Hagen **et al.**, 1998). One sector of silviculture referred to as the "re-establishment" phase, incorporating the tasks of pitting and planting, has been identified in countries such as Canada and Columbia as the most physically strenuous of the silviculture tasks (Robinson **et al.**, 1993; Workers' Compensation Board of British Columbia, 1996; Sullman and Byers, 2000; Lyons, 2001).

This high prevalence of musculoskeletal health complaints in tree planting is probably due to the repetitive, physical nature of the work (Robinson **et al.**, 1993; Giguère **et al.,** 1993). Roberts (2003) stated that the high workload and duration of the planting day can be compared to ultra-endurance events, making tree planting a severely taxing task. Lyons (2001) stated that risk factors for developing cumulative trauma injuries in tree planting work are the high force required to dig holes, the high repetition of the work and the awkward postures assumed by the workers within a dynamic environment. All these factors are considered to be hazardous when found alone in any work situation, and the problem is intensified when they are all combined together as they are in tree planting. It has been found that in British Columbia the first and last two weeks of the planting season resulted in the most injuries (Lyons, 2001); the first two weeks due to improper conditioning of the individuals and the last two because of "burn out", a phenomenon also reported by Trites **et al.** (1993), demonstrating the need for increased research and recommendations on how to reduce the stressful nature of the work, particularly during vulnerable periods.

Manual tree planting is an extremely important task as the quality of the planters work will affect the growth of the tree over the next 20 to 30 years and the tree's eventual economic return (Sullman and Byers, 2000). At the same time an increasingly greater demand for wood is occurring, therefore the quantity of planting is increasing and consequently the amount of time spent on the job is extended (Byers and Adams, 1995). Thus workers are required to work efficiently and quickly in order to ensure quality as well as quantity. This balance is difficult to achieve and is likely to place additional strain on the workers.

As ergonomics becomes more recognised in South Africa, it is important to start bringing the basic concepts into different industries in order to aid in improving working conditions, enhancing worker well-being and ensuring better quality of work, all of which would benefit the silviculture sector specifically and the forestry industry in general. Lyons (2001) reported to the Summit Reforestation and Forest Management Company in British Columbia that ergonomic concepts are needed in order to better prepare the planters for the season and to decrease the injury rate during and after the season. This study used the tasks observed in a silviculture plantation to establish a laboratory experiment based on the problem of load carriage which is the predominant task of the hydrogel carriers.

CARRYING OF HYDROGEL

Physical workloads

Components of the physical workload of planting include the static effort and monotypicity of operational movements, along with the more dynamic physical effort (Giefing **et al.**, 2003). In the task addressed in this study there is a substantial amount of walking in the compartments over rough terrain, as well as more body part-specific work such as carrying and holding the barrels and placing the gel in the pits. The method these workers use to carry the hydrogel is one-handed load carriage, with the mass of the barrel varying regularly due to it emptying and then being refilled. Therefore, these workers will not only feel the strain of local muscle fatigue but also elevated physiological responses.

Posture

The importance of working posture has been recognized since at least the 18th century, when Ramazzini (1713) described the harmful consequences for workers experiencing 'irregular motions' and 'unnatural postures of the body'. Researchers have since found that musculoskeletal symptoms and cardiorespiratory effects may be experienced by operators performing tasks in postures which are largely static and held for prolonged periods of time or are awkward in nature (van Wely, 1970; Westgaard and Åaras, 1984; Sanders and McCormick, 1992, Keyserling, 2000; Gallagher, 2005). Unfortunately a clear definition of posture in the discipline of ergonomics has not been determined. This is largely because anatomists, biomechanists and engineers each utilise their own definition (Haslegrave, 1994). For the purpose of this research, posture was defined as the configuration of the body's head, trunk and limbs in space, which is the configuration adopted by the skeletal framework throughout the execution of the task, from initiation to completion. This definition was chosen because it is necessary to define posture according to the techniques that will be used for the assessment of postural responses (Haslegrave, 1994), which in this study was the software package *ErgoImager*™, which although a very crude measure, provides some indication of postural concerns during task execution.

Gallagher (2005) contends that although the human body is remarkably adaptable, it cannot perform equally well under all conditions. The performance and strength of a worker can be severely affected by the posture they adopt to perform a task (Haslegrave **et al.**, 1997). Limitations in performance are noted when workers have to adopt unusual or restricted work postures (Gallagher, 2005), and Wilson and Corlett (1995) proposed that trunk bending, such as that observed when filling the pits with hydrogel, is one of the postures that can be considered hazardous even without a high external force. Silviculture tasks such as tree planting create risks of developing cumulative trauma disorders (CTDs) due to awkward working postures (Lyons, 2001). Manual forestry workers, including those in silviculture, have a high susceptibility to lower back, neck and shoulder disorders (Hagen **et al.**, 1998), as well as wrist, hand and lower extremity occupational pains (Giguère **et al.**, 1993) due to postures adopted.

Although in the area observed in this study the carrying of hydrogel is done with one hand (asymmetrical), there are various other methods of load carriage used in various occupations and recreational activities worldwide. These include carrying in two hands (symmetrically), on the back or chest, waist, arms, or on the head (Legg, 1985). Studies have found that limitations encountered in load carrying are mostly due to the poor positioning of the load rather than from the mass of load *per se* (Soule **et al.**, 1978; Martin and Nelson, 1986; Haisman, 1988). Research findings have shown that locating the load centre of mass as close as possible to the body centre of mass tends to keep the body in an upright position and results in the lowest energy cost (Knapik **et al.**, 2004). These authors also report that loads carried by other parts of the body also result in poor postures and musculoskeletal strain. However, most authors have reported that load carriage by hand is the most inefficient and physically straining method (Viry **et al.**, 1999; Chung **et al.**, 2005) and that carrying on the head or close to the body is the most efficient (Soule **et al.**, 1978; Martin and Nelson, 1986; Haisman, 1988; Charteris **et al.**, 1989). As it was not viable to examine all methods of load carriage, the current research project compared responses to one hand carrying with backpack carriage in order to demonstrate to industry which method was more appropriate and confirming the findings of other studies (Winsmann and Goldman, 1976; Laurensen **et al.**, 2000). However, another aim was to try and mimic other aspects of the task, as observed in industry, in order to make tangible recommendations to management based on actual task requirements and as such, load mass and gradients were also manipulated.

Unilateral carrying causes lateral bending of the trunk in order to try counteract the asymmetric placement of a load and this has been suggested to be a major risk factor for a number of lower back disorders (Marras and Granata, 1997). Recent research has found that by carrying a load unilaterally, the side flexion of the trunk (in the opposite direction to the load) significantly increases compared to walking upright and that this lateral deviation occurred only in the lumbar region of the spine (Fowler **et al.**, 2006). This is the main region for commonly found lower back disorders in industry (Marras, 2000). DeVita **et al.** (1992) found that carrying asymmetrically on the shoulder also caused increased forces on the lower back, hips and knees. It has been found that load carriage in the hand requires the load to be supported primarily by the upper extremities (Bhambhani **et al.**, 1997), which contract statically to sustain the load, and sometimes a portion of the load is even supported by the front of the body (Deeb **et al.**, 1985; Drury and Pizatella, 1983). This places great strain on the upper extremities which are not as robust as the lower extremities or trunk, which is where the load would be supported in backpack carrying.

Symmetrical carriage can take on many forms such as various types of backpacks, front packs and double packs. Legg and Mahanty (1985) found no significant differences in cardiorespiratory measurements when loads were carried using a double pack, a trunk jacket, a backpack without frame, backpack with frame, or backpack with a waist belt. It appears that where the pack is carried on the trunk is not the issue, as long as it is close to the body. In contrast, Knapik **et al.** (1996) found that a double pack (placed on the back and trunk) was the best method for load carriage. However, they did state that the backpack, as opposed to a double pack, creates greater versatility in most situations and this was the intervention proposed in this study.

Although it has been found that a backpack is a better method than one-handed carrying, it is also not without its risks. For example, *erector spinae* tension measured by electromyography activity decreases when a load is carried on the back while the activity of the *rectus abdominis* increases (Motmans **et al.**, 2006). This activity of the *rectus abdominus* is likely due to the forward flexion of the trunk when walking with a backpack (Fowler **et al.**, 2006). With backpack carrying it has also been found that there is an increased spinal curvature in the thoracic to lumbar region as duration of load carriage increases, creating a poor posture (Orloff and Rapp, 2004). Furthermore LaFiandra and Harman (2004) found that a backpack exerts consistent force on the lower back, although these researchers also determined that only 30% of the force from the backpack was carried on the lower back and that 70% was held on the upper back, which would aid in decreasing the risk of low-back pain. The consequences of a forward lean and increased activity of the *rectus abdominis* muscles (Pascoe **et al.**, 1997; Filiare **et al.**, 2001) and increased spinal curvature and forces upon the lower back, shows the need for caution when implementing any intervention. The posture of workers is known to result in muscular discomfort (Corlett, 1981) as well as influence energy requirements (Wilson and Corlett, 1995).

The mass of the loads in hydrogel carrying varies considerably throughout the work shift, but can be as little as 1kg when the barrel is empty, to approximately 18kg when the barrel is full. Meyers **et al.** (2000) found that carrying heavy loads is ranked as a high risk task with high intervention priority. It has been shown that as the mass of the load carried increases, gait patterns are altered, resulting in increased musculoskeletal discomfort (Gordon **et al.**, 1983; Martin and Nelson, 1986; Epstein **et al.**, 1988). Furthermore, with one-hand carrying, the degree of lateral bending will increase as load mass increases, placing more stress on the musculoskeletal system (Fowler **et al.**, 2006).

In addition to changes in posture with different load masses, gradient is seen to alter overall body postures (Patla, 1980). Vogt and Banzer (1999) found that walking on sloping ground requires specific adaptation of the locomotor system, such as stride time and cadence, which in turn will have an effect on the musculoskeletal system of the body. When walking uphill, while carrying a load on the back, individuals will lean forward (Fowler **et al.**, 2006) because as they do this they are able to lower the centre of mass of the body and thereby stabilise themselves as well as distribute the weight of the load around different parts of the body so that the strain is not felt in one area particularly. These postural changes may aid the carrier in the short term although it is likely that other body parts will then start taking more of the strain.

Physiological responses

Table I: Grade of physical work based on energy expenditure levels.
(Adapted from Sanders and McCormick: 1993. p 241)

Grade of work	Energy expenditure (kcal.min^{-1})	Heart rate (bt.min^{-1})	Oxygen consumption (L.min^{-1})
Rest	1.5	60 – 70	0.3
Very light work	1.6 – 2.5	65 – 75	0.3 – 0.5
Light work	2.5 – 5.0	75 – 100	0.5 – 1.0
Moderate work	5.0 – 7.5	100 – 125 *	1.0 – 1.5
Heavy work	7.5 – 10.0	125 – 150 *	1.5 – 2.0
Very heavy work	10.0 – 12.5	150 – 180	2.0 – 2.5**
Unduly heavy work	>12.5	>180	>2.5**

* Findings from Kirk and Parker (1996), and Sullman and Byers (2000)
** Findings from Wilson and Corlett (1995)

Kirk **et al.** (1998) measured heart rates between 130 bt.min^{-1} and 150 bt.min^{-1} for planters in New Zealand and later research by Sullman and Byers (2000) also working in New Zealand, recorded similar mean working heart rates during tree planting of between 129.6 bts.min^{-1} and 153.1 bts.min^{-1} (depending on the terrain). These values place manual planting in the category of "very heavy" to "extremely heavy" work, as classified by Åstrand and Rodahl (1986), and "very heavy" according to Table I (Sanders and McCormick, 1993).

With respect to oxygen uptake, forestry workers required to work manually consume between 2.0 L.min^{-1} and 3.0 L.min^{-1} of oxygen during their work shift (Wilson and Corlett, 1995). This falls in the "very heavy" to "unduly heavy" work load categories put forward by Sanders and McCormick (1992), as seen in Table I. With specific reference to tree planters, Apud (1983) found that the range found for oxygen consumption responses was between 6.50 ml.kg^{-1}.min^{-1} and 11.40 ml.kg^{-1}.min^{-1}, depending on the terrain and tools used. Recommendations for a percentage VO_2max value that workers should be working at has ranged from 30% - 50% VO_2max for an 8-hour day (Grandjean, 1986; Åstrand and Rodahl, 1986; Saha **et al.**, 1979; Evans **et al.**, 1980; Kemper **et al.**, 1990). Roberts (2003) contended that tree-planters work at 40-65% of their VO_2max for six hours, and this may be done for 4-7 days a week, commonly five days on one day off (Lyons, 2001), which leads to cumulative stress both mentally and physically (Roberts, 2003). In terms of energy cost, Passmore and Durnin (1955) found that manual tree planting had a mean energy expenditure of 6.5 kcal.min^{-1}.

One of the main reasons for this increased energy cost may be due to the positioning of the load, which has a considerable impact on the energy required to execute the task. In order to reduce the energy cost of load carriage the load must to be placed as close to the centre of mass as possible (Carey and Crompton, 2005; Knapik **et al.**, 2004). It has also been found that arm work alters ventilatory responses as it can limit the movement of the chest wall, restricting expansion of the rib cage, and respiratory muscles, and thus breathing capacity may limit performance of tasks which require sustained, heavy use of the arms (Cerny and Ucer, 2004). An alteration in the breathing pattern can then alter the energy cost of breathing (McIlory **et al.**, 1954), creating a greater need for oxygen and thus increasing VO_2. Arm work can interfere with normal breathing mechanics, which will result in breathlessness and this may prevent normal exchange of oxygen and carbon dioxide, altering VO_2 and VCO_2 responses (Martin **et al.**, 1991). It has been found that carrying in the hands had an energy cost almost double that of a double pack, and was also substantially higher than head carriage and backpack carrying (Legg, 1985). Later, Legg **et al.** (1992) also found a significantly increased oxygen cost with asymmetrical shoulder carriage compared to that of backpack carrying. These findings were confirmed by Laurensen **et al.** (2000) who found that asymmetrical carriage resulted in a higher oxygen uptake and placed more stress on the body than symmetrical carriage. Recently Abe **et al.** (2004) found that there is energy saving in backpack carrying compared to hand carriage. Symmetrical carriage generally appears to be the more efficient and less straining method of carriage compared to asymmetrical carriage.

Pimental and Pandolf (1979) and Epstein **et al.** (1988) and later Motmans **et al.** (2006) reported that the mass of the load would have a significant effect on the energy cost and many researchers even suggested that there is a linear increase in energy cost and metabolic demand with increasing load mass while walking with loads (Soule and Goldman, 1969; Soule **et al.**, 1978; Keren **et al.**, 1981; Gordon **et al.**, 1983; Duggan and Haisman, 1992; Legg **et al.**, 1992; Christie and Scott, 2005). Abe **et al.** (2004) found that backpacks of between 15kg and 18kg did not allow for a physiological 'steady-state' to develop when walking at faster speeds. In contrast, Laurensen **et al.** (2000) found that there was not much difference in metabolic rate between a 10kg load and a 20kg load although again, these loads were carried on the back. It is likely that these responses will be exacerbated when transferred to one hand.

Although there has been some debate regarding the optimal load to be carried (Carre, 1908; Renbourne, 1954; Pierrynowski **et al.**, 1981; Laurensen **et al.**, 2000), there is no universal recommendation due to the widely varying circumstances which might apply to different load carriage situations (Haisman, 1988). Shoenfeld **et al.** (1977) recommended that the mass of a backpack for a male in good physical condition should not be more than 25kg while others have also given absolute load mass recommendations of 30kg (Soule **et al.**, 1978) and up to 40kg (Pierrynowski **et al.**, 1981). However, these authors did admit that further factors need to be considered when addressing load mass. In recent research less focus has been given to determining what a maximal load mass would be, as researchers have determined that an absolute mass to be carried cannot be accurately established. Others have argued that load mass should be made relative to body mass (Maloiy **et al.**, 1986; Charteris **et al.**, 1989; Gordon **et al.**, 1983). Maloiy **et al.** (1986) demonstrated what was referred to as a 'metabolic free ride' for loads up to 20% of body mass. This meant that increasing load up to 20% of body mass resulted in no significant increase in energy cost as opposed to unloaded walking. This was supported by Charteris **et al.** (1989), but they extended the 'free ride hypothesis' to loads of up to 30% body mass. However, the latter study argued that this was mostly applicable to head loading.

A further factor which causes an increase in energy expenditure is that of gradient (Pimental and Pandolf, 1979; Sagiv **et al.**, 2000) or the terrain the workers transgress. The terrains of silviculture operations vary substantially depending on the area and can be flat or extremely steep. A common feature, however, is the large amount of debris which needs to be negotiated by the worker. Increasing gradient while carrying a backpack increases oxygen uptake independent of the mass carried (Laurensen **et al.**, 2000; Sagiv **et al.**, 2000). In fact, Laurensen **et al.** (2000) found that metabolic cost almost doubled when walking uphill compared to horizontal walking regardless of whether the load was carried asymmetrically or symmetrically. Gordon **et al.** (1983) had similar findings but added that ratings of perceived exertion increase with increasing gradient. Todd (2002) concluded that gradient was the major determining factor in increasing physiological responses during backpack carriage. Martin and Nelson (1986) found that the increase in oxygen uptake with the change in gradient may be due to the change in the position of the load with backpack load carriage; when walking on level ground the load is carried centrally and the hips and legs take most of the load, but as the gradient increases and the body fatigues so the locomotion biomechanics are altered, which further affects the cardio-respiratory system.

Additional load carriage considerations

The factors of load carriage identified as affecting the risk of developing musculoskeletal injuries and disorders, particularly low-back pain (Orloff and Rapp, 2004), include mode of carriage or position of load, mass of load, terrain or ground walked on, length of time carrying and speed of locomotion while carrying (Gordon **et al.**, 1983; Legg, 1985; Patton **et al.**, 1991; Knapik **et al.**, 1996; Bhambhani **et al.**, 1997; Motmans **et al.**, 2006). The main problems addressed in this study were the mode of carriage, mass carried and the gradient.

In terms of walking speed, energy expenditure is highest at slow and faster walking speeds (Cathcart **et al.**, 1920; Bunc and Dhoula, 1997), with an optimal walking speed occurring at approximately 4 km.h^{-1} (Bunc and Dhoula, 1997). However, this is the case for unloaded, level walking and does not consider external loads and varying gradients. When a load is added, individuals naturally reduce their walking speed to compensate for the increased effort required (Hughes and Goldman, 1970; Knapik **et al.,** 1993). Generally, however, it has been found that speed has a far greater impact on energy cost than load mass (Soule **et al.**, 1978). For the purposes of this study, a fixed walking pace (3 km.h^{-1}) was selected based on field observations and assessments, as well as because of the fact that speed impacts physiological responses more so than load and the variables manipulated were method of carriage, load mass and gradient. Pilot studies confirmed that this speed had very little impact on physiological responses with unloaded walking at different gradients.

As this study focused specifically on varying combinations of method of carriage, load mass and gradients, an understanding of the interactive effect is important. For example, research done by Christie (2001) found that the combination of walking speed and load mass was important in determining the overall physiological load while subsequent findings found that the combination of speed, load and gradient was important (Todd, 2002). Todd (2002) found that of the three factors (speed of walking, mass of the load and gradient) gradient had the greatest impact on energy expenditure. These findings are supported by several authors (Patton **et al.**, 1991; Knapik **et al.**, 2004).

A further important factor is that load carrying tasks are often performed for extended periods yet research into load carriage has generally been focused on short-duration carrying (Patton **et al.**, 1991). The task of hydrogel carrying can take between 4 and 8 hours depending on the area, the motivation of the worker and their financial situation, in addition to many other work and personal factors.

Any form of exercise that is performed over a prolonged period of time will result in fatigue in both the musculoskeletal system (Kumar **et al.**, 2006) and the physiological systems (McArdle **et al.**, 2001), and can negatively impact on cognitive abilities (Grego **et al.**, 2005).

This will cause responses to be altered, which will be detrimental to performance and efficiency (Rosa, 1995). In the silviculture industry in British Columbia, Trites and colleagues (1993) found that excessive fatigue caused "burn out" to result in many of the workers, causing deletrious effects to producitivty. Together with fatigue, exercise over prolonged periods of time can cause dehydration if proper rehydration methods, and an awareness of the importance of hydration, are not employed (Wästerlund **et al.**, 2004). This was found to be a particular problem in the New Zealand forests, with dehydration causing elevations in heart rate responses, increasing the strain experienced by the workers (Kirk **et al.**, 1998).

Prolonged walking with a load causes many physiological changes and particularly increases in cardiovascular responses and oxygen consumption (VO_2) (Patton **et al.**, 1991). A gradual increase in VO_2 is seen during prolonged, submaximal, constant-rate exercise and this is known as VO_2 drift. This drift is said to be caused by increased body temperature, increased minute ventilation, reduced mechanical efficiency and a shift in substrate utilisation (Casaburi **et al.**, 1987; Kalis **et al.**, 1988). Patton **et al.** (1991) found that during prolonged load carriage the continuing increase in VO_2 was likely due to a reduction in mechanical efficiency with altered biomechanics of locomotion as the individual has to adjust to the mass of the pack. In contrast, Sagiv **et al.** (1994) found no significant increases in metabolic cost between 5 and 240 minutes of load carriage, although it can be noted that the participants of the current study were more well trained than in other studies, for example those subjects in the study done by Patton **et al**. (1991).

Cardiovascular drift is the gradual, time-dependent downward shift in many cardiovascular responses, the most notable being stroke volume and a concomitant increase in heart rate during prolonged activity (McArdle **et al.**, 2001). This is particularly true in prolonged activity performed in the heat, as over time there is progressive water loss through sweating and fluid shifting from plasma to tissues (McArdle **et al.**, 2001). During submaximal exercise in hot environments, adjustments will be made to blood flow to the skeletal muscles and skin blood flow (González-Alonso **et al.**, 1998). González-Alonso **et al.** (1998) found that blood flow to active skeletal muscles is significantly reduced with dehydration during prolonged exercise in the heat. They concluded from their investigation that the upward drift in whole body oxygen consumption during prolonged exercise, as seen in the study by Patton **et al.**, (1991), is normally confined to the exercising skeletal muscles.

OTHER TASK RELATED FACTORS

Repetitive work

Repetition refers to the cycle time and rate of repeating a particular task. A high repetition refers to a cycle time of 30 seconds or less, or when repeating sub-cycles occupying more than 50% of the fundamental cycle (Wilson and Corlett, 1995). Tasks are generally assessed by investigating the amplitude (load level), repetition and duration of the task (Juul-Kristensen **et al.**, 1997), as these are three factors that significantly influence the work load. NIOSH (1997) stated that, although work-related musculoskeletal disorders have a multifaceted genesis some epidemiological evidence suggests that repetition and force trigger these disorders (Coury **et al.**, 2000). Snook **et al.** (1999) contend that cumulative trauma disorders (CTD) are a problem in the upper extremities of workers who perform repetitive tasks, and Coury **et al.** (2002) cautioned that high repetition movements are closely associated with musculoskeletal disorders (MSDs). It has also been demonstrated by Hansson **et al.** (2000) that repetitive movements in the hands and wrists can also lead to a higher prevalence of disorders in workers' necks and shoulders, as well as their hands and wrists.

Although there are subtasks in tree planting such as moving between work-sites, there is still a great deal of repetition. The carrier is repeatedly bending down and standing up and bending down again in order to pour the hydrogel into the pits, and even where it is possible to pour the gel from a standing position, there is the continual wrist movement of filling the cup with gel and tipping it out. There is brief relief from that aspect of the job when the workers walk between each planting area. However, during this subtask they still have to carry heavy barrels to different sites, resulting in other strains being placed on the body. However, it is important to acknowledge that this task diversity is preferable to just executing one single task for extended periods. It has also been established that females who do the tree planting in South Africa experience greater risk of developing MSDs when performing repetitive tasks (Hagberg and Wegman, 1987). Coury **et al.** (2002) demonstrated that although gender may not be a primary factor affecting the chance of developing MSDs, it is a secondary factor that influences the symptoms.

Repetition increases the intensity and is likely to exacerbate the physical strain placed on the worker. Repetition of a task may also be mentally draining and cause the worker to become bored and dissatisfied with their work (Kroemer and Grandjean, 1997). Kroemer and Grandjean (1997) contend that boredom and dissatisfaction have been shown to decrease the efficiency of workers, which in turn will lower productivity. According to Petersson **et al.** (2000), the easiest and most commonly used method for determining repetitiveness of a task is observation and self-rating. These methods were utilised in this study in order to determine how frequently the workers were in a specific posture during the day, and how often they had a break from the basic stooped posture.

Piece-rate payment / working to task

Silviculture workers in New Zealand, British Columbia and South Africa get paid through a piece-rate system (Lilley **et al.**, 2002, Trites **et al.**, 1993) and in fact Trites **et al.** (1993) state that it is the favoured payment practice among tree-planting contractors worldwide. Piece-rate wage system refers to workers being paid per tree planted as opposed to a set wage. Due to this system of payment, the workers are less likely to take breaks throughout the day as they need to do as much work as possible in order to get paid enough to survive and support their families (Lilley **et al.**, 2002). In the Swedish forestry industry it was found that piece-rate work led to unsafe behaviours; this was due to the fact that workers tried to accomplish as much as possible, seldom adhered to safety requirements and often took short-cuts (Sundström-Frisk, 1984). In Sweden the piece-rate wage system was replaced with flat monthly salary systems or basic salary plus productivity bonuses, after which the occurrence of accidents was reduced. It is contended that "piece-work" encourages lower occupational health standards and employees are more likely to overwork and strain themselves physiologically and psychologically, which jeopardises their safety and health (Trites **et al.**, 1993).

If not enough rest is taken during the day then the workers will become fatigued and may become prone to errors (Slappendel **et al.**, 1993). This is because if a worker is being paid per tree planted they are less likely to take breaks, which workers view as "wasting" time in which they could be earning money. This means the workers will be fatigued, particularly at the end of the work shift, and this will accumulate over days, months maybe even years and the ultimate outcome is that the workers health will suffer and the productivity will be low.

Worker characteristics

South African workforce

South Africa's past political concerns have led to a large percentage of the population having limited education and thus the majority are semi-literate and semi-skilled. The outcome of this situation is that many people are forced to accept jobs requiring predominantly manual labour in often suboptimal conditions in order to earn enough money to take care of themselves and their families. But the country has a unique standing in that it is in a 'transitional period' (Scott, 1993) between a third world country and a first world country and therefore has unique problems and areas of concern, particularly with the manual labour force of the country.

Within South Africa the majority of the workforce are living in poverty with food shortages and thus many are malnourished (Asogwa, 1987; Shahnavaz, 1996; Scott, 1999; Christie, 2002; O'Neill, 2005), have poor housing and living conditions (Shahnavaz, 1987; Christie, 2002; O'Neill, 2005). They are paid low wages for the work they do, which for the majority of the population is most commonly heavy manual labour (Asogwa, 1987; Shahnavaz, 1996). Due to heavy manual work and a shortage of nutritious food, there is generally an imbalance between energy intake and energy expenditure in these workers (Christie, 2002). This imbalance along with other factors will cause workers to fatigue easily and decrease performance efficiency (Lambert **et al.**, 1994). Workers tend to have low motivation levels and increased physical and mental stress (Shahnavaz, 1987; Trites **et al.**, 1993). This then results in a high absenteeism and turnover rate and there is a greater occurrence of occupational diseases and accidents (Shahnavaz, 1987; O'Neill, 2000; Scott and Christie, 2004b). All these factors together contribute to a low productivity and exacerbation of chronic ill-health.

The workers, and the country, are paying an unacceptably high price in terms of suffering, sickness and loss of production due to labourers suffering from work-related injuries (Shahnavaz, 1987) caused and exacerbated by the factors mentioned above. Thus manual labour with a weakened workforce is costly in terms of human suffering, workers' compensation claims (Dempsey and Hashemi, 1999) and worker productivity. In order for the labourers to be productive they need to be healthy and the work needs to be safe, which will not only generate a productive, efficient and strong workforce but will also decrease the money that is spent on workers' compensation due to health and safety problems.

Females

In developing countries more women are participating in formal, non-traditional work (Attanapola, 2004) and there is concern for the dual role of women in these societies, as the family caretakers and income earners (Tucker and Sanjur, 1988). Lukmanji (1992) has reported that this problem is clearly on the increase. Women are performing not only 'paid work' but also 'unpaid work', which will contribute substantially to the pain and MSDs they suffer (Dahlberg **et al.**, 2004). Attanapola (2004) contends that women in fact have three roles to play in society, that of reproduction and care of the family, productive work (or paid work) and community work. This is placing a lot of stress physically and mentally on females in society and is leading to musculoskeletal disorders (Loewenson, 1999) and psychological or mental health problems (World Health Organisation, 1997). During work, Dahlberg **et al.** (2004) report that females take fewer breaks than males, perform fewer 'miscellaneous' tasks such as walking without burden, and instead of spending their 'free' time relaxing, they are usually performing household activities. All of this will contribute to the contention that MSDs are more common in females than in males, particularly in the neck and shoulder regions (de Zwart **et al.**, 2001), although this is difficult to measure as males and females tend to participate in different types of occupational and leisure activities.

Productive or formal labour is predominantly manual in nature which can be particularly taxing to females who may not, as a generalisation, be as robust and physically capable as men. Popkin (1989) found in the late 1980s, that females were contributing more than 40% of agriculture labour in 52 developing countries and more than 50% in 24 of them, which is in addition to their wife, mother, household and community duties. Females may have been shown to be less physically strong than males (Ayoub and Mital, 1989; Sanders and McCormick, 1993; Kumar **et al.**, 1995; Voorbij and Steenbekkers, 2001), and yet they are now expected to perform the same manual tasks as men without any investigation into their capabilities and limits. Attanapola (2004) reported that female workers are often verbally and physically harassed due to their gender by fellow workers and supervisors, who make them work through breaks and decline sick leaves. This will lead to detrimental effects on the workers' health and work efficiency.

Sujatha **et al.** (2000) contended that the energy cost of household and occupational activities of women in underdeveloped countries have not really been measured, therefore they attempted to do so, in order to place household and occupational activities in categories of energy expenditure. They found that household and childcare activities could be classified as 'moderate' to 'heavy work', with energy costs reaching 12kJ.min^{-1}. Silviculture is one of the main industries that employ females as a large portion of its work force (Giguère **et al.**, 1993; Blombäck and Poschen, 2003). Females have been seen to be the dominant tree planters and pruners, tasks which require primarily manual work, and although it may not be "heavy lifting", great strain is still placed on the planters (Robinson **et al.**, 1993; Trites **et al.**, 1993).

ERGONOMICS

It has long been established, even as far back as Bernardo Ramazzini's studies in the 1700s on the relationship between work and diseases, that a primary goal of ergonomics is to ensure that job demands do not exceed workers' capabilities, together with ensuring safety, improving productivity and operator satisfaction (Franco and Fusetti, 2004; Garg **et al.**, 1978; Asogwa, 1987; Helander 1997). Bao and Shahnavaz (1989) stated that ergonomics has great potential in improving working conditions and efficiency particularly in Industrially Developing Countries (IDCs). The multi-disciplinary nature of ergonomics allows it to play a unique role in the protection of people's health and in the prevention of work-related health hazards (Koradecka, 1997; Jafry and O'Neill, 2000).

Marras (2000) reported that despite extensive ergonomics research and input, MSDs are still prevalent in Industrially Advanced Countries (IACs). If this is the case in advanced countries it can only be estimated how much worse the situation is in developing countries, such as South Africa, where in spite of the advances in work automation in most industries, Manual Materials Handling (MMH) tasks are still seen as a major feature of a vast number of industrial operations (Chaffin and Andersson, 1991; Dempsey, 1998; Yoon and Smith, 1999, Scott, 1999). Mohan (1987) argues that this is due not only to less mechanisation but where machinery is evident, there is a lack of knowledge and skills required to effectively utilise this equipment. This highlights the need to investigate the compatibility between the workers and their tasks (Wisner, 1985; Shahnavaz, 1987; Koradecka, 1997; Scott and Shahnavaz, 1997). A large problem which O'Neill (2005) points out, is that many people argue that ergonomics is a luxury for "rich" countries and not for developing countries but, as Jafry and O'Neill (2000) indicate, ergonomic practices focus on the harmony between workers and their tasks in the working environment, which is a very effective method to raise productivity and promote individual well-being. Ergonomics would therefore arguably be more beneficial to IDCs, where there is a substantially greater imbalance between worker capabilities and manual task demands, than advanced countries. As a result, several papers have argued that the application of ergonomics in developing countries could bring about major benefits to productivity of the company and health of the workers, thereby improving the economy of the country (O'Neill 2000; 2005; Scott, 1993; 1999; 2001; Scott **et al.**, 2004). It is further contended that these ergonomics interventions need to be cost effective in developing countries (Scott, 1993).

Intervention

One approach to utilising ergonomics within any workplace in order to improve the working conditions is to implement an intervention strategy. As ergonomics is an 'applied science' it is vital that what is done in the laboratory not remain there but be taken out and applied to 'real' situations (Scott and Renz, 2006). Intervention strategies developed within the rigorous confines of the laboratory and taken out for use in the 'real world' allow for the gap between the theoretical knowledge and the practical use of this knowledge to be narrowed. Westgaard and Winkel (1997) defined an "Ergonomics Intervention research" as using field study ergonomics to develop interventions and thus make them applicable to workplaces.

It was identified by Scott and Renz (2006) that although ergonomics is good at identifying problems it falls short on solving problems. This is likely due to the lack of follow-up in industries once interventions have been implemented (Westgaard and Winkel, 1997). Thus there is a need for test-retest research to be performed where industries are assessed, interventions implemented and then re-assessed, allowing for the quantification of the benefits of these interventions. Of great importance within IDCs is also the need for 'low-cost/no-cost' interventions at a micro-level due to technical and economic constraints (Scott and Shahnavaz, 1997; Kogi, 1997; Zalk, 2001), which was the premise of the intervention proposed in this study.

Laboratory versus field research

The long-standing question of whether experimental results obtained in the laboratory are compatible to *in situ* measurements is still one of contention. Westgaard and Winkel (1997) state that the main reason ergonomics has been unable to decrease the huge amount of work-related musculoskeletal disorders is that there is a gap between theoretical knowledge and practical application, and this gap needs to be closed in order for ergonomic research to truly make an impact on the workforce.

The main shortcoming of field experiments is that there is less rigorous control compared to laboratory research (Oborne, 1995; Westgaard and Winkel, 1997), which is due to the multitude of extraneous variables that are out of the researcher's control. In the laboratory, experimental treatments, situations, variables assessed and even subjects can be controlled and variables of interest selected so as to be studied in isolation in order to obtain "controlled" results (Scott and Renz, 2006). However, Oborne (1995) pointed out that it is a better option to experiment with the workers themselves in order for results to be applicable to industry, although this is not always viable. Zalk (2001) emphasised the importance of gathering data in the field under actual working conditions in order to realistically quantify the workers' exposure to various stressors. The best option would be to combine both field and laboratory studies to ensure rigorous experimentation with real life value (Scott and Renz, 2006). These authors state that by drawing on knowledge that is gained from years of rigorous laboratory investigations it is possible to effect good quality research within the field of work. An alternative method is for the experimentation to be theoretically based and carried out exclusively within the laboratory. Meister (2000) states that in order for ergonomics to be successful it is of critical importance that research be related to application.

The present study could not be done completely in the field, but the task assessed was observed in the field and crude measurements were taken to aid in the simulation of the task in the laboratory. The aims of this research were to evaluate physical responses to the task found *in situ* and determine an appropriate intervention strategy or strategies. The idea was that the findings of the laboratory research could be taken back to the field and implemented to improve the working procedures and optimise the efficiency of the task.

ASSESSMENT APPROACHES

No approach used in assessing human ability should be utilised in isolation, thus when assessing any task involving human movement it is important to ensure that a holistic approach is taken (Charteris **et al.**, 1976; Jiang, 1986; Dempsey, 1998; Marras, 2000). This effectively means that the biomechanics, physiological and psychological aspects of the human operator performing the task need to be assessed in relation to each other. Although the present study will be taking a holistic approach in assessing carrying tasks by evaluating the spinal kinematics, physiological loads and perceptual responses to the task, the physiological responses were the primary focus and thus the spinal kinematics and perceptual responses will be crudely assessed.

Biomechanical approach

Designers of workplaces often have difficulty in trying to design for the human operator in the arrangement of workplaces (Feyen **et al.**, 2000). This is mainly due to not only having to account for the external forces working on the body, such as a mass being pushed, but also the internal forces that need to be accounted for, such as the forces placed on the musculoskeletal system due to the postures that are adopted. Together with this, manual jobs with a high degree of variability also create limitations to assessing risk, particularly to the lower back, therefore probabilistic representations of biomechanical stresses are required (Mirka **et al.**, 2000). This is done through theoretical models, which is an indirect method of quantifying the effects work activities have on the human body when it is not always possible to measure them directly. Bellan **et al.** (2000) state that this realistic simulation of human behaviour plays a primary role in modern industrial ergonomics. The models which have been developed have been predominantly biomechanical in nature (which will be used in this project to assess spinal kinematics), but physiological and psychophysical models have also been created.

Biomechanical models generally assess the theoretical forces placed on the human body and the acceptable amount of force the body can handle. Dempsey (1998) asserts that biomechanical models need to be utilised using either static or dynamic, 2 or 3 dimensional models, or combinations of these. These biomechanical models have been used to assess various working postures and activities; however, the lower back seems to have been the focus of most research studies. Chaffin (2005) contends that biomechanical models have become more sophisticated in recent years and are very useful in simulating manual tasks and aiding in understanding the stresses placed on individuals during the execution of certain tasks.

Over the last three decades, several low-back injury risk assessment tools have been developed to provide ergonomics practitioners with the ability to evaluate the relative risk posed by manual materials handling tasks (Mirka **et al**., 2000). There has been the Ovaka Working Posture Analysing System (OWAS) (1977), The *Work Practices Guide for Manual Lifting* from NIOSH in 1981, and then the revised NIOSH Lifting Equation (1997). Many researchers have used electrogoniometers to study trunk positions (Nordin **et al**., 1984), as well as the Lumbar Motion Monitor, which is arguably the most accurate of the tools and was first developed by Marras and colleagues in 1993.

In more recent years, due to the common use of computer-aided programmes, they are continually being improved upon and being further developed to help determine and quantify the forces placed on the body, particularly the lower back (Kuo and Chu, 2005). Examples of software packages include JET, CAD, *ErgoImager* ™ and the Three-dimensional Static Strength Prediction Program developed by practitioners at Ohio State University. Photos or videos can be downloaded onto a computer and then analysed using software programs such as *ErgoImager*™ in order to model the postures adopted and manually calculate the forces on the body. All of these models and computer programmes have been effective, although not completely accurate when used in isolation (Mirka **et al.**, 2000), therefore a combination of these models is recommended. As the focus of this study is on the physiological measures, only one model, *ErgoImager*™, was utilised for crude assessments.

Due to the numerous sources of error and inaccuracies that exist when performing biomechanical analyses of MMH tasks, the most valuable use of the biomechanical models is as a relative comparison of alternative tasks (Dempsey, 1998). This is most useful when determining whether an intervention is having a positive effect on the workers performance, thereby helping in determining whether an intervention strategy is in fact effective. In the present research study the postures and resulting forces on the body will be assessed for two types of load carriage.

Dempsey (1998) recommends that ideally, models, whether biomechanical, physiological or psychophysical, should be flexible enough to model various types of MMH tasks including combination tasks, and they should be developed and validated using a large industrial population. They should also be used together so that all factors of a task are investigated. For this study posture will be assessed using one of the biomechanical based computer-aided programmes, *ErgoImager*™, together with physiological and perceptual measures.

Physiological measures

The physiological approach to studying a task is focused on determining how to ensure that the physiological response to the task falls within acceptable limits. One method of assessing physiological responses is the use of computer assessment models, although Kuo and Chu (2005) argue that these need to be further developed. Regression models are also commonly used, specifically for predicting energy expenditure from heart rate measures. The physiological responses that are of most interest in assessing physical tasks are generally those related to whole body fatigue, and to a lesser degree local muscle fatigue (Dempsey, 1998). The criteria commonly assessed are those of oxygen consumption (VO_2) and energy expenditure during the task while other measures of importance are heart rate and respiratory responses, these responses give an indication of the strain experienced due to the stress of the task (Sanders and McCormick, 1993). The equipment used in this study to assess the physiological cost of the tasks was polar heart rate monitors and an online, metabolic system, the Quark b^2 (Rome, Italy). This equipment incorporated breath-by-breath analyses of numerous physiological responses, although for this study heart rate, ventilation, oxygen consumption, carbon dioxide production, respiratory quotient and energy expenditure were the responses considered.

Heart rate

Any increase in energy expenditure, such as with exercise, requires rapid adjustments in blood flow that affect the entire cardiovascular system (McArdle **et al.**, 2001), thus requiring the cardiac system to adjust to maintain homeostasis in the body. This is done by cardiac output rising in order to supply working tissues with increased amounts of oxygen and nutrients (Tortora and Grabowski, 2000). In order to increase cardiac output, heart rate and stroke volume will increase from the outset of physical activity, but whereas stroke volume stabilises at about 40% of an individual's maximum capacity for physical work, heart rate generally continues to increase in response to increasing exercisel intensity (Sanders and McCormick, 1993). Manual work of various types affects heart rate as the oxygen requirement to the muscles increases. Heart rate is an easy to measure physiological response but it can be greatly affected by a host of factors such as emotional stress, fatigue and temperature, particularly heat stress (Bales **et al.**, 2001; Strath **et al.**, 2001), which need to be taken into account.

Respiratory responses

Physical activity affects oxygen consumption and carbon dioxide production more than any other physiologic stress, and in turn increases ventilation in order to maintain gaseous exchange (McArdle **et al.**, 2001). During physical activity there is an immediate increase in ventilation proportional to the workload and afterwards there is a more progressive increase resulting in a 'steady-state' if the activity is submaximal in nature (McArdle **et al.**, 2001). Increases in V_E are achieved through increasing breathing frequency (F_B) or tidal volume (V_T) or a combination of both. During light to moderate exercise, when ventilation increases linearly with oxygen consumption and carbon dioxide production, ventilation increases are generally due to tidal volume increasing, whereas at higher intensities breathing frequency takes on a more important role (McArdle **et al.**, 2001).

Oxygen uptake (VO_2)

As the body increases its activity level more oxygen is required by the cardiac and skeletal muscles in order to perform the activity without causing detrimental effects to the body. The more intense the activity, the more oxygen is required, and as the duration of the task increases and the body begins to physically fatigue, increasing amounts of oxygen will be required to sustain the activity at the required intensity. Energy-releasing reactions in the body ultimately depend on oxygen use, and arm work specifically has been seen to affect VO_2 due to the effects it has on breathing responses (Martin **et al.**, 1991). Measuring oxygen consumption during physical activity can give researchers an indirect, yet highly accurate, estimate of energy expenditure (McArdle **et al.**, 2001). Oxygen consumption or uptake is the amount of oxygen consumed per unit time (Sanders and McCormick, 1992). Measuring oxygen consumption rates through indirect calorimetry as a basis for measuring energy expenditure is the most commonly utilised method (Passmore and Durnin, 1955) and was the method utilised in this study.

Oxygen consumption has been shown to rise exponentially at the start of activity and then level off at three to four minutes, where it will generally reach a 'steady-state' (McArdle **et al.**, 2001). This investigation collected responses for four minutes ascertaining from pilot studies that this was sufficient time for 'steady-state' to be reached. It must be noted that at the extreme conditions, with the heaviest mass and the steepest gradient, 'steady state' was not expected to occur as the strain placed on the physiological systems would be great, however the measurements would still be applicable for determining the demand placed on the body.

Respiratory Quotient (RQ)

Substrates such as carbohydrates, fats and proteins are stored in the body in various forms and these are utilised together in varying ratios as fuel for all types of physical work. Carbohydrates serve as the primary energy fuel for high intensity exercise, as the catabolism of glucose and glycogen is used to power the contractile elements of muscles (McArdle **et al.**, 2001). Fats supply different amounts of energy for physical activity depending on various factors including exercise intensity and duration; with lower intensity and longer duration activities, fats are used as a primary source of energy (McArdle **et al.**, 2001; Brooks and Mercier, 1994).

Respiratory quotient is the ratio of the amount of oxygen consumed to the amount of carbon dioxide produced, which gives an indication of the oxidation of fuels. This is a useful measure during rest and submaximal 'steady-state' activity as it provides an estimation of the ratio of fuels being burned (Goedecke **et al.**, 2000). The task done in the present study was a 'steady-state' exercise and thus RQ could be used to determine the ratio of carbohydrates to fats oxidized for energy and give an indication of exercise intensity. At high intensity exercise it can be seen that RQ measures often will be greater than 1.00 which indicates an individual is hyperventilating and thus RQ can no longer be used to determine substrate utilisation.

Energy expenditure

Metabolism is an energy-balancing act between catabolic reactions and anabolic reactions (Tortora and Grabowski, 2000). These metabolic reactions occur due to energy transfer in order to keep chemical reactions of the body in balance and allow for movement abilities of the body. Human energy expenditure is profoundly affected by physical activity (McArdle **et al.**, 2001), and specifically carrying of different loads has been found to increase energy expenditure to varying degrees (Passmore and Durnin, 1955; Pimental and Pandolf, 1979; Epstein **et al.**, 1988; Knapik **et al.**, 2004). It is an important measure as it is necessary in determining the intensity of a task. It can be determined indirectly by the measurement of oxygen consumption, which gives an accurate estimate of energy expenditure (McArdle **et al.**, 2001).

Psychological approach

Any physical task undertaken by an individual will not only affect their musculoskeletal and cardiorespiratory systems but will also be perceived differently depending on the demands of the activity (Borg, 1978). The psychosocial risk factors, which will affect the productivity and health of the worker, are said to be associated with the amount of mental concentration or demands, job responsibility, lack of diversity, job satisfaction and mental strain (Davis and

Marras, 2003). The assessment of these psychological factors usually takes the form of determining the perception of the worker to the amount of effort it takes to complete the task. Gamberale (1985) contended that subjective reactions to physical work have been found to correlate with the intensity and performance of activity, but it has not been considered as representing a basis for criteria in the assessment of manual handling tasks. This is due to subjective reactions being difficult to define and measure, as they can only be assessed indirectly through the use of self-reporting methods, which is why researchers have attempted to quantify subjective 'feelings'. It is imperative to find a valid means to measure mental responses because when assessing any type of activity involving a human, one can not avoid their subjective experience of a task.

Physiological and biomechanical factors will cause changes in perceptual ratings and the interaction of these influences is seen to be a complex one (Goslin and Rorke, 1986). A positive relationship has been found to exist between perceived exertion and workload, thus the more difficult a task, the more demanding the individual perceives that task. One method that has been developed to assess how individuals perceive their bodies to be working during tasks is referred to as the Rating of Perceived Exertion scale (RPE scale) developed by Borg in 1970 (see Appendix B). Noble (1982) stated that perceived exertion has important application in occupational settings when assessing man-machine interface and this is likely the reason this scale has been widely used to study perception of exertion during exercise in the laboratory, occupational and clinical settings (Noble **et al.**, 1983), and has also been used in some manual handling risk assessments (Straker **et al.**, 1997). Borg (1970) developed the scale from the curvilinear relationship demonstrated between the intensity of physical stimuli (measured by heart rate) and an individual's perception of the intensity. It has a range of 6-20 ratings, which were developed to correlate with heart rate; 6 correlates with 60 bt.min^{-1}, 8 to 80 bt.min^{-1} and so on, with 20 referring 200 bt.min^{-1}, which is generally a maximum heart rate.

Ekblom and Goldberg (1971) proposed a two-factor model building on the RPE scale which suggested when assessing perceived exertion there is a need to separate 'local' influences of strain in the muscles and joints, and 'central' influences involving the cardio-pulmonary system. This has been demonstrated many times since then,m with Ayoub (1992) reporting that the combined effect of biomechanical and physiological stress leads to the overall perception of exertion. There are two major physiological sensory factors that determine perceived exertion during physical work, that of the sensations perceived by the heart and lungs and the strain in the working muscles (Pandolf, 1978; Watt and Grove, 1993), both of which were assessed in this study.

Corlett and Bishop (1976) developed a Body Discomfort Scale (see Appendix B) as a means of quantifying muscular discomfort that is experienced due to work postures, and to express the intensity of the discomfort on a scale of 1-10, with 1 referring to very minimum intensity and 10 referring to maximum intensity. In this study the postural changes were mostly trunk flexion and lateral bending, which is likely to cause the individual to experience discomfort in their back, neck and perhaps their legs. Utilising this scale will aid in determining whether there are any areas of the body that may experience discomfort due to method of carriage, mass and gradient.

SUMMARY

Due to the high risk nature of asymmetrical carrying, particularly at the extremities of the body, one-handed carrying needs to be holistically assessed to determine ways to optimise the efficiency of carrying. There are many factors that will affect any task and it is the combination of these factors that determine the overall risk. This research therefore was a laboratory based study established from field observation, which focused specifically on the carrying of hydrogel of varying masses and on a variety of gradients.

CHAPTER THREE
METHODOLOGY

INTRODUCTION

Of the various manual operations, the task of carrying has been one of the least investigated (Laurensen **et al.**, 2000) and yet it is a task found in many industrial settings (Bhambhani and Maikala, 2000) as well as in many daily and recreational activities (Bhambhani **et al.**, 1997). Malhotra and Sen Gupta (1965) found that one hand carriage of a load is the most inefficient method of carrying, while a backpack with two straps was found to require much less energy in comparison. Although there is contention as to what exactly is the best mode of load carriage most researchers agree that asymmetrical carrying is the worst in terms of stress on the musculoskeletal and physiological systems (Malhotra and Sen Gupta, 1965; Winsmann and Goldman, 1976; Viry **et al.**, 1999; Laurensen **et al.**, 2000; Abe **et al.**, 2004).

It has been shown that the mode of carriage, the mass of the load carried, walking velocity, body mass, length of time carrying together with terrain factors such as gradient and surface have a direct effect on the energy cost of carrying loads (Soule **et al.**, 1978; Gordon **et al.**, 1983; Legg, 1985; Patton **et al.**, 1991; Knapik **et al.**, 1996; Bhambhani **et al.**, 1997; Motmans **et al.**, 2006). Specific to this investigation it has been demonstrated that the energy cost of walking increases when an external load is carried and that the magnitude of increase depends on the mass of the load (Borghols **et al.**, 1978; Patton **et al.**, 1991; Quesada **et al.**, 2000; Sagiv **et al.**, 2000) and the gradient of the terrain (Sagiv **et al.**, 2000). Therefore, these factors need to be considered when determining the optimum load carriage method and load mass for workers, in order to find a way to decrease risk of injury and accidents.

PILOT RESEARCH

Prior to the laboratory experimentation being conducted, field observation and several pre-pilot and pilot studies were completed in order to aid in the intended design of the procedures and ensure that all relevant factors were considered. The field observation aided in experimental design as it needed to replicate the actual working tasks as closely as possible. The pilot studies allowed for familiarisation with the equipment and identification of any problems that may occur, as well as eliciting clarification of the testing protocol.

Field observation

An industry in South Africa that was observed to require a substantial amount of manual carrying was the tree planting sector of the forestry industry. The main tasks encompassed in tree planting include spraying, hoeing, pitting, pouring hydrogel and placing the sapling (Figure 4). All tasks were observed *in situ* but only one task, carrying of the hydrogel (Figure 4D), was chosen to be simulated in the laboratory for further, more rigorous research to be conducted.

A. Spraying

B. Hoeing

C. Pitting

D. Carrying hydrogel

E. Placing sapling

Figure 4: The tasks of tree planting including A: Spraying, B: Hoeing, C: Pitting, D: Carrying hydrogel and E: Placing sapling.

The task of carrying and pouring hydrogel requires workers to fill the barrels with hydrogel from a primary drum where the gel is made, then carry it to the various planting sites walking over terrains covered in "slash" and debris (Figure 5), and often on steep slopes. These barrels can be as heavy as 18kg. Each pit requires two cups of hydrogel, and there are approximately 35 cups per full barrel, which equates to between fifteen and seventeen pits. A daily target of between 512 and 640 seedlings is generally set. Therefore at a minimum the carrier has to refill the barrel 30 times, and up to 43 times daily. It was observed that the carriers have to refill the barrels approximately every three to five minutes, and the carrying distance varied from 3m to 100m, depending on the location of the drum in relation to the planting area, necessitating a lot of walking up and down steep slopes with these heavy barrels.

Figure 5: Female workers observed carrying loads of up to 18kg on uneven terrain.

Field Analyses

Before any basic working responses were measured in the field, a make-shift laboratory was set-up in a room and covered cement veranda (Figure 6) where the workers gathered before being taken to the work areas. This was done at one of the worksites of a forestry industry in KwaZulu-Natal in South Africa. This area was set up for measurements of anthropometric variables, reference cardiovascular function and to obtain basic demographic information. Heart rate monitors were placed on a random sample of workers in order to measure heart frequency responses during the working day. Observation of the task was done in the field for three days, with the researcher and four helpers each observing a selection of the sample workers and recording in detail the requirements of the task and the techniques used by the workers to perform the tasks. These observations were then compiled to get an overall view of the tasks. Digital images were also taken to aid in the basic analysing of the tasks.

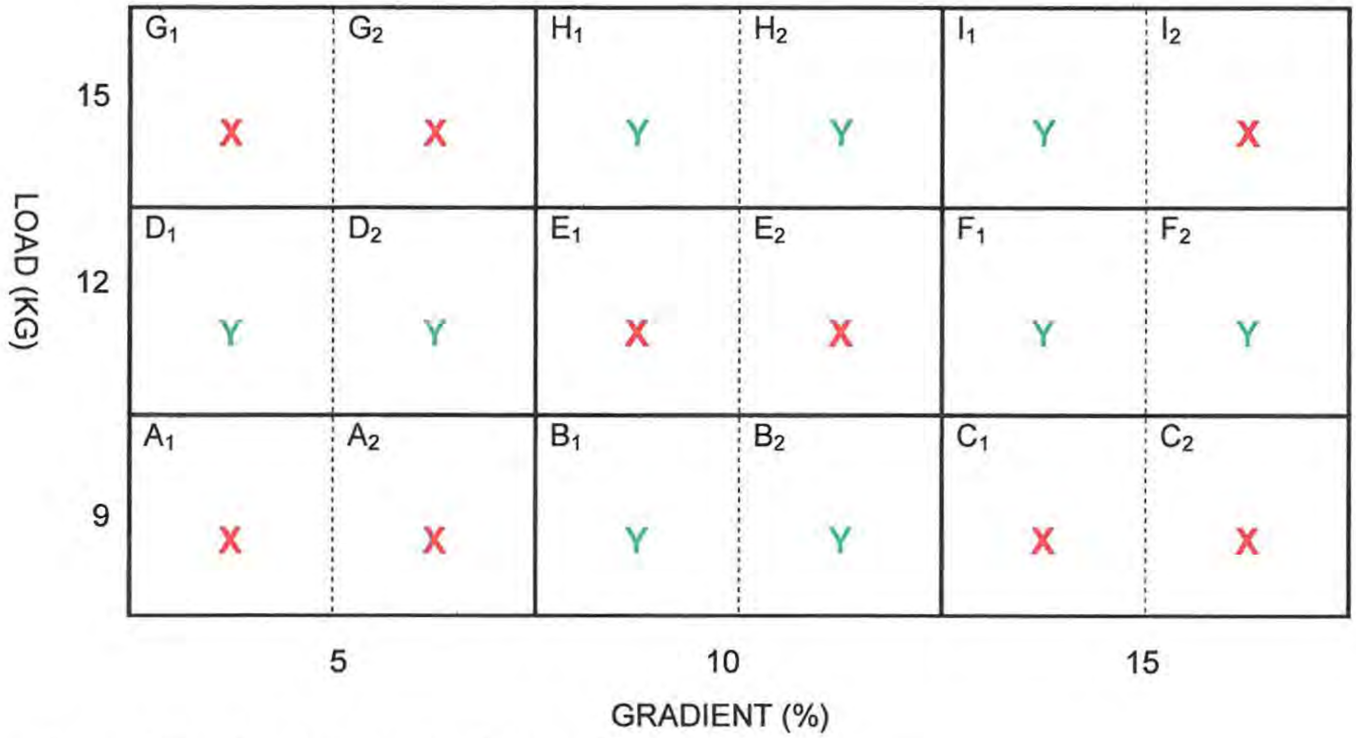
Figure 6: Make-shift laboratory set up *in situ.*

EXPERIMENTAL DESIGN

It has been extensively demonstrated that the position of the load being carried can greatly affect the physical responses of the carriers (Soule **et al.**, 1978; Martin and Nelson, 1986; Knapik **et al.**, 2004). Carrying asymmetrically as compared to carrying symmetrically increases muscle metabolic rate as well oxygen uptake (Laurensen **et al.**, 2000) and has been found to be the most inefficient method of carriage. Conversely, a backpack with two straps requires significantly less energy expenditure compared to one-handed carrying (Malhotra and Sen Gupta, 1965). Research has also found that load carriage by the extremities places the body at greater risk of suffering strain compared to carrying closer to the trunk and centre of mass (Malhotra and Sen Gupta, 1965; Winsmann and Goldman, 1976; Viry **et al.**, 1999; Knapik **et al.**, 2004). The observation of this one-handed load carriage task led to this investigation primarily focusing on the physical responses to unilateral versus backpack carrying, in order to determine whether the use of backpacks would reduce the risk of this task.

From field observation and the findings of Borghols **et al.** (1978), Patton **et al.** (1991), Quesada **et al.** (2000) and Sagiv **et al.** (2000), the mass and slope of ground appear to have a significant impact on postural and physiological responses of workers. Therefore in simulating the present task in the laboratory these factors were incorporated. A range of load masses that reflected what was observed in the field were used in pilot studies and three masses were chosen, which elicited responses within ethical boundaries and fell within the range observed *in situ*. The barrels carried generally begin at a mass of 18kg, and as the gel is poured out they reduce in mass until the barrel is refilled. Loads of 9kg, 12kg and 15kg were therefore used in the present study to investigate the change in responses as the drum emptied. Various gradients were also experimented with in order to determine which would maximise the responses, again taking into account ethical considerations and that they fell within gradients that planters are working on in the field. Taking into account all these considerations and conducting several pilot studies, the gradients of 5%, 10% and 15% were chosen. These three variables in different combinations were then divided into 18 conditions, presented in Figure 7.

Although walking speed can play a large role in postural, physiological and perceptual responses to load carriage, it was out of the scope of this research to assess its effect, thus a fixed walking speed was selected after observation in the field, research into the literature and pilot studies. It has been suggested that an optimal walking speed is 4 $km.h^{-1}$ with regard to energy expenditure (Cathcart **et al.**, 1920; Soule **et al.**, 1978; Bunc and Dhoula, 1997). Energy requirements have been found to increase with increasing speed of walking up to 4 $km.h^{-1}$ where energy cost appears to level out or even decrease, thus below the optimal speed of 4 $km.h^{-1}$ energy cost increases (Pimental and Pandolf, 1979; Bunc and Dhoula, 1997). Once speed begins increasing above 4 $km.h^{-1}$ energy cost increases concomitantly. When a heavy load is carried during walking, energy cost will increase (Soule **et al.**, 1978) and thus speed adjustments will need to be made. Following field observation and several pilot studies it was found that a walking speed of 3 $km.h^{-1}$ was the most appropriate walking speed for load carriage at these load masses and gradients, as it did not have a significant effect on responses and was comparable to the speeds observed in the field. Therefore a controlled walking speed of 3km.h^{-1} was used. Fatigue was not a focus in the present study, thus it was only necessary to consider responses up to a 'steady-state'. It has been demonstrated that four minutes is a sufficient period of time for physiological measures to level off or reach a 'steady-state' (McArdle **et al.**, 2001). In assessing the results of the physiological variables the measurements taken in the last two minutes of exercise were averaged and this data was then used for analysis. The first two minutes would reflect an increasing effort and it was only during the last two minutes that subjects reached 'steady state' and thus these are the measurements that would give information about the continual strain experienced by the participants. In this study 'steady state' was determined using heart rate measures as the primary indication, and gaseous exchange measures as secondary. The results of pilot studies for the present investigation concurred with this and determined that within four minutes physiological variables were levelling off and the subjects were not overly fatigued or unable to continue. It is acknowledged that at the extreme conditions 'steady state' would not be reached as significant stress would be placed on the physiological systems, however information can still be determined from this data.



LOAD (KG)						
15	G_1 X	G_2 X	H_1 Y	H_2 Y	I_1 Y	I_2 X
12	D_1 Y	D_2 Y	E_1 X	E_2 X	F_1 Y	F_2 Y
9	A_1 X	A_2 X	B_1 Y	B_2 Y	C_1 X	C_2 X
GRADIENT (%)	5		10		15	

Figure 7: The grid presenting the eighteen conditions.
*($_1$ – Symmetrical, $_2$ – Asymmetrical)

The grid developed to outline the 18 conditions to be assessed is seen in Figure 7. As it would be excessive to require each participant to complete all 18 conditions, two groups were compiled and are represented by X and Y in Figure 7. The conditions in each of the groups were roughly equivalent in strain. Each group comprised of different combinations of the three variables of interest; mode (hand carriage or backpack carriage), mass (9kg, 12kg, 15kg) and gradient (5%, 10%, 15%). The groups were set up and the 28 subjects were randomly assigned to the different conditions in each group. The nine subjects in group X completed conditions: A_1, A_2, C_1, C_2, E_1, E_2, G_1, G_2, I_2 and the nine subjects in group Y completed conditions B_1, B_2, D_1, D_2, F_1, F_2, H_1, H_2, I_1. The conditions with one $(_1)$ next to the letter were the backpack carriage conditions and those with two $(_2)$ next to the letter were hand carriage conditions. To facilitate rigorous experimentation only three subjects were tested in a session and each subject completed three conditions per session. Unrelated t-tests revealed that the individuals in the two groups were equally matched in age, stature, mass and body mass index (BMI).

ETHICAL CONSIDERATIONS

Informed consent

All volunteers were informed of the nature of the study through written and verbal explanation and provided written consent (refer to Appendix A).

Privacy of results

A simple data coding system was used to ensure the anonymity of the volunteers. The name taken at the start of the study was kept merely for record purposes and any data that was to be kept was utilised only for statistical purposes.

MEASUREMENTS AND EQUIPMENT PROTOCOL

Anthropometric parameters

The composition and anthropometry of an individual will have an effect on the responses measured during carrying tasks. For this reason the stature of the participants was delimited to 1650mm and above.

Stature – Harpenden Stadiometer

The Harpenden Stadiometer was used to measure stature (mm). Subjects removed their shoes, jewellery and any heavy clothing and stood with their head, gluteus and calcaneus in contact with the back column of the harpenden stadiometer. Their head faced forward aligned with the Harvard Anatomical Plane. Stature was then taken from the vertex in the mid-sagittal plane to the ground.

The subsequent measures of stature that were taken after each experimental condition were measured with a measuring tape attached securely to the surface of a wall. The same procedures as above were followed. The stature measures taken after each condition were used to obtain a crude measure of spinal shrinkage, particularly when the backpack was used. Due to compression on the vertebrae there is likelihood of nominal shrinkage in stature due to fluid loss from the intevertebral discs, this is especially probable when loads are carried on the shoulders and back as the force is placed on the spine. These shrinkages would have been temporary as the conditions were of short duration and thus would not have elicited chronic changes in stature. Measurements done at the second two sessions demonstrated that stature was within a 3mm range of the original stature measured.

Body Mass – Toledo® Scale

Mass was measured using the Toledo® electronic scale. Shoes were removed and subjects were requested to stand in the centre of the scale, relaxed with their heads up and facing forwards. Mass was measured to within 0.1kg for each participant.

Spinal kinematics

The effect of load carriage on postural changes and associated strain on the musculature of the body has long been established (Marras and Granata, 1997; Orloff and Rapp, 2004). A simple, effective method of assessing the movements of the spine and likely risk imposed on the body is the use of theoretical models, particularly computer-aided programmes, such as the *ErgoImager*™, which was utilised in the current study.

Digital images

Working postures were assessed using digital imagery. Four pictures were taken from the lateral and posterior sides of the body, two at each respectively, while the participants were performing the task in the laboratory setting. Two (one lateral and one posterior) were taken at two minutes and two just before four minutes. These digital pictures were utilised primarily to obtain a theoretical measure of kinetic responses that are associated with the postures that are adopted during the task. *ErgoImager*™, a software package based on biomechanical modelling, was used to assess the joint angles and the associated forces acting on the joints.

Physiological analyses

Load carriage while walking has been found to significantly increase energy cost (Passmore and Durnin, 1955; Legg and Mahanty, 1985; Patton **et al.**, 1991; Sagiv **et al.**, 2000). A valid and commonly used method for assessing physiological stresses to the body is indirect calorimetry, which was utilised in this study, along with the simple measurement of heart rate to give a measure of the response of the cardiovascular system to load carriage.

Polar heart rate monitors

The contention that heart rate bears a close relationship to energy expenditure has generally been accepted (Maas **et al**., 1989; McArdle **et al.**, 2001; Wareham **et al.**, 1997). However, it was solely cardiac strain that was the purpose of heart rate monitoring in the present investigation.

Cardiovascular responses to the various conditions were recorded using the Polar Accurex Plus™ (Polar Electro, Finland) heart rate monitors. The monitor has three components: the watch, electrode strap and a transmitter. The electrode strap was placed on the skin around mid-chest at the inferior border of the *pectoralis major* muscles, in line with the apex of the left ventricle situated slightly left of the mid-centre of the chest. The electrode picks up the electrical activity of the heart, which is stored as a measure of heart rate. Good contact between the transmitter and the skin is essential and can be achieved by moistening the conductive electrode straps with water or an electro-conducting gel. The heart monitor watch is a display unit allowing various functions to be programmed into it and also a data logger. The watch was kept close to the volunteer to ensure that it remained within the range of the transmitter, although the display is kept out of sight of the participants as to not affect their natural responses. The heart rate watches were programmed to record heart rate every five seconds and the heart rate was manually recorded from this display every minute during the task and again at completion.

A base-line reference heart rate was recorded prior to activity with the volunteer sitting quietly until a steady heart rate occurred. This reference heart rate was then used to conclude that the subject had recovered sufficiently after each task before participating in a subsequent condition.

Quark b^2 (Ergospirometer)

Measurement of energy expenditure during the task of load carriage was necessary to determine the intensity of the task. These assessments allowed for classification of the different conditions into different levels of stress, according to accepted guidelines and statistical significance and allowing for the comparison of the various combinations of variables.

The Quark b^2 is a metabolic online system that measures an individual's gaseous exchange breath-by-breath over a specific period of time. Each volunteer is required to wear a suitably sized face mask from which tubes lead to a unit containing oxygen and carbon dioxide analysers, as well as a sampling pump, barometric sensors and electronics. This unit is attached to a computer with a programme which displays the information. Heart rate, breathing frequency (F_B), tidal volume (V_T), minute ventilation (V_E), oxygen consumption (VO_2), respiratory quotient and energy expenditure were the specific measurements assessed using the Quark b^2.

Calibration

Under standardised laboratory conditions any variation in metabolic and ventilatory measurements should not reflect technical variability but rather biological. The Quark b^2 was calibrated before each session first using a 3L syringe. The volume transducer found on the Quark b^2 was connected to the 3L syringe and the calibration process was initiated from the main unit with specific volume measurements conducted and the average compared to the nominal value. The equipment was then calibrated using ambient room air (20.95% O_2, 0.03% CO_2, 78% N_2), and then gas calibration from a gas cylinder of known concentration (16% O_2 and 4.09% CO_2).

Treadmill habituation

It was necessary to familarise all the participants with the equipment and laboratory test conditions before starting the data collection period. As the experiment involved load carriage on a motorised treadmill, participants were habituated to walking on the Quinton treadmill in the Physiology Laboratory at the Department of Human Kinetics and Ergonomics at Rhodes University. Volunteers were taught how to mount the treadmill safely, and before the testing process began, they walked with and without varying loads on diverse gradients until they were comfortable. This also served as a warm-up period for the participants.

Psychophysical parameters

It is especially important when investigating human responses to take into account the "human element" and to obtain a tangible assessment of the perception of the participants in the study. There are scales that exist to aid in understanding subjects perception of the external demands placed on them during the task. In this study the well known and widely utilised Rating of Perceived Exertion Scale (Borg, 1970) was used, together with the established Body Discomfort Scale (Corlett and Bishop, 1976).

Ratings of Perceived Exertion (RPE) – 'Central' and 'Local'

The scale utilized in this study was Borg's rating of perceived exertion (RPE) scale (1970), which is the most commonly used psychophysical scale to assess strain experienced by individuals. The scale ranges from 6, for almost no strain, to 20, for maximal exertion, and it is expected to correlate with heart rate, where 6 will refer to approximately 60 bt.min^{-1} and 20 to 200 bt.min^{-1} (refer to Appendix B). The scale was thoroughly explained to volunteers before experimentation began. Talking would affect the physiological responses being measured by the Quark b^2,therefore the participant was required to point to the rating, which was then repeated back to them to ensure it was recorded correctly. The scale allows for two measurements to be taken, 'local' RPE, which was based on the feelings of strain in the back specifically, and 'central' RPE, which referred to the cardiorespiratory strain experienced. Both RPE measures were collected at the end of every minute for the four minute period.

Body discomfort

Corlett and Bishop (1976) developed what is referred to as the Body Discomfort Map (Appendix B). An adapted version of this provides a picture of an anterior and posterior body with 27 segments mapped out on each side, and a 10-point Lickert scale, with 1 referring to 'Minimal discomfort' and 10 referring to 'Extreme discomfort'. The Body Discomfort scale was administered at the end of each condition while the participant was in the recovery period of assessment. Two or three body regions could be selected and the subjects were required again not to speak but to point to the sites where the most discomfort was felt and to a rating (1-10) of the intensity of discomfort.

PARTICIPANTS

The observation of the task *in situ* comprised 33 rural, female workers living and working in KwaZulu-Natal. The volunteer group used for the laboratory experimentation comprised 28 female student volunteers ranging in age from 18-28 years. All these volunteers were healthy and fairly active, with no injuries and came from various ethnic groups. Table II shows the basic demographic and anthropometric variables of the workers observed in the field and the volunteers used in the laboratory investigation.

Table II: Subject characteristics of workers and volunteers.

	Silviculture Workers			Laboratory Subjects		
	Mean	SD	CV(%)	Mean	SD	CV(%)
Age (yr)	29	7.43	25.53	21	3.14	14.83
Mass (kg)	55.19	8.36	15.15	65.50	7.84	11.96
Stature (mm)	1560.38	41.32	2.65%	1697	41.60	2.45
BMI (kg.m^2)	22.63	-	-	23.24	-	-
Experience (yr)	2	4.49		-	-	-

SD: standard deviation
CV: coefficient of variation (%)

The workers on average were eight years older than the students. It can also be seen that the workers had a lower body mass than the student participants, which is likely due to an imbalance between energy intake and energy expenditure in favour of expenditure due to the physical nature of their work. The workers were also shorter than the students by 136.62mm, although both samples had body mass index measures which fell within normal ranges (20 – 24.9 kg.m^2). These differences pose a limitation to the study, however the differences found suggest that the stress placed upon the experimental group would be exacerbated by the older age, lower mass and smaller stature of the *in situ* participant group. Thus it is viable to use the findings from the experimental group to suggest more guidelines for the workers, which would need to be more conservative when taking into account that the physiological and postural strain experienced by the workers will be worse due to the differences in anthropometry.

EXPERIMENTAL PROTOCOL

Laboratory experimentation was conducted at the Department of Human Kinetics and Ergonomics of Rhodes University. Twenty eight female volunteers participated and each were required to take part in three sessions of approximately two hours. Each subject completed nine conditions, three at each session. During the first session an explanation was given of the project and experimental procedures with the requirements of the volunteers. During this session habituation to the equipment and the treadmill took place. The volunteers were able to ask questions or raise concerns at any stage during the experimentation although they were encouraged to do so during this initial stage of the testing. Once the volunteers were completely satisfied with their understanding and what was required of them consent was given. Following this, stature and mass were recorded and each volunteer was fitted with a polar heart monitor. The masks used to attach to the Quark b^2 were placed on the individual, and when possible were not removed until all conditions were completed for that session as this would allow for time saving as the participants could be directly attached to the Quark b^2 when it was their turn for testing. Once the Quark b^2 was attached, the individual was then required to sit calmly, without speaking or moving, while their physiological variables decreased to as close to resting values as possible.

In the backpack conditions the backpack was placed on the back prior to the participant having the Quark b^2 attached. They were required to adjust the straps of the backpack for their personal comfort preference following the method used by Motmans **et al.** (2006). Once the subject had reached a resting state, a physiological reference measure was recorded and the volunteer stood up next to the treadmill as it was turned on and then slowly stepped onto the treadmill. In the unilateral carriage protocols the barrel was passed to the participant when they were comfortably walking on the treadmill. Once the participant was comfortable walking with the load, metabolic measurement began. During the four minutes, four photos were taken posteriorly and laterally at two minutes and just before ending at four minutes for the postural analyses with the *ErgoImager*™ at a later stage. Figure 8 presents both methods of carriage from a lateral and posterior view.

Figure 8: Frontal and lateral views of the two methods of carriage during experimentation.

The subject was required to rate RPE every minute, both centrally and locally, by pointing to the scale. After the four minutes, for the one-handed carrying conditions, the load was taken from the participant. They were warned before the treadmill was turned off and the participant was required to remain on the treadmill until it had reached a complete stop at which point they were able to step off. They then sat down and recovery data was collected; in the backpack conditions the backpack was removed at this point. During the recovery time Body Discomfort was recorded, with the subject pointing to areas of discomfort and the intensity of that discomfort (1-10). Recovery data was collected until the physiological responses returned to the reference point. The Quark b^2 mouth piece was removed, and the mask left on and the subject then sat quietly in a demarcated area to recover further while the next two subjects were tested, this rest period was between 15-20 minutes. Following each protocol the volunteer's stature was measured and recorded.

In session 2 and session 3 the explanation and habituation were not necessary as the volunteers were now familiar with the protocols. Therefore, stature and mass were measured and the subjects were immediately fitted with polar heart rate monitors and masks. The protocols were carried out in exactly the same way, as explained above, during each session and for each individual.

STATISTICAL PROCEDURES

All experimental data was downloaded to a STATISTICA (version 7) statistical package. Firstly, unrelated t-tests were calculated to determine whether there were any significant differences between the two groups of subjects (X and Y). Basic descriptive statistics, relative to the variables assessed were gathered, providing some general information regarding the sample assessed. Two-way ANOVAs were utilised to calculate the differences found between each of the conditions. In order to compare differences between the two modes, three load masses and three gradients one-way ANOVAs were used. The 0.05 level of probability was employed throughout the statistical analysis of the results obtained. This allowed for 5 chances in a hundred that a Type 1 error, which is when a true hypothesis is rejected, could be committed. The sample size provided a sufficient limit to the chance of a type 2 error being committed, which is when a false hypothesis is failed to be rejected.

CHAPTER FOUR
RESULTS AND DISCUSSION

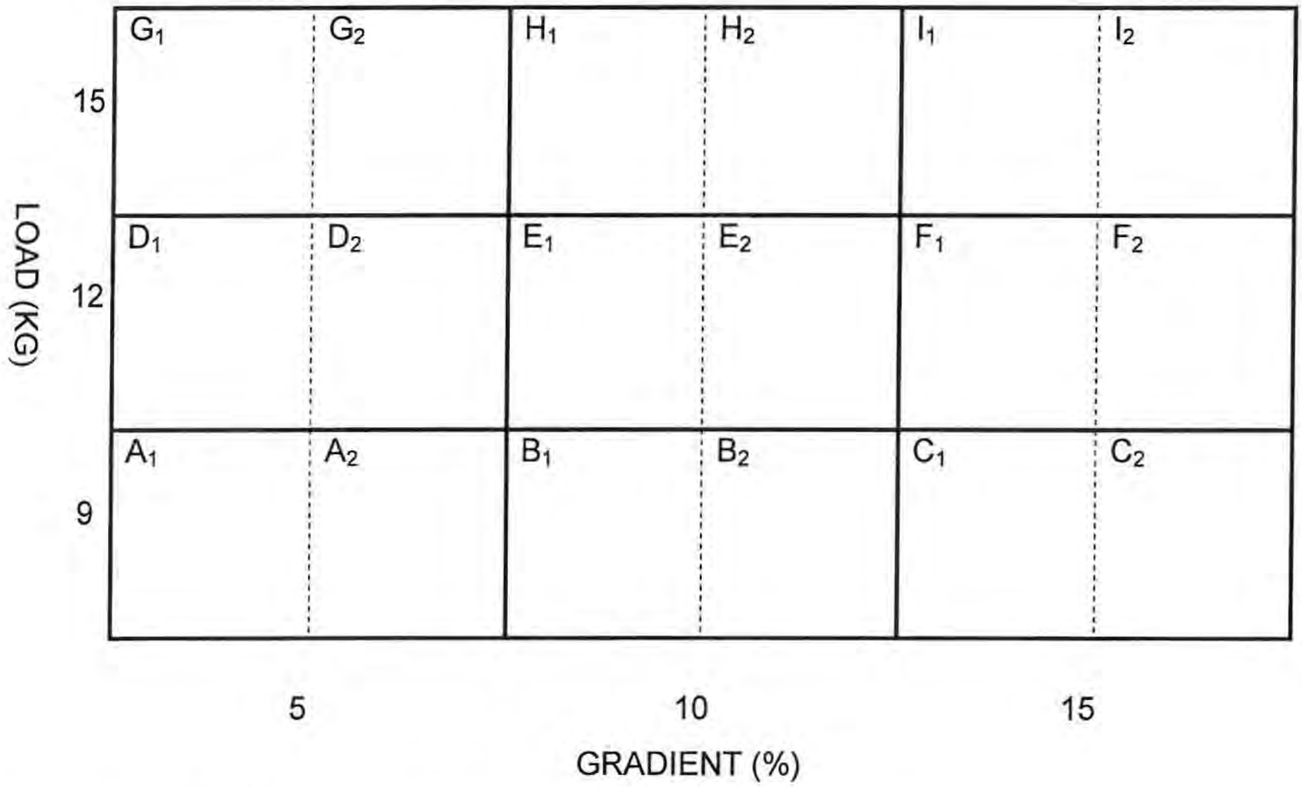
INTRODUCTION

Although the task of carrying has been researched within certain areas, such as with scholars (Hong **et al.**, 1998; Mackie **et al.**, 2005) and the military (Soule and Goldman, 1969; Lafiandra and Harman, 2004), it is unknown whether the findings of this research can be applied to the industrial sector and in particular, the silviculture area of forestry. What can be assumed is that load carriage of any form will have musculoskeletal, cardiovascular and respiratory effects on the individual performing the task. Also acknowledged is that the postures adopted during the activity will place strain on certain parts of the body (Orloff and Rapp, 2004). Additionally heart rate, oxygen consumption and associated energy expenditure will increase to a greater or lesser degree depending on various factors, including mode of carriage, load mass and gradient among others.

There are a variety of ways to carry loads, including in one or two hands, on the back, or chest, on the shoulders and even by the legs or feet, and all these methods will have varying effects on the responses of the worker (Soule **et al.,** 1978; Martin and Nelson 1986; Haisman, 1988; Knapik **et al.**, 2004). It would be of benefit to determine, within any given task, which method of carriage yields the least amount of strain while still allowing the worker to carry out the task effectively. In many studies it has been shown that carriage using the hands, and particularly one hand, places the worker at the most risk physically (Malhotra and Sen Gupta, 1965; Viry **et al.**, 1999). More specifically Legg and Mahanty (1985) report that using small muscle groups, such as the hands, should be avoided when heavy loads are carried because of the physical strain that is placed on the upper extremities. The most physically efficient methods of load carriage have been found to be either on the head or a double pack on the chest and back (Malhotra and Sen Gupta, 1965; Winsmann and Goldman, 1976; Charteris **et al.**, 1989).

Regardless of method of carriage, other factors have been reported as exacerbating the strain that can be experienced during load carriage, and include load mass (Carre, 1908; Renbourne, 1954; Pierrynowski **et al.**, 1981; Laurensen **et al.**, 2000) and gradient (Madras **et al.**, 1998; Vogt and Banzer, 1999; Laurensen **et al.**, 2000). It is generally accepted that increasing load mass and traversing a steep gradient will have a deleterious effect on postural, physiological and perceptual responses to load carriage. This investigation observed a task requiring female workers to carry large barrels in one hand. The task was simulated in a laboratory setting and a proposed intervention was tested in the laboratory to compare the responses. Considering a holistic, integrated approach, postural, physiological and perceptual responses should be assessed in that order. However, due to the main focus of this study being on the physiological responses, these findings will be discussed first and the more crude postural data will be discussed together with the perceptual responses.

Presentation of most of the data is primarily in the form of a three-by-three matrix with load mass on the ordinate and percentage gradient on the abscissa (Figure 9). Within this matrix each of the eighteen conditions (A to I) are represented in the blocks. The dotted lines in each block separate the backpack (1) and the hand carriage (2) conditions.



LOAD (KG)	5		10		15	
15	G_1	G_2	H_1	H_2	I_1	I_2
12	D_1	D_2	E_1	E_2	F_1	F_2
9	A_1	A_2	B_1	B_2	C_1	C_2

Figure 9: Grid showing the division of the eighteen conditions.
*($_1$ = backpack, $_2$ = hand carriage)

PHYSIOLOGICAL RESPONSES

Statistical significances will be discussed where applicable but due to the numerous significances, and for ease of discussion, where applicable the physiological data have been categorised into conditions which place 'moderate', 'heavy' or 'very heavy' demands on the participants, which is in accordance with the guidelines of Sanders and McCormick (1993). The physiological measures that are not included in Sanders and McCormick's guidelines were compared to crude guidelines determined from the findings of past research.

For all the physiological variables the results were assessed from an average of the last two minutes, as this was when participants had reached 'steady state', which was primarily determined using heart rate. This average measurement was then used in the analysis of the data.

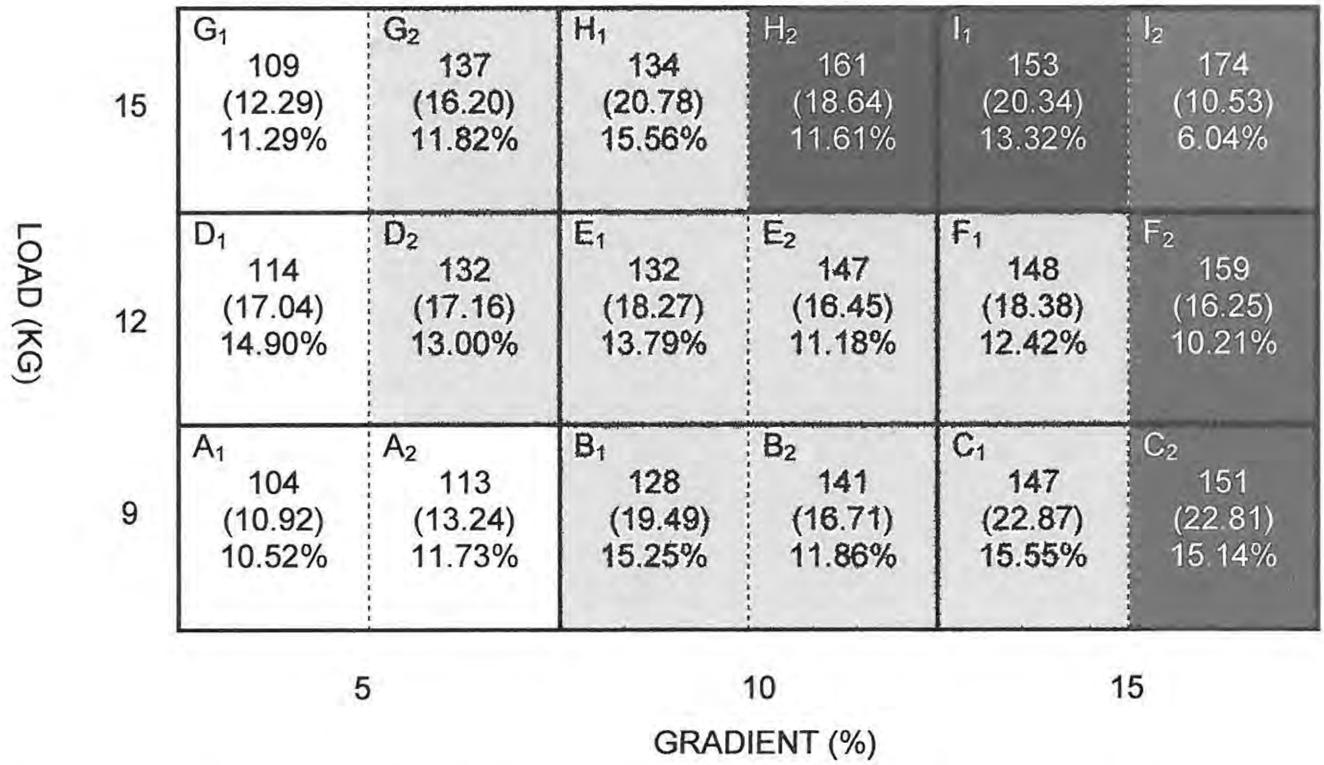
Heart rate

During each experimental session, before participants began each condition, a 'Reference' heart rate was recorded while individuals were seated and resting. The mean resting heart rate for the group of 28 participants was 71 bt.min^{-1}, which according to McArdle **et al.** (2001) is a 'normal' adult resting heart rate.

Before beginning any activity humans will experience an increased cardiac frequency, which is largely associated with anticipation due to the control of the circulatory system, referred to as feed-forward (Rowell, 1986). Anticipatory heart rate was found to be highest before the first conditions of the experimental session. However, once the participants had completed this first condition, cardiac frequency did not increase much prior to starting the remaining conditions. This, therefore, suggests that once the subjects were more settled in the experimentation process they were less apprehensive.

The heart rates measured during the experimental phase ranged between 104 bt.min^{-1} and 174 bt.min^{-1} (Figure 10), the majority fell between 120 bt.min^{-1} and 150 bt.min^{-1}, which are considered to place 'heavy' stress physically on the individual (Sanders and McCormick, 1993). These responses concur with the findings of Sullman and Byers (2000) in New Zealand, where heart frequencies of 130 bt.min^{-1} to 153 bt.min^{-1} were recorded for manual silviculture work. Field measures done in the present study were also found to be within the 'heavy' range measured in the experimentation, with heart rates reaching 150 bt.min^{-1}. The condition which yielded the lowest working heart rate was condition A_1 (a backpack condition with mass of 9kg carried at a 5% gradient). The condition which placed the highest amount of strain on the heart was condition I_2 (hand carriage with a mass of 15kg at a gradient of 15%).

From Figure 10 it is evident that the standard deviations are relatively large, demonstrating the considerable human variability that needs to be taken into account when doing human-centred research. A notable finding is that the lowest standard deviations are found at the two extreme conditions. This was during condition I_2 (hand carriage with a mass of 15kg at a gradient of 15%) and during condition A_1 (backpack carrying of a mass of 9kg at a gradient of 5%), which were also found to yield the highest and lowest heart rate responses respectively. This may suggest that at very low and very high intensities of effort human variability begins to play less of a role, compared to when work is at a moderate stress level. It is anticipated that this degree of variability would be greater in a silviculture work sector where individuals of varying morphologies and nutritional and health status are all performing the same task.



LOAD (KG)						
15	G_1 109 (12.29) 11.29%	G_2 137 (16.20) 11.82%	H_1 134 (20.78) 15.56%	H_2 161 (18.64) 11.61%	I_1 153 (20.34) 13.32%	I_2 174 (10.53) 6.04%
12	D_1 114 (17.04) 14.90%	D_2 132 (17.16) 13.00%	E_1 132 (18.27) 13.79%	E_2 147 (16.45) 11.18%	F_1 148 (18.38) 12.42%	F_2 159 (16.25) 10.21%
9	A_1 104 (10.92) 10.52%	A_2 113 (13.24) 11.73%	B_1 128 (19.49) 15.25%	B_2 141 (16.71) 11.86%	C_1 147 (22.87) 15.55%	C_2 151 (22.81) 15.14%
	5		10		15	

GRADIENT (%)

Figure 10: Mean (± standard deviation) working heart rate responses (bt.min^{-1}) recorded during each of the experimental conditions.

*($_1$ = Backpack; $_2$ = hand carriage; white blocks = 'moderate' conditions; light grey blocks = 'heavy' conditions; dark grey blocks = 'very heavy' conditions; %= coefficient of variation)

Figure 10 demonstrates that carrying loads of 9kg, 12kg and 15kg in a backpack at a 5% gradient result in statistically similar heart rate responses. This was also the same for carrying 9kg at a 5% gradient in one hand. Therefore, the majority of 'moderate' conditions are backpack carriage, and the one condition that is hand carriage is the condition at the lowest load mass (9kg) and lowest gradient (5%). A demonstration of the greater effect of gradient is seen in the conditions that fall under 'moderate' stress as all are being at the lowest gradient (5%) but at a range of loads. The four conditions classified as placing 'moderate' stress on the individual according to the guidelines of Sanders and McCormick (1993) are as follows:

- A_1 (9kg, 5%, BP)
- A_2 (9kg, 5%, HC)
- D_1 (12kg, 5%, BP)
- G_1 (15kg, 5%, BP)

'Moderate' stress

There are nine conditions that fall into the category of 'heavy' (Sanders and McCormick, 1993), and consist of conditions with a range of methods, load masses and gradients. Just over half of the conditions were backpack carriage. All the hand carriage conditions in this category were low to moderate load masses and gradients whereas in contrast, some of the backpack conditions were at the heaviest load or steepest gradient. This demonstrates that within the category of 'heavy', hand carriage is seen as the less efficient method of carriage. Of the nine conditions, 33% were with load masses of 9kg while 44% were at 12kg and only 22% at 15kg. In terms of gradient, 22% of the conditions were at a gradient of 5%, 56% were at a 10% gradient and 22% at a gradient of 15%. It is noteworthy that the range of load masses and gradients seen in this category show the importance of the interaction of all the factors. This was found in other studies conducted at Rhodes University's Department of Human Kinetics and Ergonomics (Christie 2002; Todd 2002). The 'heavy' conditions were as follows:

- B_1 (9kg, 10%, BP)
- B_2 (9kg, 10%, HC)
- C_1 (9kg, 15%, BP)
- D_2 (12kg, 5%, HC)
- E_1 (12kg, 5%, HC)
- E_2 (12kg, 10%, HC)
- F_1 (12kg, 15%, BP)
- G_2 (12kg, 5%, HC)
- H_1 (15kg, 10%, BP)

'Heavy' stress

Following the same guidelines of Sanders and McCormick (1993) the results show that all the hand carriage conditions at 15% gradient fall in the 'unduly heavy' category. Included in this category is condition H_2, which was at a 10% gradient but included the combination of a heavy mass (15kg) and hand carriage. The only backpack condition that falls into the category of 'very heavy', is condition I_1, which is in fact the backpack condition with the heaviest load (15kg) at the steepest gradient (15%) and thus this was expected. Of the five conditions classified as 'very heavy' four are hand carriage, none are at a low gradient (5%) and only one is at a low load (9kg). These findings suggest, as seen with the conditions classified as 'moderate' and 'heavy', that gradient has a greater impact on heart rate responses than load mass, and that hand carriage is seen to be less efficient than backpack carriage. This is in agreement with findings of others (Laurensen **et al.**, 2000). The conditions in this classification are as follows:

- C_2 (9kg, 15%, HC)
- F_2 (12kg, 15%, HC)
- H_2 (15kg, 10%, HC)
- I_1 (15kg, 15%, BP)
- I_2 (15kg, 15%, HC)

'Very heavy' stress

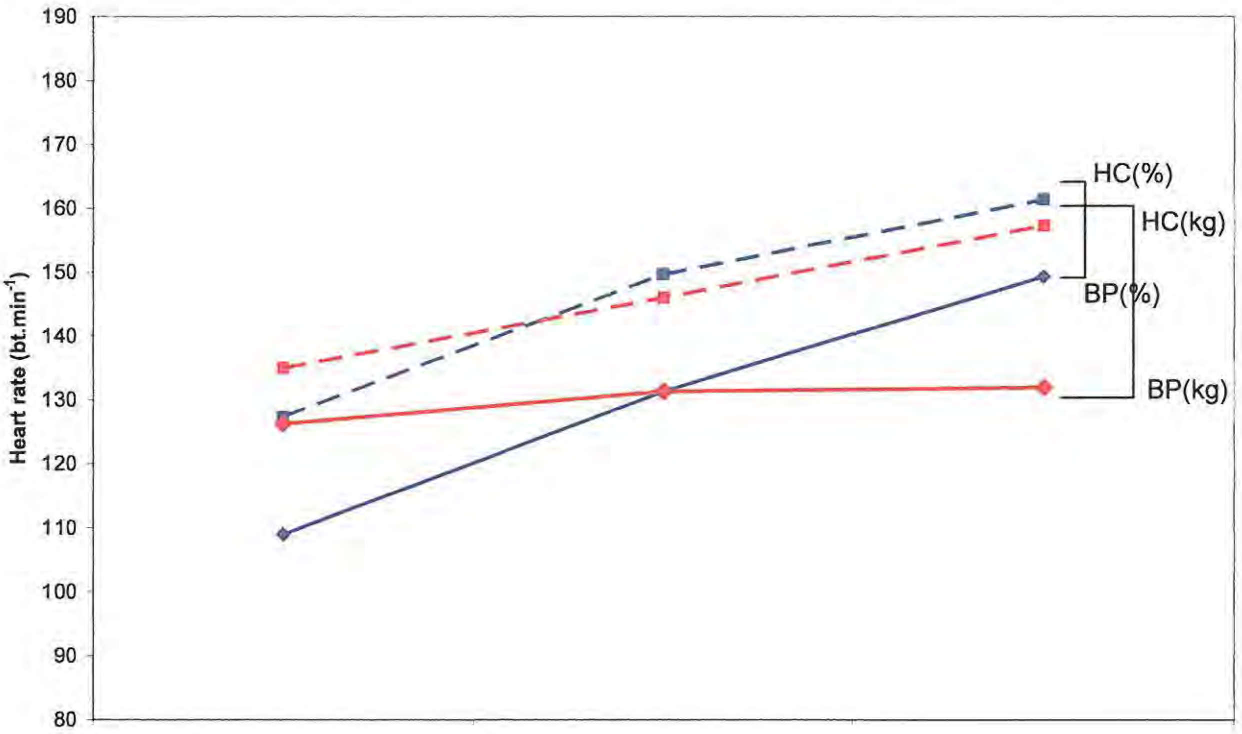


Figure 11: **Comparing the effect of load mass (kg) and gradient (%) on mean heart rate responses during backpack (BP) carrying and hand carriage (HC).**

Further analysis demonstrates that in response to only gradient, heart rate increased from the lowest (5%) to the steepest (15%) gradient by an average of 27% in the backpack conditions and by a 21% in the hand carriage conditions. In contrast, heart rate increased less (4% and 14% for backpack and hand carriage) in response to increasing load from 9kg to 15kg. This shows that gradient has a greater effect on heart rate responses than load mass and elicited greater responses overall independent of the mode of carrying (Figure 11). This is in agreement with the findings of Laurensen **et al.** (2000) but contrasts to those of earlier research by Winsmann and Goldman (1976). Research conducted in this department found similar results to the current study (Todd, 2002). Additionally, Figure 11 shows how overall the hand carriage conditions elicited higher responses compared to the backpack conditions.

Ventilatory responses

In order for equilibrium to be maintained during physical activity, changes in ventilation, by adequate changes in respiratory variables, need to occur in order for efficient performance of the activity (Åstrand and Rodahl, 1986). Due to an increased oxygen demand, minute ventilation (V_E) will increase in response. This is due to changes in frequency of breathing (F_B) and in the amount of air inhaled and exhaled per breath, known as tidal volume (V_T). Increases in V_E occur due to either an increase in F_B or in V_T. Due to more variability in the breathing responses, varying conditions of strain are not highlighted in the figures. Noteworthy, however, is that the trends were very similar to the heart rate responses.

Breathing frequency (F_B)

Referring to Figure 12 the lowest breathing frequency measured in this study was during condition A_1 (a backpack condition with a mass of 9kg at a 5% gradient), which concurs with the heart rate responses. The highest breathing frequencies measured were during condition I_2 (hand carriage of a mass of 15kg at a 15% gradient) and condition H_2 (hand carriage condition at a mass of 15kg on a 10% gradient) with both having mean F_B responses above 40 br.min^{-1} and which were statistically similar. This was likely due to the mode of carriage being the hand, which when done with a heavy load or at a steep gradient, causes elevated physiological responses (Winsmann and Goldman, 1976; Laurensen **et al.**, 2000); specifically, Cerny and Ucer (2004) found that breathing frequency increases with tasks that require arm work at a range of intensity levels.

LOAD (KG)	5		10		15	
15	G_1 24.23 (5.61) 23.15%	G_2 33.25 (6.12) 18.41%	H_1 30.33 (6.17) 20.34%	H_2 41.62 (7.16) 17.20%	I_1 35.61 (5.54) 15.56%	I_2 40.56 (6.80) 16.77%
12	D_1 29.51 (4.70) 15.93%	D_2 34.23 (6.32) 18.46%	E_1 27.28 (5.03) 18.44%	E_2 32.36 (5.44) 16.86%	F_1 31.57 (6.16) 19.51%	F_2 37.35 (5.33) 16.95%
9	A_1 22.82 (4.62) 20.23%	A_2 27.03 (4.72) 17.46%	B_1 27.90 (5.76) 20.65%	B_2 31.93 (4.90) 15.35%	C_1 28.03 (5.80) 20.69%	C_2 31.77 (6.99) 22.00%

GRADIENT (%)

Figure 12: Mean (± standard deviation) breathing frequency responses (br.min^{-1}) recorded during each of the experimental conditions.

*($_1$ = backpack, $_2$ = hand carriage; %= coefficient of variation)

From Figure 12 it can be seen that backpack conditions at all levels of gradient and masses elicited lower breathing frequencies than their counterpart conditions of hand carriage, although these differences were not always statistically significant. It is also noted that of the four conditions with the highest breathing frequency, which is considered to be a F_B greater than 35 br.min^{-1}, three are hand carriage conditions and only one is a backpack condition, which was at the steepest gradient (15%) and highest load (15kg). In the less stressful conditions (F_B < 30 br.min^{-1}) six are backpack conditions and only one is a hand carriage condition, and this was at the lowest gradient (5%) and lowest mass (9kg).

With the backpack conditions, mass alone caused breathing frequencies to increase on average by 12% while increasing gradient caused an increase of 19% in F_B. For the hand carriage conditions, increasing mass caused an increase of 21% in breathing frequency and increasing gradient resulted in an increase of 14% in F_B. Therefore, with backpack carriage, increasing gradient rather than load appears to play a greater role in affecting breathing frequency, while in hand carriage increasing mass plays the greater role. The greater effect of mass with hand carriage may be due to the increased musculoskeletal demands experienced in the smaller musculature of the hands, arms and shoulders as load increased (Legg and Mahanty, 1985) and results in a concomitant increase in breathing frequency. In contrast, with backpack carriage, as the load is more evenly distributed on the larger musculature of the trunk, increasing gradient results in the increased recruitment of the lower limb musculature and will increase the breathing response although to a lesser degree than with arm work (Cerny and Ucer, 2004).

Tidal volume (V_T)

LOAD (KG) \ GRADIENT (%)	5		10		15	
15	G_1 1.27 (0.23) 18.11%	G_2 1.39 (0.29) 20.86%	H_1 1.27 (0.21) 16.54%	H_2 1.41 (0.17) 12.06%	I_1 1.50 (0.24) 16.00%	I_2 1.88 (0.14) 7.60%
12	D_1 1.02 (0.17) 16.67%	D_2 1.17 (0.25) 21.37%	E_1 1.49 (0.23) 15.44%	E_2 1.56 (0.22) 14.10%	F_1 1.51 (0.26) 17.22%	F_2 1.53 (0.19) 12.42%
9	A_1 1.26 (0.2) 15.87%	A_2 1.25 (0.2) 16.00%	B_1 1.25 (0.18) 14.40%	B_2 1.28 (0.15) 11.72%	C_1 1.60 (0.14) 8.75%	C_2 1.62 (0.12) 7.41%

Figure 13: Mean (± standard deviation) tidal volume (L) values recorded during each of the experimental conditions.
*($_1$ = Backpack, $_2$ = hand carriage; %= coefficient of variation)

The V_T values measured in this study ranged from 1.02L to 1.88L (Figure 13), which are over double that of normal resting levels. The increase from resting to exercising values was on average 16% during backpack conditions and 26% for hand carriage conditions, demonstrating that hand carriage has a greater effect on tidal volume than backpack carrying. Overall, gradient was found to have a greater effect on tidal volume with an average increase of 31% with increasing gradient compared to increasing load mass which caused an average increase of 8%, which is similar to the findings of other researchers (Santee **et al.**, 2001; Minetti **et al.**, 2002).

Minute Ventilation (V_E)

Minute ventilation is the volume of air breathed each minute (McArdle **et al.**, 2001) and is the product of F_B and V_T (Tortora and Grabowski, 1996). A 'normal' resting V_E value for healthy adults is 6L.min^{-1}. Figure 14 presents the mean values for V_E for all 18 conditions. As with the other breathing variables, the lowest minute ventilation values were measured during condition A_1, while the highest value measured was during condition I_2, which was also statistically different to all other conditions (Figure 14). The difference in V_E between these two conditions was 63%.

LOAD (KG)	5		10		15	
15	G_1 29.47 (5.52) 18.73%	G_2 45.00 (10.17) 22.60%	H_1 37.21 (4.52) 12.15%	H_2 57.39 (8.38) 14.60%	I_1 52.03 (6.41) 12.32%	I_2 73.66 (15.62) 21.21%
12	D_1 29.15 (4.13) 14.17%	D_2 38.40 (4.21) 10.96%	E_1 39.40 (7.32) 18.58%	E_2 49.24 (9.32) 18.93%	F_1 46.24 (5.81) 12.56%	F_2 57.67 (7.90) 13.70%
9	A_1 26.90 (4.96) 18.44%	A_2 33.10 (6.69) 20.21%	B_1 33.83 (4.47) 13.21%	B_2 40.02 (4.47) 11.17	C_1 48.28 (11.89) 24.63%	C_2 55.17 (14.30) 25.92%

GRADIENT (%)

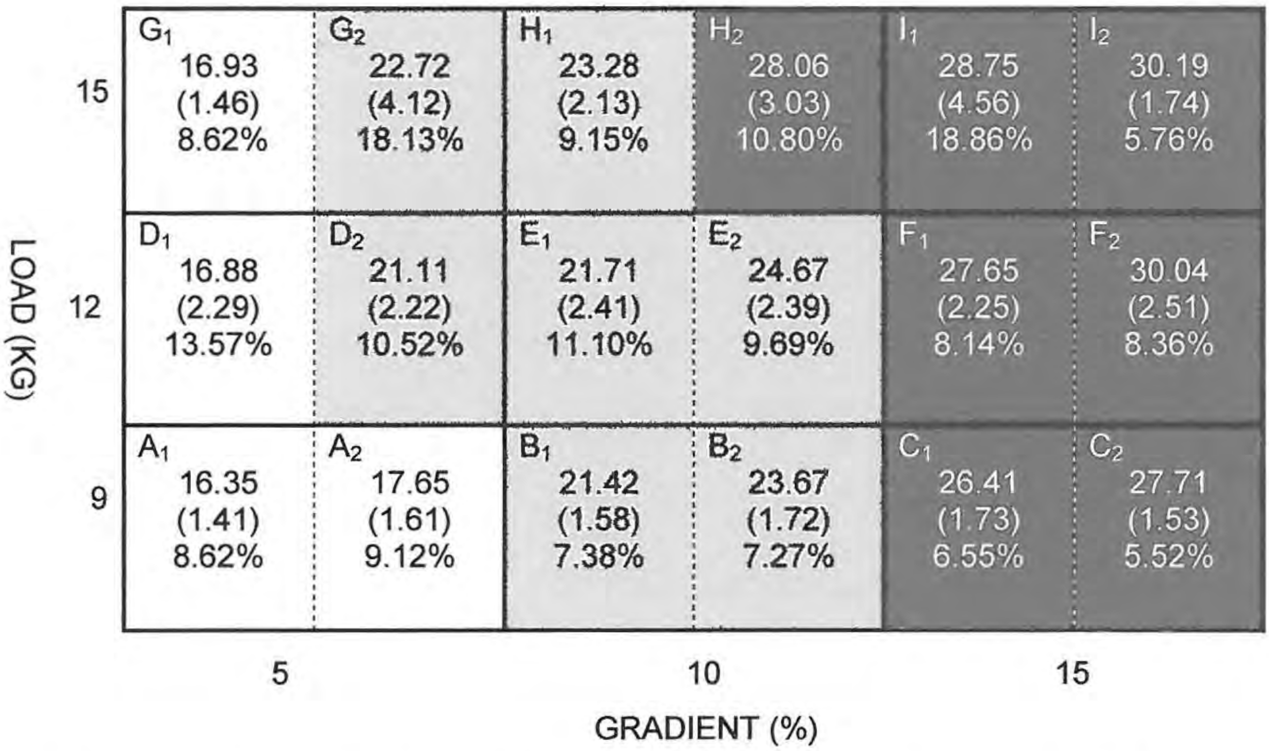
Figure 14: Mean (± standard deviation) minute ventilation ($L.min^{-1}$) values measured during each of the experimental conditions.
*($_1$ = Backpack, $_2$ = hand carriage; %= coefficient of variation)

Hand carriage was found to have a greater effect on minute ventilation, with an average increase of 55% compared to the slightly smaller increase due to backpack carriage of 48%, which was similar to the heart rate responses. There was an average increase of 59% in V_E across the gradients as opposed to a 38% increase caused by increasing load mass, which is similar to heart rate responses and V_T recordings. This suggests that tidal volume is affecting minute ventilation more than breathing frequency, which is suggestive of the subjects being healthy and relatively well trained (McArdle **et al.**, 2001).

Oxygen consumption (VO_2) responses

The oxygen uptake responses that are shown in Figure 15 are expressed relative to body mass ($mlO_2.kg^{-1}.min^{-1}$). This is due to the fact that there is a linear relationship between energy required during an activity and the body mass of the individual performing the activity (Wyndham **et al.**, 1971; McArdle **et al.**, 2001).

Although heart rate and VO_2 are considered to be closely linked, heart rate is influenced by many external variables (Bales **et al.**, 2001; Strath **et al.**, 2001) thus oxygen uptake responses are considered to be a more accurate reflection of physiological stress. Similar to heart rate responses VO_2 responses sited the same conditions (A_1,A_2,D_1,G_1) in the classification of 'moderate'. The main difference found between VO_2 and heart rate measures in the present study is that according to oxygen consumption responses more of the conditions fell within the category of 'very heavy' and less in the category of 'heavy' (Figure 15).



LOAD (KG) \ GRADIENT (%)	5	5	10	10	15	15
15	G_1 16.93 (1.46) 8.62%	G_2 22.72 (4.12) 18.13%	H_1 23.28 (2.13) 9.15%	H_2 28.06 (3.03) 10.80%	I_1 28.75 (4.56) 18.86%	I_2 30.19 (1.74) 5.76%
12	D_1 16.88 (2.29) 13.57%	D_2 21.11 (2.22) 10.52%	E_1 21.71 (2.41) 11.10%	E_2 24.67 (2.39) 9.69%	F_1 27.65 (2.25) 8.14%	F_2 30.04 (2.51) 8.36%
9	A_1 16.35 (1.41) 8.62%	A_2 17.65 (1.61) 9.12%	B_1 21.42 (1.58) 7.38%	B_2 23.67 (1.72) 7.27%	C_1 26.41 (1.73) 6.55%	C_2 27.71 (1.53) 5.52%

Figure 15: Mean (± standard deviation) oxygen consumption ($mlO_2.kg^{-1}.min^{-1}$) responses recorded during each of the experimental conditions.

*($_1$ = Backpack, $_2$ = hand carriage; white blocks = 'moderate' conditions; light grey blocks = 'heavy' conditions; dark grey blocks = 'very heavy' conditions; %= coefficient of variation)

The conditions seen in Figure 15 that fall in the 'moderate' level of oxygen consumption responses are those with VO_2 measures less than 20 $mlO_2.kg.min^{-1}$ (Sanders and McCormick, 1993) and in this study these conditions are seen to not be statistically different, and include the following conditions:

- A_1 (9kg, 5%, BP)
- A_2 (9kg, 5%, HC)
- D_1 (12kg, 5%, BP)
- G_1 (15kg, 5%, BP)

'Moderate' stress

Therefore, as with the heart rate responses, three of the four conditions are backpack carriage and only one condition is hand carriage. The hand carriage condition in this category was at the lowest gradient (5%) with the lightest load (9kg). This further demonstrates the superiorty of backpack carriage (Winsmann and Goldman, 1976; Viry **et al.,** 1999; Knapik **et al.,** 2004).

As presented in Figure 15, six conditions fall within the category of 'heavy' stress (Sanders and McCormick, 1993). In this classification VO_2 responses are between 20 and 25 $mlO_2.kg.min^{-1}$ and include the following conditions:

- B_1 (9kg, 10%, BP)
- B_2 (9kg, 10%, HC)
- D_2 (12kg, 5%, HC)
- E_1 (12kg, 5%, HC)
- G_2 (12kg, 5%, HC)
- H_1 (15kg, 10%, BP)

'Heavy' stress

In the category denoted as 'heavy' 67% of the conditions are hand carriage compared with the category of 'moderate' where only 25% of the conditions were hand carriage. Half the conditions were at a gradient of 5% and the other half at a gradient of 10%. In contrast, all the conditions classified as 'very heavy' were at a 15% gradient, supporting the conclusions of Haisman (1988) and more recently Sagiv **et al.** (2000). In the conditions considered to cause 'heavy' stress, which is the intermediate category, it is noted that there is a range of load masses and thus mass plays a less specific role in causing increases in VO_2. However, these masses were in combination with different gradients and methods of carriage, in effect demonstrating that it is essentially the combination of variables that affect responses.

In contrast to the heart rate responses measured, more conditions fell within the 'very heavy' category for oxygen uptake (VO_2 > 25 $mlO_2.kg.min^{-1}$), and in particular all the conditions with a 15% gradient were classified as 'very heavy' stress whereas for heart rate, only four of the six conditions at a 15% gradient were found to place 'very heavy' stress on the individuals. The highest VO_2 values were measured during condition I_2 (hand carriage with a mass of 15kg at a gradient of 15%). The other conditions which fell in this category were all statistically similar to I_2, except for condition C_1 (backpack with load 9kg at 15% gradient), which had the lowest VO_2 values in this category. The conditions in this category are as follows:

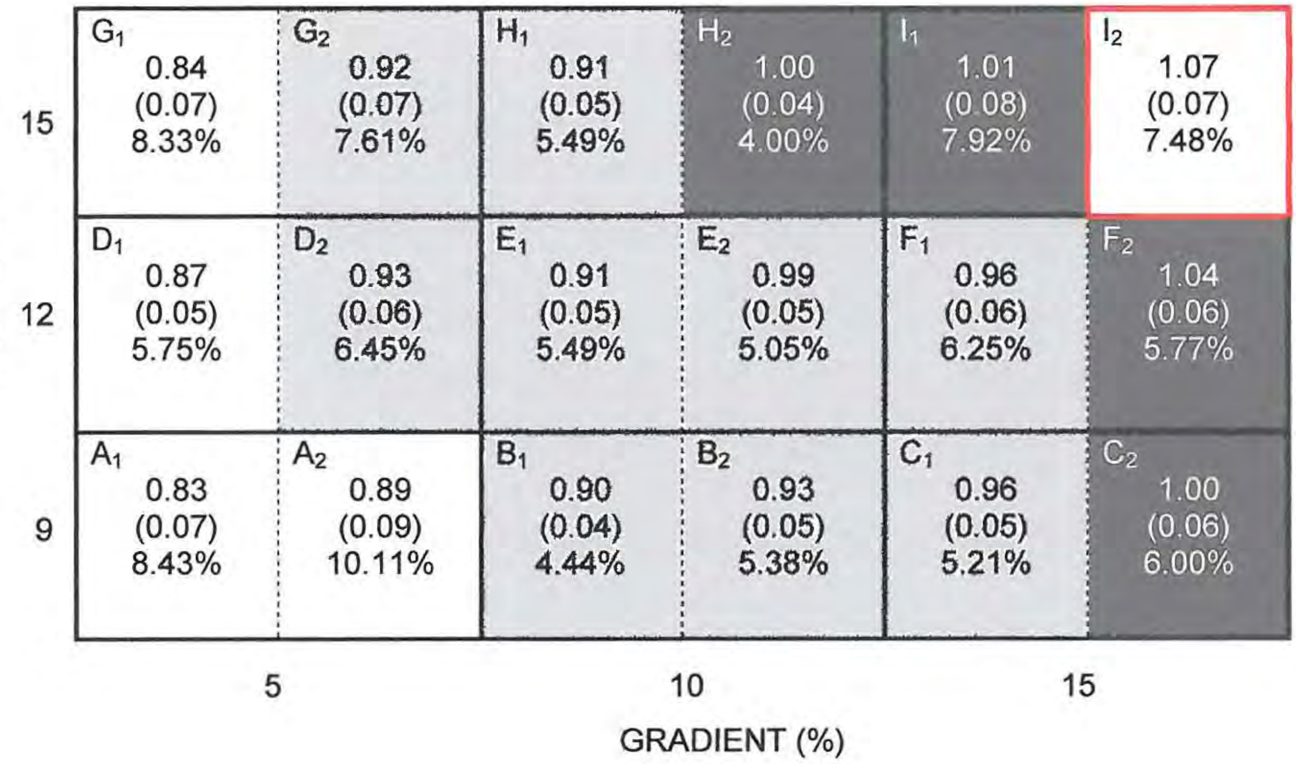
- C_1 (9kg, 15%, BP)
- C_2 (9kg, 15%, HC)
- E_2 (12kg, 10%, HC)
- F_1 (12kg, 15%, BP)
- F_2 (12kg, 15%, HC)
- H_2 (15kg, 10%, HC)
- I_1 (15kg, 15%, BP)
- I_2 (15kg, 15%, HC)

'Very heavy' stress

Referring to Figure 15, 38% of the conditions were backpack carriage, with five of the eight being hand carriage. In support of the conclusion that increasing gradients cause greater increases in VO_2 than increasing mass, regardless of method, an average increase of 43% was found in response to increasing gradient across all conditions, compared to a 22% increase seen in response to mass increases. Overall the VO_2 responses show similar trends to the heart rate data in that the backpack conditions are more efficient than hand carriage conditions and that while both gradient and mass cause increases in physiological responses, gradient has the greater effect.

Respiratory Quotient (RQ)

The respiratory quotient (RQ) is defined as the ratio of carbon dioxide expelled to the amount of oxygen consumed, which gives an indication of the fuels that are being oxidised and therefore is a useful measure to determine fuel used at rest and during submaximal, 'steady-state' activity (Goedecke **et al.**, 2000). Due to different chemical compositions of food substances, oxygen requirements to metabolise molecules differ and thus RQ is a useful indicator of the nutrient catabolism occurring in the cells. A respiratory quotient less than 0.70 shows that lipids are the primary energy source. This generally occurs at rest and during low intensity exercise or prolonged exercise. An RQ closer to 1.00 indicates greater carbohydrate metabolism, which is a faster source of energy and generally demonstrates a higher intensity of effort (McArdle **et al.**, 2001). Once RQ is measured above 1.00 it is no longer useful in determining substrate utilisation, however it is an indication of significant strain being experienced by the physiological systems.



LOAD (KG)	5		10		15	
15	G_1 0.84 (0.07) 8.33%	G_2 0.92 (0.07) 7.61%	H_1 0.91 (0.05) 5.49%	H_2 1.00 (0.04) 4.00%	I_1 1.01 (0.08) 7.92%	I_2 1.07 (0.07) 7.48%
12	D_1 0.87 (0.05) 5.75%	D_2 0.93 (0.06) 6.45%	E_1 0.91 (0.05) 5.49%	E_2 0.99 (0.05) 5.05%	F_1 0.96 (0.06) 6.25%	F_2 1.04 (0.06) 5.77%
9	A_1 0.83 (0.07) 8.43%	A_2 0.89 (0.09) 10.11%	B_1 0.90 (0.04) 4.44%	B_2 0.93 (0.05) 5.38%	C_1 0.96 (0.05) 5.21%	C_2 1.00 (0.06) 6.00%

GRADIENT (%)

Figure 16: Mean (± standard deviation) RQ measures recorded during the experimental conditions.

*($_1$ = Backpack, $_2$ = hand carriage; white blocks = 'moderate' conditions; light grey blocks = 'heavy' conditions; dark grey blocks = 'very heavy' conditions; %= coefficient of variation)

Although Sanders and McCormick (1993) have no classification of stress in terms of RQ values, the conditions were still divided into categories of 'moderate', 'heavy' and 'very heavy' as these measures followed similar trends to heart rate, breathing responses and oxygen consumption. Figure 16 presents the RQ values for each of the eighteen conditions. Conditions A_1, A_2, D_1 and G_1 had RQ values below 0.90 (0.83 – 0.89), demonstrating a mixture of carbohydrate (43.8% - 64.2%) and lipid (56.2% - 35.8%) utilisation according to Eston and Reilly (2001). Nine conditions had RQ values between 0.90 and 0.99 demonstrating a significant increase in carbon dioxide production in relation to oxygen uptake as compared to the 'moderate' conditions. This also reflects a greater oxidation of carbohydrates as an energy source (67.5% - 96.8%). The final five conditions were found to have RQ values greater than 1.00 reflecting the individuals were in hyperventilation, therefore these measurements could no longer be used for determination of substrate use, however it is a reflection of the large amount of stress being placed on the physiological systems.

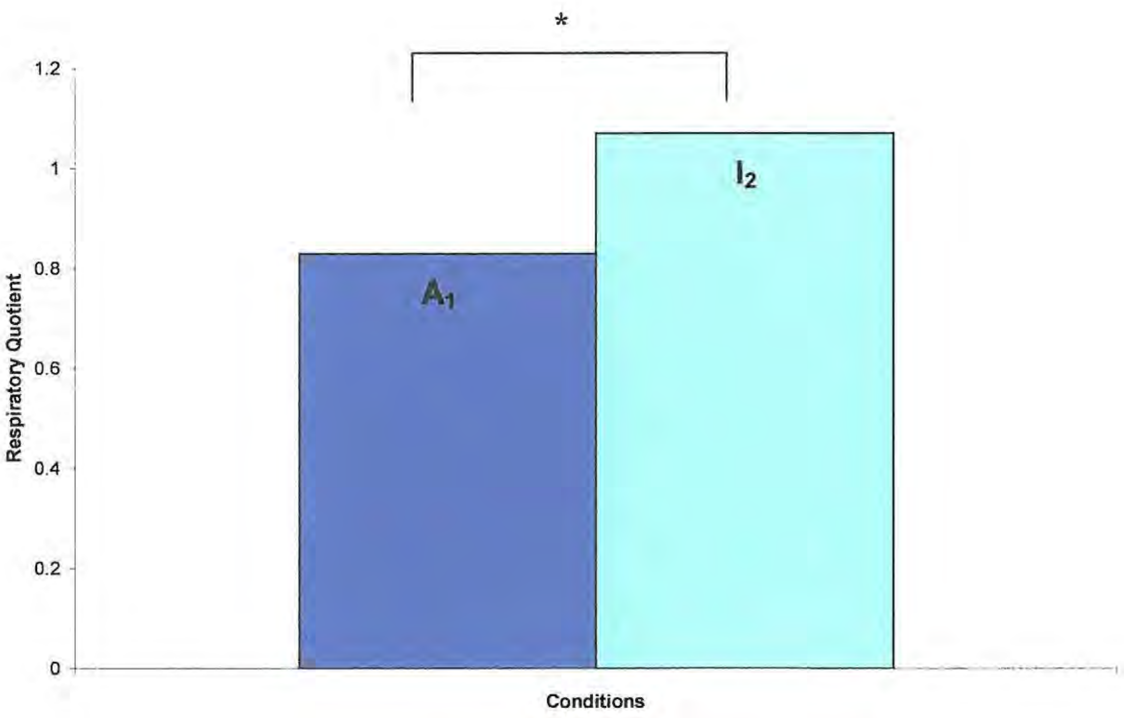


Figure 17: Respiratory Quotient for the least stressful and most stressful conditions.
(* denotes statistical significance between conditions)

Figure 17 shows the large difference (32%) between condition A_1, the condition found to be the least stressful in all the physiological variables, and condition I_2, the condition found to be the most stressful in all the physiological variables and which elicited an RQ which was significantly different ($p < 0.05$) to all the other conditions, as found with minute ventilation and carbon dioxide production. The difference in energy derived from carbohydrates between these two conditions is 43.8% (for condition A_1) and 100% (for condition I_2) and 56.7% (condition A_1) and 0% (condition I_2) for percent energy derived from fats (Eston and Reilly, 2001).

Energy expenditure (kJ.min^{-1})

Knowledge of energy expenditure for any form of load carriage is necessary to ensure that workers are able to perform efficiently. Energy expenditure expressed per minute gives an indication of the rate at which energy is being transferred while carrying. Energy expenditure should be assessed in conjunction with energy intake in order to determine if a balance exists; knowledge of this will aid in diminishing the chance of health problems and fatigue. Unfortunately, energy intake was outside of the scope of this research project and thus was not assessed, but an accurate indication of physical stress can be drawn from energy expenditure values.

Table III: Energy expenditure values for grades of work (adapted from Sanders and McCormick, 1993).

Grade of work	Energy expenditure (kcal.min^{-1})	Energy expenditure (kJ.min^{-1})
Rest	1.5	6.3
Very light work	1.6 – 2.5	6.7 – 10.5
Light work	2.5 – 5.0	10.5 – 20.9
Moderate work	5.0 – 7.5	20.9 – 31.4
Heavy work	7.5 – 10.0	31.4 – 41.9
Very heavy work	10.0 – 12.5	41.9 – 52.3
Unduly heavy work	>12.5	>52.3

Sanders and McCormick (1993) refer to energy expenditure per minute using the unit of measurement of kcal.min^{-1}. However, the present study used kJ.min^{-1}, and the adjustments to Sanders and McCormick's (1993) table can be seen in Table III. 'Moderate' stress is found to be at an energy expenditure between 20.9 kJ.min^{-1} and 31.4 kJ.min^{-1}, 'heavy' stress is between 31.4 kJ.min^{-1} and 41.9 kJ.min^{-1}, and 'very heavy' stress is between 41.9 kJ.min^{-1}and 52.3 kJ.min^{-1} (Table III).

Figure 18 shows that half of the eighteen conditions were found to be 'moderate' in stress (Sanders and McCormick, 1993) with energy expenditure values that were between 20.90 and 31.40 kJ.min^{-1}. These are similar values to the average energy expenditure of 27.21 kJ.min^{-1} found by Passmore and Durnin (1955). Within this category the two conditions that yielded the lowest rate of energy expenditure were condition A_1 (backpack carriage with a mass of 9kg at gradient of 5%) and condition D_1 (backpack condition with a load of 12kg at a gradient of 5%), which are also statistically similar.

Of the nine conditions classified as 'moderate', only 44% are seen to be hand carriage conditions and as such more backpack conditions are found in this category. Four of the conditions are with a 9kg load, and three with a 12kg load with only two at 15kg. Of the nine conditions, 56% were found to be at the lowest gradient (5%) and three conditions at

10%, with none being at the highest gradient (15%). The conditions in this classification are as follows:

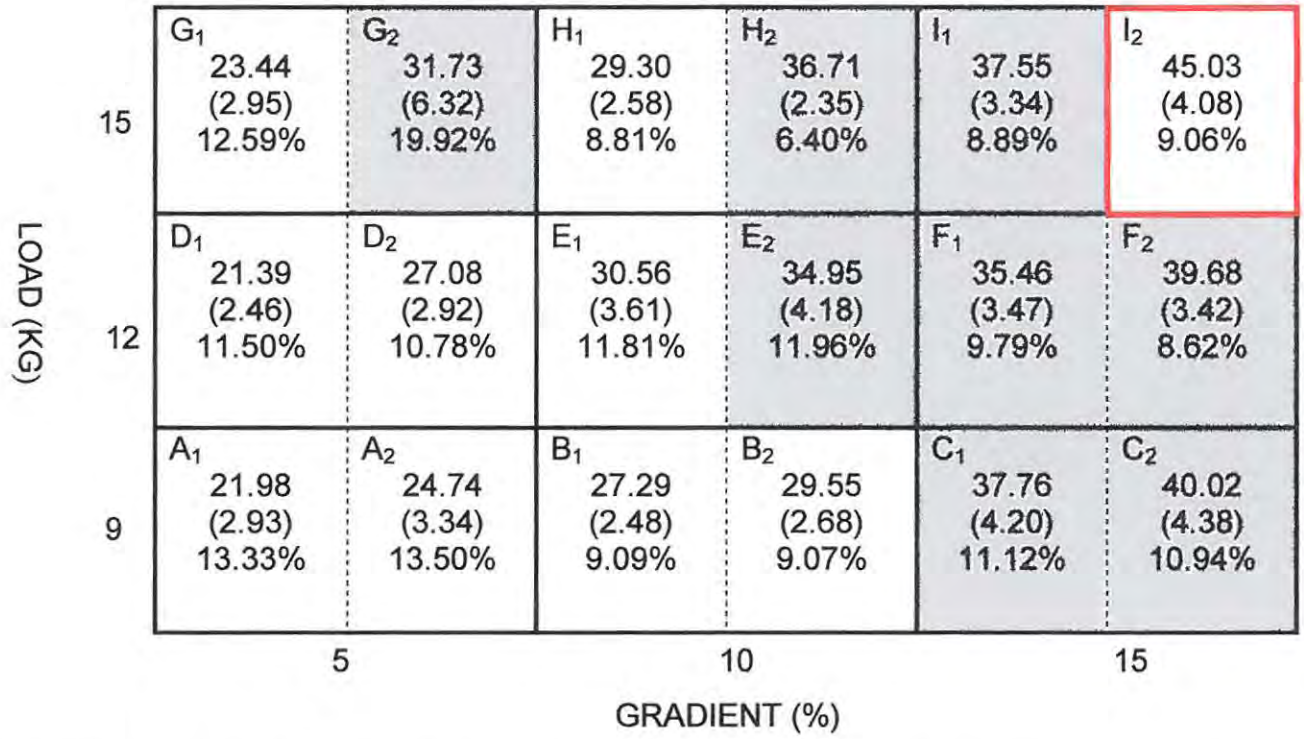
- A_1 (9kg, 5%, BP)
- A_2 (9kg, 5%, HC)
- B_1 (9kg, 10%, BP)
- B_2 (9kg, 10%, HC)
- D_1 (12kg, 5%, BP)
- D_2 (12kg, 5%, HC)
- E_1 (12kg, 10%, BP)
- G_1 (15kg, 5%, BP)
- H_1 (15kg, 10%, HC)

'Moderate' stress

The conditions that are classified as placing 'heavy' stress on the body in terms of energy expenditure included five hand carriage conditions and only three backpack conditions. Only 25% of the conditions considered 'heavy' were with a mass of 9kg, with the remaining 75% being made up of 12kg and 15kg loads. Both conditions with 9kg masses were at gradients of 15%, and one condition at a 5% gradient was a hand carriage condition with a load mass of 15kg. Noteworthy is the finding that condition G_2 was significantly higher than H_1, but this condition was a hand carriage condition with a heavy mass (15kg) and at a moderate gradient. This suggests that when carrying a 15kg load either on the back or in the hand, gradient should preferably be 5% or less as condition G_2 was at a 10% gradient. However, the biological difference is only 8% and condition G_2 had the largest standard deviation, which suggests that there was a large variability in the responses in that condition and hence that finding should be interpreted with caution. The conditions in this category include:

- C_1 (9kg, 15%, BP)
- C_2 (9kg, 15%, HC)
- E_2 (12kg, 5%, HC)
- F_1 (12kg, 10%, BP)
- F_2 (12kg, 10%, HC)
- G_2 (15kg, 5%, HC)
- H_2 (15kg, 10%, HC)
- I_1 (15kg, 15%, BP)

'Heavy' stress



LOAD (KG)	5		10		15	
15	G_1 23.44 (2.95) 12.59%	G_2 31.73 (6.32) 19.92%	H_1 29.30 (2.58) 8.81%	H_2 36.71 (2.35) 6.40%	I_1 37.55 (3.34) 8.89%	I_2 45.03 (4.08) 9.06%
12	D_1 21.39 (2.46) 11.50%	D_2 27.08 (2.92) 10.78%	E_1 30.56 (3.61) 11.81%	E_2 34.95 (4.18) 11.96%	F_1 35.46 (3.47) 9.79%	F_2 39.68 (3.42) 8.62%
9	A_1 21.98 (2.93) 13.33%	A_2 24.74 (3.34) 13.50%	B_1 27.29 (2.48) 9.09%	B_2 29.55 (2.68) 9.07%	C_1 37.76 (4.20) 11.12%	C_2 40.02 (4.38) 10.94%

GRADIENT (%)

Figure 19: Mean (± standard deviation) energy expenditure ($kJ.min^{-1}$) responses recorded during each of the experimental conditions.

*($_1$ = backpack, $_2$ = hand carriage; white blocks = 'moderate' conditions; light grey blocks = 'heavy' conditions; dark grey blocks = 'very heavy' conditions)

The highest measure of energy expenditure was found during condition I_2 (hand carriage with mass of 15kg and a gradient of 15%); it is the only condition to be classified as 'very heavy', and is significantly different to all the other conditions. The energy expended during this condition was equivalent to running cross country or doing fitness swimming, and is higher than other values measured for manual planting and recreational backpacking (McArdle **et al.**, 2001).

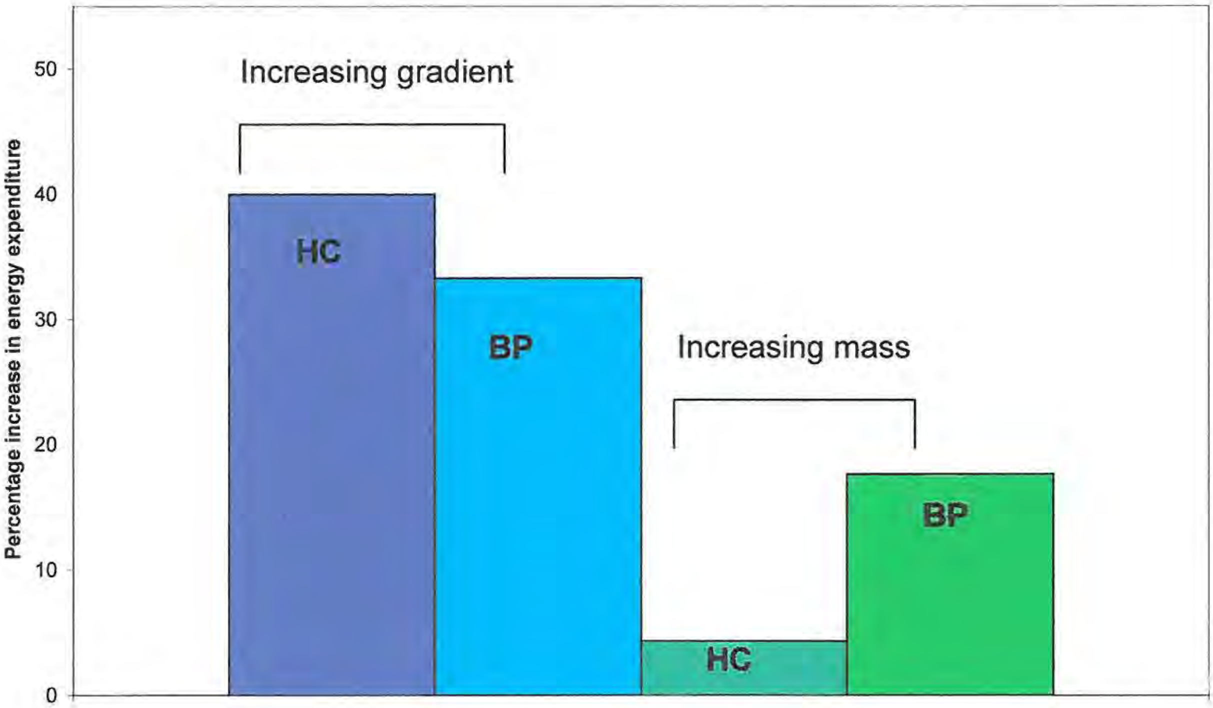


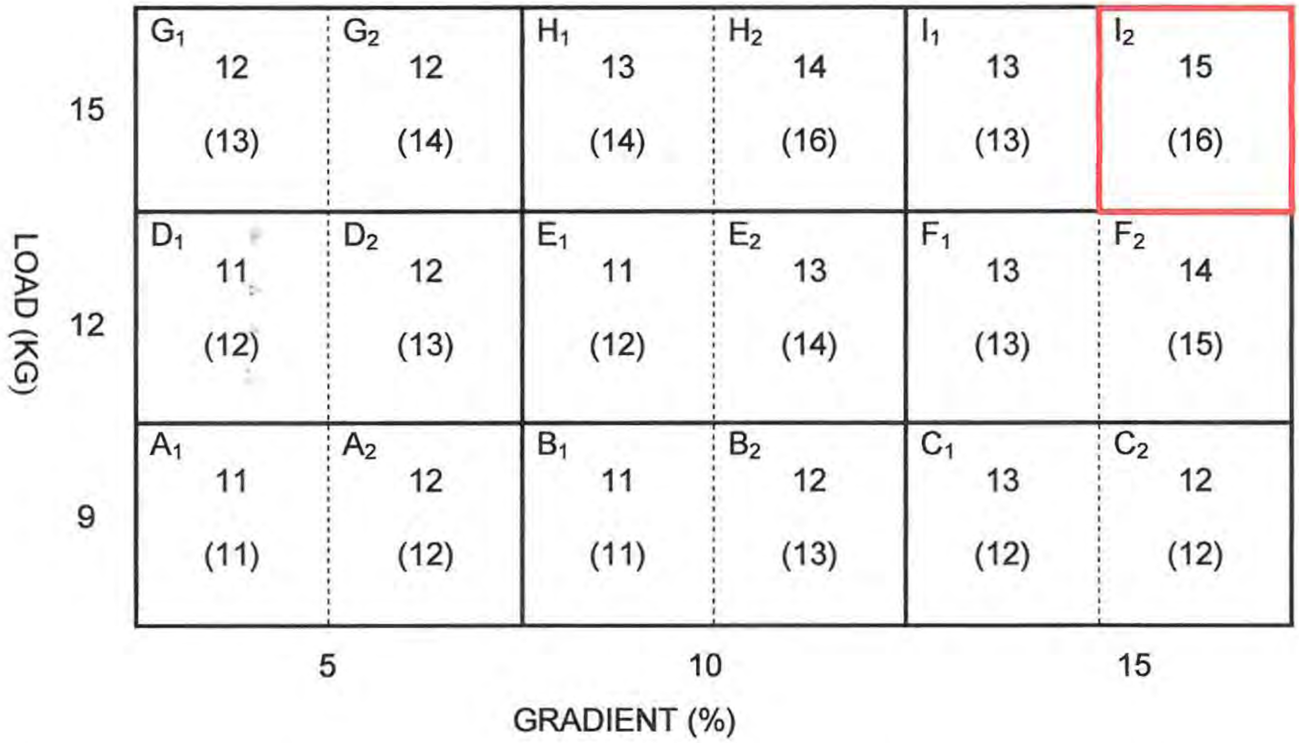
Figure 19: Average increase in energy expenditure (kJ.min^{-1}) due to gradient and mass for both modes of carriage.

Figure 19 represents the average increases found in the energy expenditure values due to all variables. For the backpack conditions the average increase in energy expenditure due to mass was 4%, and 18% for hand carriage. An increase of 40% was found due to gradient during backpack carriage and 33% during hand carriage; these increases are greater than those due to mass.

PERCEPTUAL RESPONSES

Rating of Perceived Exertion

Perceived exertion gives an indication of how individuals experience the effort required to perform an activity (Gamberale, 1985). The Rating of Perceived Exertion Scale has been shown to be accurate and applicable to many situations, including manual handling tasks (Noble, 1982). However, an important factor in using the scale is the individuals' understanding of it and their ability to correctly discern the effort experienced by the body. In the present study it was found that in terms of 'central' RPE subjects were relatively accurate in the perception of the effort required by the body. When looking at the correlation between heart rate and 'central' RPE a correlation coefficient of 0.82 was found, which demonstrates that there was a positive correlation but also shows that 68% variance in heart rate could be accounted for by 'central' RPE, thus the unaccounted for variance was only 32% showing that statistically participants were accurate in their perception of exertion. When looking at the actual ratings it can be seen that in general subjects slightly over-rated the exertion required at the more moderate conditions (A_1, B_1, D_1) and slightly under-rated exertion at the heavier conditions (F_2, H_2, I_1, I_2). This may be due to a lack of understanding of the scale or at the more stressful conditions subjects may have suppressed their perceptions. It may also be due to a lack of familiarity with the task and therefore they are less able to accurately perceive the effort experienced by the body.



LOAD (KG)						
15	G_1 12 (13)	G_2 12 (14)	H_1 13 (14)	H_2 14 (16)	I_1 13 (13)	I_2 15 (16)
12	D_1 11 (12)	D_2 12 (13)	E_1 11 (12)	E_2 13 (14)	F_1 13 (13)	F_2 14 (15)
9	A_1 11 (11)	A_2 12 (12)	B_1 11 (11)	B_2 12 (13)	C_1 13 (12)	C_2 12 (12)

Figure 20: Mean 'central' and 'local' ratings of perceived exertion during the fourth minute of experimentation.
*($_1$ = backpack, $_2$ = hand carriage; brackets indicate 'local' RPE)

'Central' RPE

Figure 20 presents the 'central' ratings during the final minute of each condition which were found to range from 11 to 15 (fairly light to hard). The highest 'central' RPE (15) was found during condition I_2 (hand carriage condition with load of 15kg at a gradient of 15%), which was found to be the condition eliciting the greatest responses for all physiological variables measured. It can be seen that for the majority of conditions, with the exception of those found with a load mass of 15kg and at a gradient of 5% (G_1 and G_2), the hand carriage conditions were perceived as worse than the corresponding backpack conditions. Generally, it was seen that an increase in mass caused an increase in RPE, with exceptions found in some cases where no increase was seen, this occurred only from 9kg to 12kg (A_1-D_1; A_2-D_2; B_1-E_1; C_1-F_1). This shows that the perceived difference between 9kg and 12kg was slight, thus load masses of 12kg and lighter do not always cause increases in how individual's perceive carrying tasks. A general trend, similar to that of increasing load, was found with gradient which showed that with an increase in slope steepness perceptions of exertion were found to increase, with two exceptions seen at increases from 5% to 10% (A_1-B_1; D_1-E_1) and two at increases from 10% to 15% (B_2-C_2; H_1-I_1) showing that an increase in gradient from 5% to 10% generally elicits only slight increases, whereas gradient increases from 5% to 15% and 10% to 15% show greater perceptions of effort.

'Local' RPE

'Local' RPE ranged from 11-16 (fairly light to hard) and it was found that 'local' ratings were found to be marginally higher in most conditions compared to the 'central' ratings, showing that participants felt slightly more strain in the musculoskeletal system compared to the physiological systems. With the exception of one set of conditions (C_1 and C_2) it was found that hand carriage conditions caused greater perceptions of effort than that of their backpack counterparts, therefore hand carriage was perceived as the more stressful conditions in terms of muscular exertion. As with 'central' RPE findings an increase in mass was seen to increase 'local' ratings, with only one exception with an increase from 12kg to 15kg (F_1-I_1). Similar to 'central' RPE findings it was found that with an increase in gradient an increase in RPE was generally seen, with two exceptions at 5% to 10% and one at 10% to 15% (A_1-B_1; D_1-E_1; H_2-I_2).

The general trend demonstrated by RPE were that hand carriage was perceived to be more stressful than backpack carriage, and that increasing mass and gradient increased the exertion perceived by the participants. These are similar findings to the physiological responses.

Body discomfort and postural analyses

During any physical activity the body is likely to feel discomfort in the musculoskeletal system as stress is placed on it. Figure 21 presents the general areas where the most discomfort was experienced by participants for both modes of carriage at various load masses and gradients.

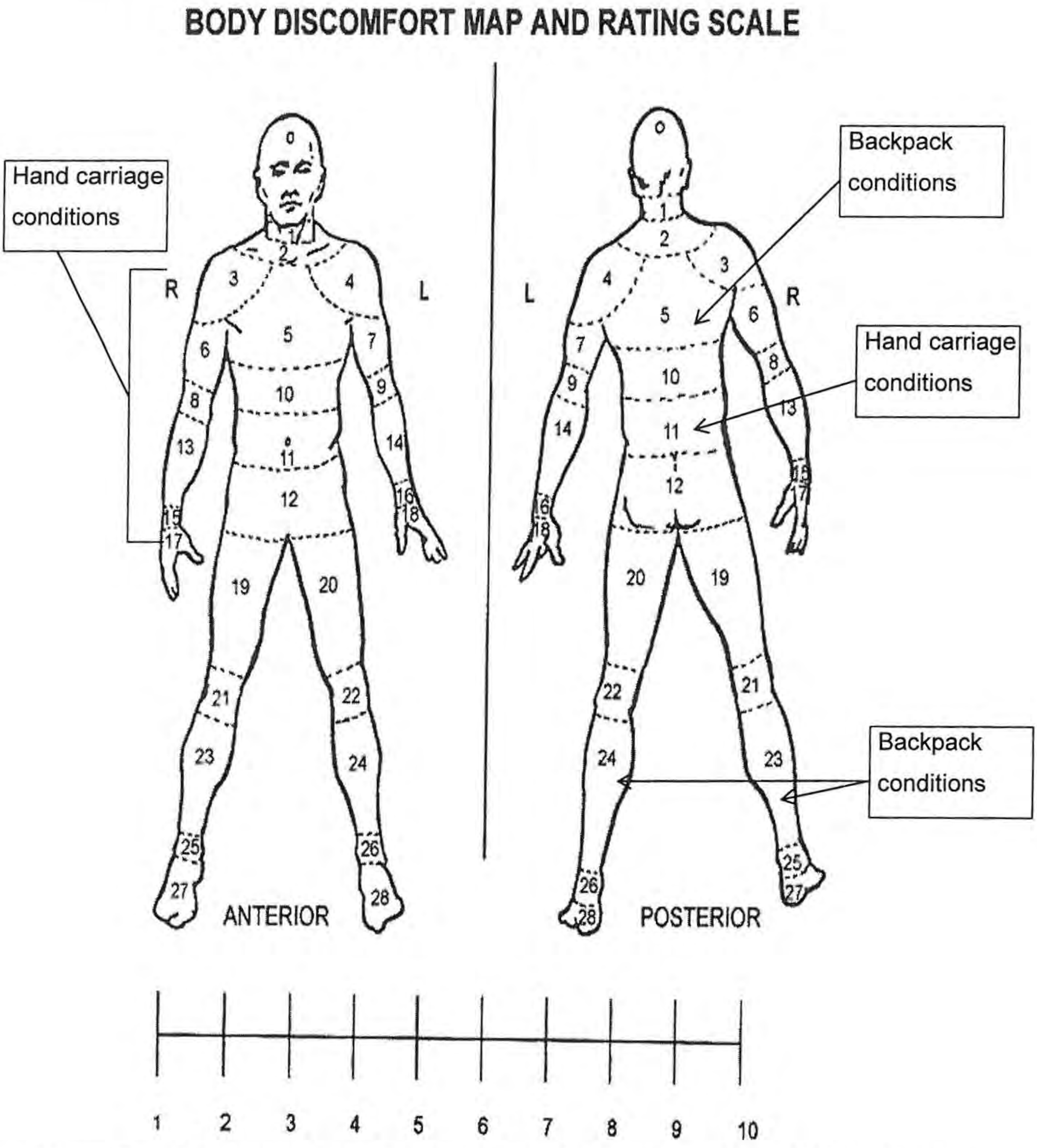


Figure 21: The areas where the most discomfort was experienced due to load carriage.

During hand carriage the highest amount of discomfort was felt in the lower back, particularly during conditions at high gradients. A large amount of discomfort was also felt in the carrying arm during hand carriage and this increased greatly with increasing load mass, demonstrating the unilateral strain felt in the musculature due to one handed carrying. Backpack carriage was found to cause the most discomfort in the lower extremities particularly the calves, this discomfort increased substantially with increases in gradient. Discomfort was also felt in the upper back for the backpack carriage conditions; this may be due to 70% of the load being carried in the upper back and 30% in the lower back when carrying with a backpack (LaFiandra and Harman, 2004).

Mode of carriage

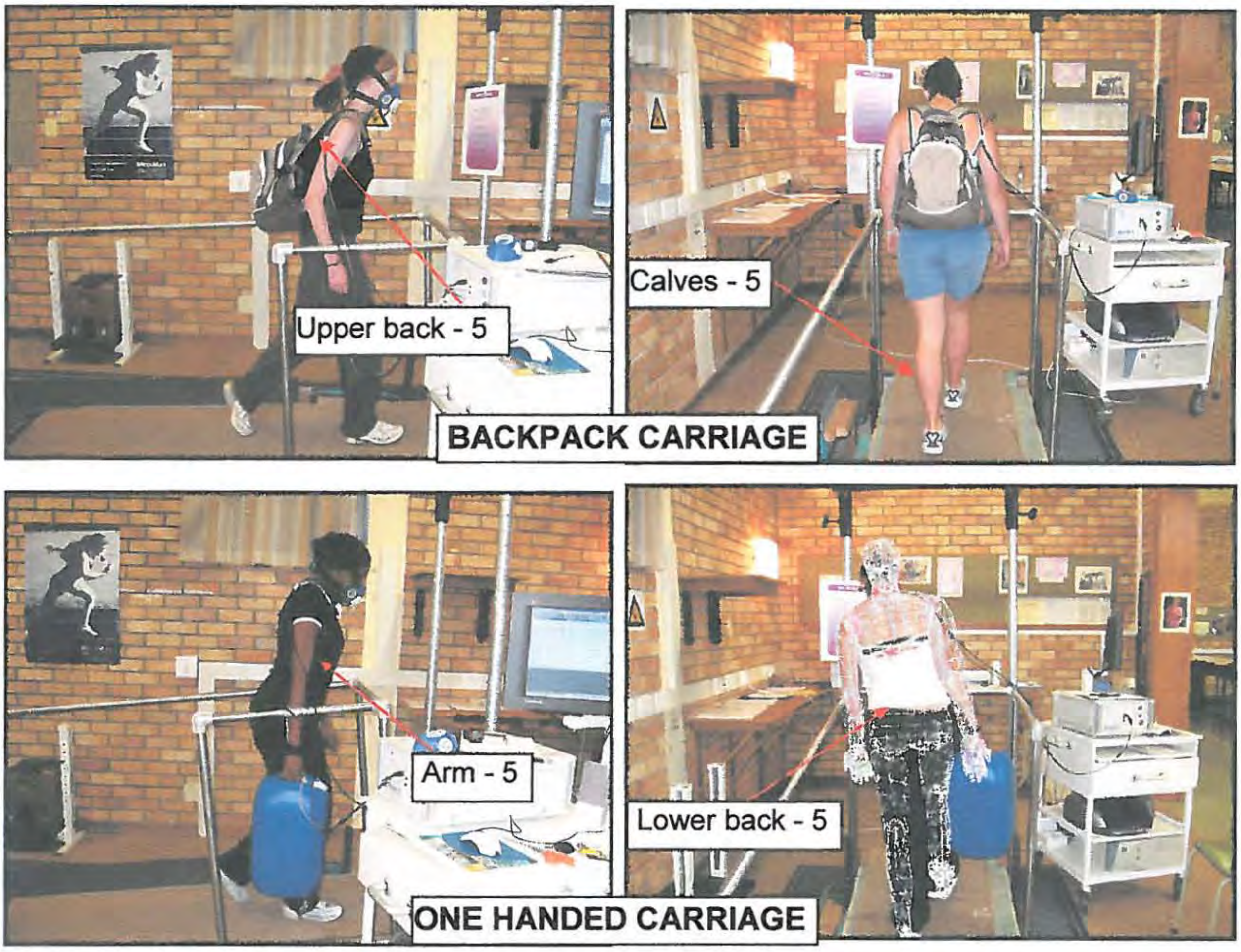


Figure 22: General postures adopted and associated areas and ratings of discomfort during the two methods of load carriage.

From Figure 22 it can be seen that both backpack and hand carriage cause forward flexion of the trunk a finding supported by others (Pascoe **et al.**, 1997; Filiare **et al.**, 2001; Fowler **et al.**, 2006). This caused discomfort to be felt in the back for both modes of carriage. With backpack carriage, due to the placement of the load more discomfort was felt in the upper back while during hand carriage because of the lateral bending towards the opposite side that the load is carried on there was more discomfort felt in the lower back, as found by others (Marras and Granata, 1997). There was found to be less lateral bending during backpack carriage.

Overall the compression forces for hand carriage conditions, which had a mean of 776N, were seen to be greater than those for backpack conditions, which had a mean of 761N, although this was only a marginal difference. However, it was found that spinal shrinkage only occurred in backpack conditions, with decreases in stature ranging from 0mm to 50mm, with a mean of 20mm. The larger decreases in stature was found with the heavier backpack loads. Mean shearing forces were 360N for hand carriage and 320N for backpack carriage. Thus hand carriage conditions placed greater stress on the L_4/L_5 area of the spine compared to backpack carriage, which concurs with the discomfort felt by the subjects which was primarily in the lower back.

The highest compression and shearing forces were found in condition I_2 (Figure 23), which is also the condition found to place the greatest amount of stress on the physiological systems, and was perceived to be the condition requiring the most effort. From crude 2D analyses the compression force was found to be 1125N and the shearing force was 251N during this condition. This large compression force is likely to be the reason for the discomfort felt in the lower back.

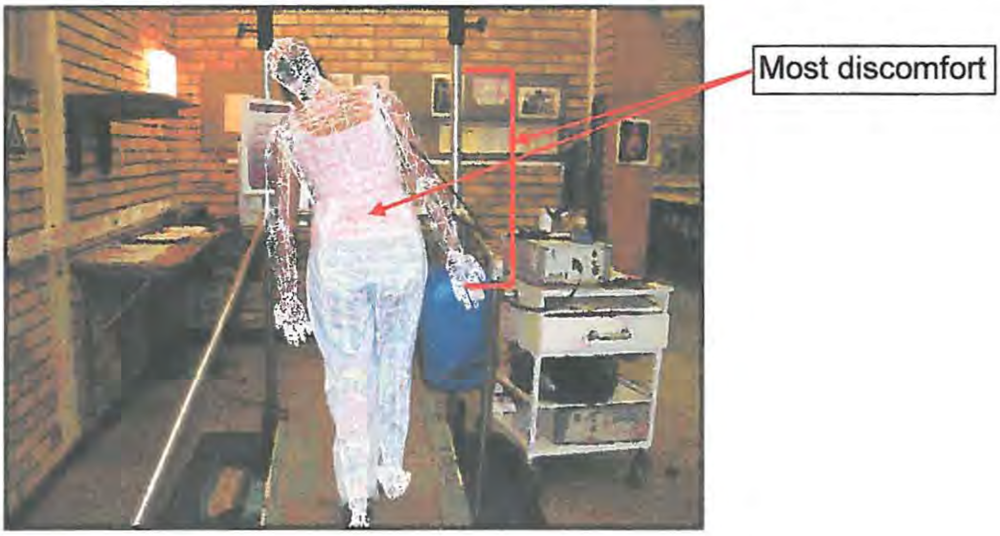


Figure 23: Condition I_2 which caused the greatest amount of compression and shearing forces and discomfort in the lower back and carrying arm.

Load mass

Along with the mode of carriage load mass will also have a considerable affect on the postures adopted as shown in Figure 24. The Figure shows the postures adopted during carrying of the heaviest mass (15kg) on a low gradient (5%).

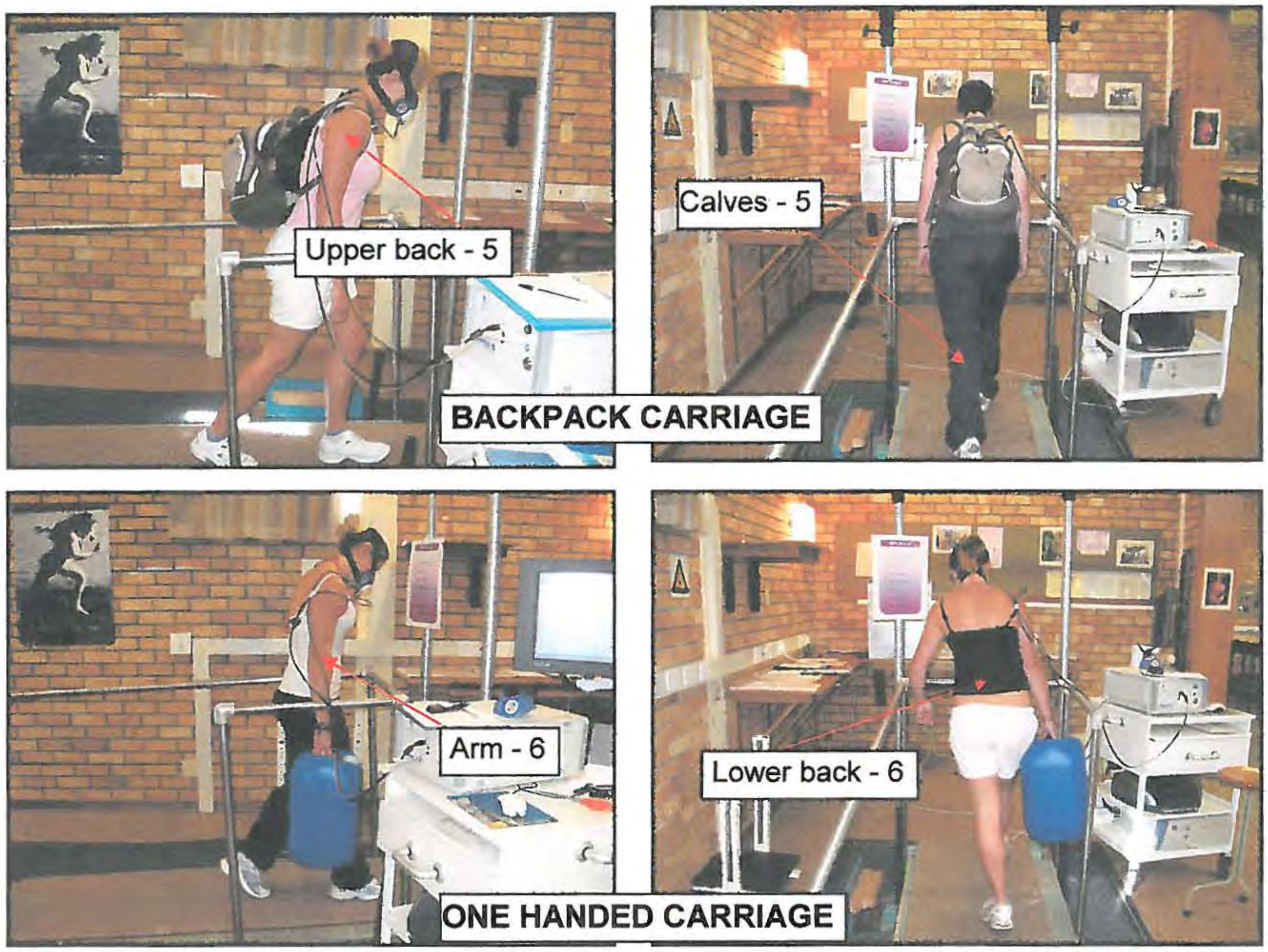


Figure 24: The affect increasing mass has on postures adopted and the associated areas and ratings of discomfort during two methods of load carriage.

Referring to Figure 24 it was found that as mass increased so the participant leant further forward in order to counteract the mass of the load and remain stable. This was greater for backpack carriage, which is in agreement with other findings (Pascoe **et al.**, 1997; Filiare **et al.**, 2001). This increased the discomfort felt in the upper back and calves. LaFiandra and Harman (2004) argued that 70% of the load is carried on the upper back when using a backpack as opposed to only 30% of the load being placed on the lower back explaining the greater discomfort in the upper region of the back. In the hand carriage conditions increasing load mass caused greater lateral bending in order to balance the asymmetrical forces due to the load on the arm, this has been found by other researchers (Fowler **et al.**, 2006). This discomfort therefore increased in the carrying arm and the lower back. In the backpack conditions lateral bending did not occur due to the mass being carried symmetrically across the back.

From the crude 2D analyses compression forces were found to increase when mass increased from 9kg to 15kg. These increases were from 723N to 780N during backpack conditions and from 751N to 935N during hand carriage conditions. Shearing forces were found to increase very little with increasing mass for both modes of carriage, with mean shearing forces of 160N for backpack conditions and 191N for hand carriage conditions. The greater shearing forces found in hand carriage conditions are likely to be the cause of the greater discomfort felt in the lower back during hand carriage conditions compared to backpack conditions.

Gradient

Along with mode of carriage and load mass another factor that will affect carrying posture is that of gradient. Figure 25 reflects backpack and hand carriage conditions at the highest gradient (15%) with the lowest mass (9kg).

In Figure 25 it can be seen that as gradient increased greater discomfort was felt in the calves for both modes of carriage and this is likely to altered gait patterns as the subjects tended to bend their legs more and had more of a flat-footed walk. Increasing gradient also caused increased forward flexion, as the subjects leant towards the slope, for both modes of carriage, but more so in the backpack conditions. The neck was also seen to flex forward, to a lesser degree than the trunk, during these conditions. As such discomfort was felt in the back and neck area during the backpack conditions. This forward lean may also account for the discomfort felt in the lower back during hand carriage as the subjects flexed from the lower back and hip area. As the gradient increased the lateral bending during hand carriage increased concomitantly which is likely to be the cause of the discomfort felt in the lower back (Marras and Granata, 1997).

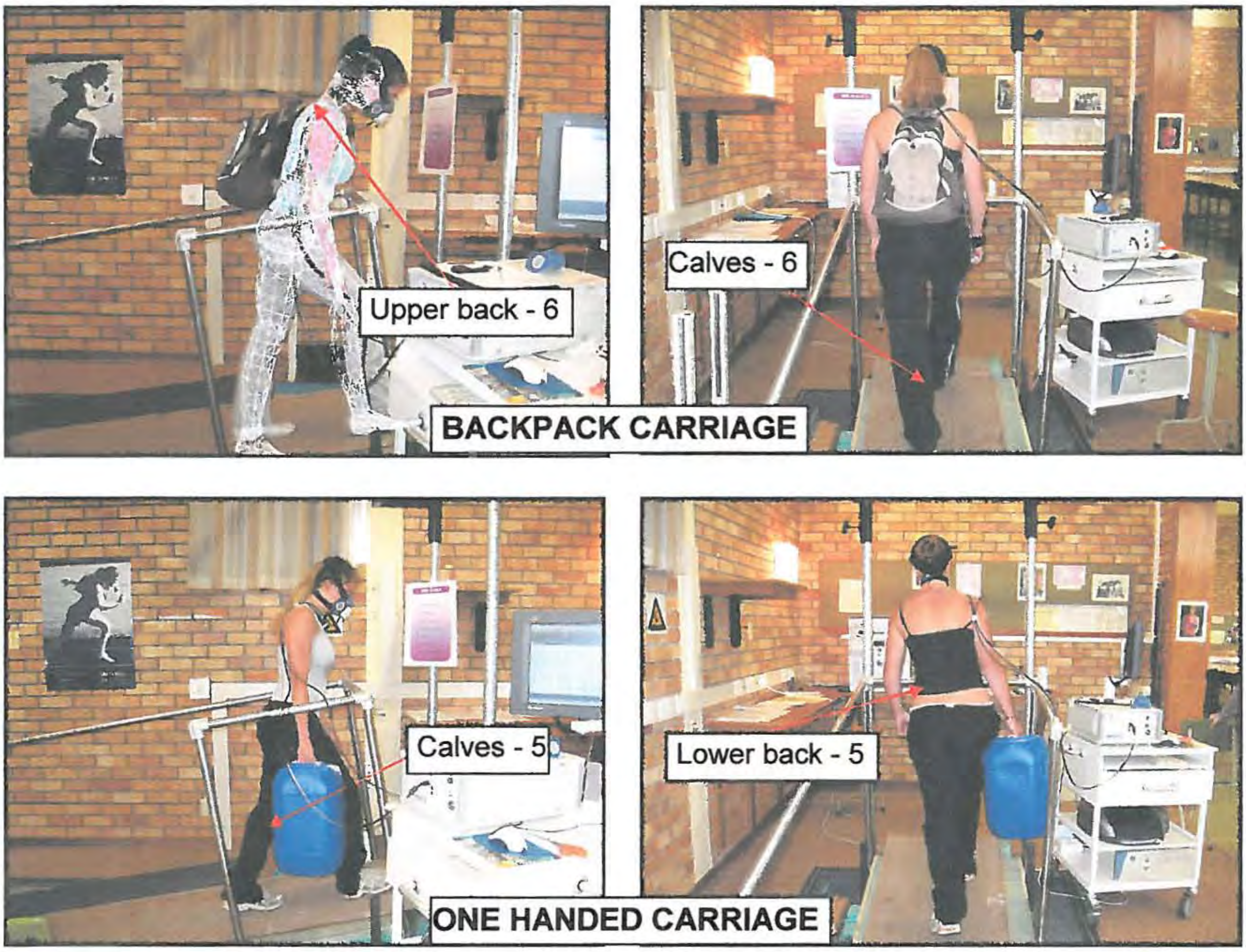


Figure 25: The affect of increasing gradient on postural responses and areas and ratings of discomfort during the two methods of load carriage.

Analyses showed that compression forces generally increased with increasing gradient for both modes of carriage. For backpack carriage compression forces ranged from 681N to 935 N and for hand carriage conditions from 570N to 793N, therefore with increasing gradient compression forces are greater during backpack carrying compared to hand carrying. Shearing forces did not increase to the same extent as compression forces and were found to be marginally higher for hand carriage conditions with mean shearing forces of 160N for backpack carriage and 169N for hand carriage.

INTEGRATED DISCUSSION

The net effect of all components of a task or job system can create fairly complex findings (Ayoub and Mital, 1989) and this is why it is vital when assessing any task to use an 'interdisciplinary holistic approach' (Charteris **et al.**, 1976). This was the approach taken in the present study, although the primary focus was on physiological responses.

Physiological responses

Overall physiological measures determined hand carriage conditions to be more stressful than that of backpack carriage. The backpack conditions which were considered to be particularly straining on the cardiorespiratory and metabolic systems were those with the heaviest load masses and at the highest gradients. A general trend for the majority of physiological responses was found where increasing gradient placed greater strain on these systems in comparison to increasing mass. Thus conditions with lighter masses at steep gradients are considered more physiologically strenuous than heavy loads on lower gradients.

Backpack conditions are seen to be generally acceptable at loads below 12kg and gradients below 15%. The hand carriage conditions considered moderate, and therefore should be acceptable in the carrying of hydrogel were those at low gradients and varying masses (A_1, B_1, D_1, G_1). The hand carriage conditions which should be avoided in the silviculture industry would be those with loads above 12kg and at gradients of 10% and above. This is highly unlikely to occur and thus backpack carriage was the method proposed to the silviculture industry as, in terms of physiological measures, backpack conditions are considered overall to be more efficient and less straining.

Perceptual responses

Although subjects were not accurate in their perception of effort the general trends showed that overall participants perceived hand carriage to require greater effort in the heart and lungs as well as the muscles of the back compared to backpack carriage. 'Local' RPE was found to be marginally higher than 'central' RPE showing that subjects felt greater effort was placed on the musculature compared to the cardiorespiratory system. Gradient was perceived to place marginally more strain on the physiological and muscular systems in comparison to load mass, and in terms of 'central' RPE only gradients at 5% and below should be considered acceptable, and load masses up to 12kg, when carried on a low slope, would be perceived as acceptable. 'Local' RPE demonstrated that only with backpack conditions could loads of varying masses be carried on a gradient of 10%, thus high gradients should be considered unacceptable for both backpack and hand carriage in terms of perceived exertion. The 'central' and 'local' ratings of perceived effort therefore support the physiological findings that backpack carriage is less straining. If workers perceive less strain they are likely to be more productive. Practically it is not feasible to reduce the load or ensure work is only done on flat surfaces and as such, the primary intervention suggested was to replace hand carriage with backpack carriage.

Postural changes and body discomfort

From basic postural analyses it was found that both backpack and hand carriage conditions caused strain on the upper and lower back as well as the carrying arm for hand carriage. Backpack carriage was perceived to cause the largest amount of discomfort on the upper back which increased with increasing load mass and increasing gradient. The calves were also rated as experiencing discomfort with backpack carriage, which increased marginally with increasing load and more so with increasing gradient. Hand carriage caused the largest amount of strain in the lower back, which increased with increasing load mass and increasing gradient, although to a greater degree with increasing load. Thus load mass was seen to affect hand carriage postures and discomfort more than it did backpack carriage, whereas increasing gradient was found to affect backpack carriage postures and discomfort to a greater degree than it did hand carriage postures. This is associated with the compression forces which were found to be worse in hand carriage overall, except with gradients of 10% and 15% where backpack carriage was found to cause greater compression forces. Thus, with increasing gradient compression forces were greater with backpack carriage than hand carriage. Shearing forces were found to be largest during all hand carriage conditions, which would account for the discomfort felt in the lower back, and shearing forces were found to increase to a greater degree with increasing load mass than with increasing gradient during hand carriage. Again, these findings support the contention that backpack carriage is superior although extremes of gradient cause substantial increases in the forces placed on the spine and thus possibly, when there are extreme gradients in particular planting areas, load should be reduced and workers should be given more frequent rest breaks.

Conclusion

In general all the findings reflect that hand carriage is the least efficient method of carriage, and yet it is the method currently employed in the silviculture industry. It is therefore argued that the most important and practically feasible option, which is relatively cost effective, is to ensure hand carriage is replaced by backpack carriage for the hydrogel carriers. However, if working on extreme gradients it must be remembered that all responses will be exacerbated and hence load mass should be reduced and workers should be given more frequent rest breaks to compensate for their elevated responses.

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

INTRODUCTION

Developing countries like South Africa rely heavily on manual labour as the primary method of work. This work is often physically strenuous and places the workforce at increased risk (Dempsey, 1998). Aggravating this situation is the fact that the majority of the manual workforce lives in extreme poverty and this is made worse by poor nutrition and health (Shahnavaz, 1996; Christie, 2002). Ergonomics research globally is lacking in the forestry industry, and because ergonomics considers the compatibility of the worker and the task (Scott, 2001), it has the potential to improve working conditions and worker efficiency in any industry (Boa and Shahnavaz, 1989). In most industries in South Africa the focus has been on low-cost, no-cost interventions in order to ensure the compliance of industry to ergonomics suggestions.

This research therefore considered, in its intervention proposal, not only the human operator but also the cost effectiveness. Although the intervention was not retested in industry, due to time and financial restrictions, it was put forward to the silviculture management and it is suggested that a follow-up study determine the efficacy of the intervention *in situ*.

SUMMARY OF PROCEDURES

The physical workloads imposed on female silviculture workers were observed *in situ* in the Kwazulu-Natal region of South Africa, a main forestry area. Demographic, anthropometric and resting cardiovascular data was obtained before measuring basic physiological and perceptual responses of workers *in situ*. The subtask of carrying of barrels of hydrogel was focused on and determined to place particularly heavy stress on the workers. This task was then simulated in a laboratory setting in order to obtain more rigorous measures of worker responses to the task.

In the experimental phase 28 female student volunteers were assessed carrying loads in two different ways at three different masses on three different gradients (18 conditions).

The participants were divided up into two groups and each individual was required to perform nine conditions of different modes, masses and gradients in total (three per session for three sessions). At the first session demographic and anthropometric were collected and habituation on the treadmill was completed, after which subjects were fitted with polar heart rate monitors and face masks for the Quark b^2, an online metabolic system. The participant was then fitted to the Quark b^2 and resting cardiovascular responses were collected. Each condition was performed for four minutes and during this time lateral and posterior digital images were recorded after the first minute and at the fourth minute, for postural analyses. Both 'central' and 'local' ratings of perceived exertion were recorded every minute, and physiological data was measured continuously. At the end of the four minutes the subject stepped off the stationary treadmill and sat quietly while physiological variables returned to reference values. During this time areas of body discomfort were recorded. Once the metabolic measures returned to reference values, the Quark b^2 was detached from the subject. Stature was measured against a wall in order to obtain crude measures of spinal shrinkage. The participant then sat and relaxed while other participants performed conditions.

The investigation took a holistic approach, as suggested by Charteris **et al.** (1976), and the following variables were analysed:

Spinal Kinematics:	Postural changes
Physiological variables:	Heart rate, ventilatory responses, oxygen consumption, carbon dioxide production, respiratory quotient and energy expenditure
Perceptual variables:	'central' RPE, 'local' RPE and body discomfort

SUMMARY OF RESULTS

Cardiovascular, respiratory and metabolic responses revealed that, in general, hand carriage placed more strain on the participants compared to backpack carriage. Mean heart rate, oxygen uptake (VO_2) and energy expended per minute for all backpack carriage conditions were 129 $bt.min^{-1}$, 22.15 $mlO_2.kg^{-1}.min^{-1}$ and 29.41 $kJ.min^{-1}$ as opposed to 146 $bt.min^{-1}$, 25.09 $mlO_2.kg^{-1}.min^{-1}$ and 34.49 $kJ.min^{-1}$ for the hand carriage conditions. Every hand carriage condition elicited higher physiological responses than its counterpart backpack condition, and the highest responses (heart rate of 174 $bt.min^{-1}$,

VO_2 of 30.19 $mlO_2.kg^{-1}.min^{-1}$ and energy expenditure of 45.03 $kJ.min^{-1}$) were recorded during the hand carriage condition at the heaviest mass (15kg) and at the highest gradient (15%). The majority of conditions which were categorised as 'very heavy' according to Sanders and McCormick (1993), for all the physiological variables, were hand carriage conditions, and the majority of conditions classified as 'moderate' by these same authors were backpack conditions. In the middle category of 'heavy' there were a range of modes, masses and gradients. It was found that both mass and gradient had significant effects on physiological responses; however, gradient was found to have the greater affect. The average increases across conditions, due to increasing gradient, were larger than those due to mass. For increasing gradient heart rate responses increased by 32%, VO_2 by 43% and energy expenditure by 36%. For increasing mass, heart rate increased by 20%, VO_2 by 22% and energy expenditure by only 11%. Overall, physiological responses demonstrated that hand carriage was the more stressful mode of carriage and that gradient had a greater impact than mass on all physiological variables.

The perceptual responses to hand carriage showed that participants perceived hand carriage tasks to be slightly more taxing than backpack carriage conditions with a mean 'central' RPE for the fourth minute being 13 for hand carriage conditions and 12 for backpack conditions. Mean 'local' RPE was 14 for the hand carriage conditions and 12 for the backpack conditions. 'Local' RPE values were found to be marginally higher than those of 'central' RPE, showing that participants felt more strain in the musculoskeletal system, specifically the back, than they did in the heart and lungs. A positive correlation with R = 0.82 was found between these 'central' RPE and heart rate measures. At the conditions classified as 'moderate' there was more of a tendency to overrate perceived exertion and at the conditions in the category of 'very heavy' there was more underestimation of exertion by participants but in general subjects were accurate in their perceptual ratings.

From crude postural analyses it was found that backpack carriage caused subjects to adopt a posture of forward flexion at the trunk, which increased with increasing mass and to a greater extent with increasing gradient. During hand carriage conditions subjects adopted postures that involved more lateral bending, although slight forward flexion was noted. This lateral bending increased with increasing mass and the forward flexion increased slightly with increasing gradient. These postures adopted account for the discomfort felt in the lower back by the participants. For backpack carriage, discomfort was felt primarily in the upper back and calves, particularly as gradient increased which is likely due to the posture of forward flexion. Stature was found to have decreased following backpack conditions with a mean decrease of 20mm, this is reflective of spinal shrinkage due to fluid loss from the intervertebral discs. In the hand carriage conditions discomfort was also experienced in the carrying arm which was due to the majority of the mass being carried by the smaller muscles of one extremity. Compression forces were found to be higher in hand carriage compared to backpack carriage except at 10% and 15% gradients. Shearing forces were greater in hand carriage than in backpack carriage.

STATISTICAL HYPOTHESES

The hypotheses are discussed with reference to the responses recorded during the fourth minute of experimentation. Due to the large number of conditions assessed, and the extensive number of significant differences found throughout conditions, the rejection or tentative acceptance of hypotheses will be based on the majority of statistically significant responses which have been identified as a percentage of the total number of responses.

Physiological responses were the lowest during the conditions which were classified as 'moderate' stress and the highest during conditions in the classification of 'very heavy' stress. In general it was found that hand carriage was less efficient in terms of physiological responses than backpack carriage, and that increasing gradient had a greater impact on responses than increasing load mass.

Hypothesis 1:

The null hypothesis 1(i) is rejected as the hand carriage conditions were found to be statistically different to those of the backpack conditions in the majority of conditions. Significant differences were found between load masses of 9kg and 15kg as well as between 12kg and 15kg, but no difference was found between 9kg and 12kg. Therefore the null hypothesis for 1(ii) is rejected. Significant differences were found between each increase in gradient, 5% to 10%, 10% to 15% and 5% to 15%, thus the null hypothesis 1(iii) is also rejected.

In terms of perceptual responses significant differences were not found between hand carriage conditions and backpack conditions therefore hypothesis 1B (i) is tentatively retained, and no differences were found with increasing load mass or increasing gradient, thus hypotheses 1B (ii) and 1B (iii) are tentatively retained.

Hypothesis 2:

With respect to cardiac responses, less than half of the conditions (44%) were statistically different thus hypothesis 2A (i) is tentatively retained. In terms of oxygen uptake (VO_2) and energy expenditure (EE), the majority (66% and 69% for VO_2 and EE respectively) of the conditions were statistically different thus hypotheses 2 A (ii) and (iii) are rejected.

In terms of the perceptual responses, there was no significant difference with 'central' RPE between all conditions except with condition I_2, which was significantly different to 56% of the other conditions. With 'local' RPE most of the conditions were not statistically different. Therefore, with respect to perceptions of effort, the null hypothesis 2B (i) is retained.

CONCLUSION

The results found in this study indicate that backpack carriage in general is a less stressful and more efficient method of carriage compared to hand carriage. The results show that an increase in gradient while walking with a load significantly affects postural changes, physiological and perceptual responses. Although to a lesser degree, increasing load mass also causes significant changes in posture, physiological and perceptual responses. Load mass was seen to have a greater affect on hand carriage conditions and gradient to have a greater affect on backpack conditions. The combination of heavy load mass and steep gradient caused 'very heavy' strain to be placed on the participants during both modes of carriage; thus, even with the more efficient method of backpack carriage, if performed with heavy loads at steep gradients it would be considered an unacceptable task. As gradient and mass decreased so the strain became less, even with hand carriage; therefore at lower gradients and with lighter loads hand carriage is an acceptable method of carriage.

The primary intervention proposed was therefore to replace the barrels with a backpack. It was suggested that the backpack be designed to ensure that not only was the load evenly distributed but also that a 'pipe' be engineered which would lead from the backpack to the carriers hand. This would ensure that the carrier would not have to bend forward continuously, a subtask not investigated in this study but one which will increase the forces on the spine.

Additional to suggestions put forward in the ergonomics consultancy report (Scott **et al.**, 2005) were as follows:

- Task rotation: with the other workers who are performing the tasks of spraying, hoeing, pitting and placing saplings. It is acknowledged that this may require additional training and that workers are often reluctant to do this as it has been found that sometimes some tasks are seen as more 'superior' and hence have higher wages. The suggestion was given therefore from the perspective of ensuring that less strain was placed on the workers
- Work-to-rest rations: Ensure adequate rest breaks are given and possibly abolish the piece-rate system of payment.

RECOMMENDATIONS

Future investigations into postural, physiological and perceptual responses of varying combinations of methods of load carriage, load masses and gradients specific to the task of carrying of hydrogel in the South African silviculture industry, should consider the following recommendations:

1) Further laboratory investigations, where various factors can be rigorously controlled, should be performed in order to gain a greater understanding of the biomechanical, metabolic and psychophysical responses to load carriage. These investigations should consider the following:

    a. Most load carriage tasks are performed over prolonged periods of time thus longer duration testing sessions should be done in order to do a more accurate investigation with respect to 'physiological drift' and the impact of fatigue.

    b. Other methods of carriage should be investigated to determine the 'ideal' mode of carriage, and further load mass and gradient combinations need to be assessed in order to determine guidelines as to the 'ideal' combinations for load carriage.

2) In order for ergonomics to have a significant impact on industries, and specifically the forestry industry, more research needs to be done *in situ* and in combination with laboratory studies. Thus future load carriage research in the silviculture sector needs to assess workers' responses in their work environments in order to obtain more realistic measures. Laboratory studies should also implement proposed interventions in real situations and re-evaluate responses to determine whether the interventions are beneficial.

    a. More comprehensive *in situ* studies of the task of carrying of hydrogel should be done. A larger sample size should also be assessed. A greater selection of measures should be investigated, as well external variables that affect worker responses such as temperature, clothes and worker experience.
    b. Worker capabilities should be assessed in further detail and factors such as training status, work experience and injury history should be considered. In addition an important consideration, from a South African perspective, is the need for more detailed analyses of workers' health and nutritional status should be done.
    c. Research done *in situ* should include assessments of the balance between the energy cost of silviculture tasks and the associated energy intakes of the workers.

REFERENCES

Note: Asterisked citations * are secondary sources. These are not directly consulted and are referenced as fully as primary sources, indicated in brackets, permit.

Abe D, Yanagawa K and Niihata S (2004). Effects of load carriage, load position, and walking speed on energy cost of walking. **Applied Ergonomics**. 35: 329-335.

Apud E (1983). **A Human Biological Field Study of Chilean Forestry Workers**. PhD Thesis, Loughborough University of Technology.

Apud E (1995). Ergonomics in Forestry: The Chilean case. **MSc, PLD**. Sergio Valdes, Forest engineering. International Labour Office, Geneva.

Ashby L and Parker R (2003). **The Forest Silviculture Accident Reporting Scheme. Summary of Reports – 2002**. Centre for Human Factors and Ergonomics.

Asogwa SE (1987). Prevention of accidents and injuries in developing countries. **Ergonomics**, 30(2): 379-386.

Åstrand PO and Rodahl K (1986). **Textbook of Work Physiology – Physiological Bases of Exercise,** Third Edition. New York: McGraw Hill.

Attanapola CT (2004). Changing gender roles and health impacts among female workers in export-processing industries in Sri Lanka. **Social Science and Medicine**. 58:2301-2312.

Ayoub MM (1992). Problems and solutions in manual materials handling: the state of the art. **Ergonomics,** 35 (7/8): 713-728.

Ayoub MM and Mital A (1989). **Manual Materials Handling.** London: Taylor and Francis.

Bales DW, Craig BN, Congleton JJ, Kerk CJ, Amendola AA, Gaines WG and Jenkins OC (2001). The influence of supporting the Oxylog instrument on estimated maximal aerobic capacity during a step test and heart rate in a lifting test. **Applied Ergonomics,** 32: 367-377.

Bao S and Shahnavaz H (1989). The promises and problems of ergonomics application in the People's Republic of China. **Applied Ergonomics**. 20(4): 287-292.

Bellan Y, Gaia E and Rizzuto F (2000). ANNIE: Standard bio-mechanics and cognitive models for computer aided ergonomics. **Proceedings of the XIVth Triennial Congress of the International Ergonomics Association and 44th Annual Meeting of the Human Factors and Ergonomics Association, 'Ergonomics for the New Millennium',** pp. 857-860.

Bentley TA, Parker RJ, Ashby L, Moore DJ and Tappin DC (2002). The role of New Zealand forest industry surveillance system in a strategic Ergonomics, Safety and Health Research Programme. **Applied Ergonomics,** 26: 395-403.

Bhambhani Y, Buckley S and Maikala R (1997). Physiological and biomechanical responses during treadmill walking with graded loads. **European Journal of Applied Physiology**, 76:544-551.

Bhambhani Y and Maikala R (2000). Gender differences during treadmill walking with graded loads: biomechanical and physiological comparisons. **European Journal of Applied Physiology**, 81:75-83.

Blombäck P and Poschen P (2003). Decent work in forestry? Enhancing forestry work and forest-based livliehoods. **Paper presented at XII World Forestry Congress.** Quebec City, Canada.

Borg GAV (1970). Perceived exertion as an indicator of somatic stress. **Scandinavian Journal of Rehabilitaion Medicine,** 2:92-98.

Borg G (1978). Subjective Aspects of Physical and Mental Load. **Ergonomics**. 21(3): 215-220.

*Borghols EAM, Dressen MHW and Hollander AP (1978). Influence of heavy weight carrying on the cardiorespiratory system during exercise. **European Journal of Applied Physiology** 38:161-169. (See Haisman, 1988).

Brooks GA and Mercier J (1994). Balance of carbohydrate and lipid utilization during exercise: the "crossover" concept. **American Physiological Society**, 2253-2261

Bunc V and Dhoula R (1997). Energy cost of treadmill walking. **Journal of Sports Medicine and Physical Fitness**, 27(2): 103-109.

*Byers J and Adams D (1995). Otago/Southland forestry workforce 1993: Five years later. **LIRO project report No. 58. New Zealand: New Zealand logging institute** (See Lilley **et al.**, 2002).

*Carre LT (1908). Historical review of the load of the foot soldiers. La Revue D'Infanterie, 1907. Translated by PH Miles. **Infantry Journal,** 5: 757-916. (See Pierrynowski **et al.**, 1981).

Carey TS and Crompton RH (2005). The metabolic costs of "bent hip, bent knee" walking in humans. **Journal of Human Evolution**. 48: 25-44.

Casaburi R, Storer TW, Ben-Dov I and Wasserman K (1987). Effect of endurance training on possible determinants of VO_2 during heavy exercise. **Journal of Applied Physiology,** 62 (1): 199-207.

Cathcart EP, Lothian NV and Greenwood M (1920). A note on the rate of marching and the expenditure of energy in man. **Journal of the Royal Army Medical Corps**, 34(4): 297-305.

Cerny FJ and Ucer C (2004). Arm work interferes with normal ventilation. **Applied Ergonomics,** 35: 411-415.

Chaffin DB and Andersson GBJ (1991). **Occupational Biomechanics.** Second Edition. United States: John Wiley and Sons, Inc.

Chaffin DB (2005). Improving digital human modelling for proactive ergonomics in design. **Ergonomics,** 48 (5): 478-491.

Charteris J, Cooper LA and Bruce JR (1976). Human Kinetics: A Conceptual Model for Studying Human Movement. **Journal of Human Movement Studies**, 2: 223-238.

Charteris J, Nottrodt JW and Scott PA (1989b). The 'free-ride' hypothesis: a second look at the efficiency of African women headload carriers. **South African Journal of Science**, 85: 68-71.

Christie CJ (2002). Relationship between energy intake and energy expenditure during manual work in South Africa. **Proceedings of the Third International Cyberspace Conference on Ergonomics,** 15 September-15 October.

Christie CJ (2002). Effects of varying speed-load combinations on selected physiological, biomechanical and perceptual responses. **Unpublished MSc Thesis,** Department of Human Kinetics and Ergonomics, Rhodes University, Grahamstown, South Africa.

Christie CJ and Scott PA (2005). Physiological and perceptual responses of female debarkers during forestry work. **Proceedings of the Fourth International Cyberspace Conference on Ergonomics,** 15 September-15 October.

Chung MK, Lee I and Kee D (2005). Quantitative postural load assessment for whole body manual tasks based on perceived discomfort. **Ergonomics**. 48(5): 492-505.

Coury HJCG, Leo JA and Kumar S (2000). Effects of progressive levels of industrial automation on force and repetitive movements of the wrist. **International Journal of Industrial Ergonomics** 25: 587-595.

Coury HJCG., Porcatti IA, Alem MER and Oishi, J (2002). Influence of gender on work-related musculoskeletal disorders in repetitive tasks. **International Journal of Industrial Ergonomics,** 29 (1): 33-39.

Corlett EN (1981). **The evaluation of posture and its effects**. Part V, 23 in Evaluation of Human Work. pp 662-713.

Corlett EN and Bishop RP (1976). A technique for assessing postural discomfort. **Ergonomics,** 19 (2): 175-182.

Dahlberg R, Karlqvist L, Bildt C and Nykvist K (2004). Do work technique and musculoskeletal symptoms differ between men and women performing the same types of work tasks? **Applied Ergonomics,** 35(6): 521-529.

Davis KG, Jorgensen MJ and Marras WS (2000). An investigation of perceived exertion via whole body exertion and direct muscle force indicators during the determination of the maximum acceptable weight of lift. **Ergonomics,** 43 (2): 143-159.

Davis KG and Marras WS (2003). Partitioning the contributing role of biomechanical, psychosocial, and individual risk factors in the development of spine loads. **Spine Journal,** 3 (5): 331-338.

*Deeb JM, Drury CG and Begbie KL (1985). Handle positions in a holding task as a function of task height. **Ergonomics,** 28(5): 747-763 (See Bhambhani **et al.**, 1997).

Dempsey PG (1998). A critical review of biomechanical, epidemiological, physiological and psychophysical criteria for designing manual materials handling tasks. **Ergonomics,** 41(1): 73-88.

Dempsey PG and Hashemi L (1999). Analysis of workers' compensation claims associated with manual materials handling. **Ergonomics**. 42(1): 183-195.

DeVita P, Hong D and Hamill J (1992). Effects of asymmetric load carrying on the biomechanics of walking. **Journal of Biomechanics,** 24 (12): 1119-1129.

de Zwart BCH, Frings-Dresen MHW and Kilbom A (2001). Gender differences in upper extremity musculoskeletal complaints in the working population. **International Archives of Occupational and Environmental Health,** 74 (1): 21-30.

Drury CG and Pizatella T (1983). Hand placement in manual materials handling. **Human Factors,** 25 (5): 551-562.

Duggan A and Haisman MF (1992). Prediction of the metabolic cost of walking with and without loads. **Ergonomics,** 35 (4): 417-426.

*Ekblom B and Goldbarg AN. (1971). The influence of physical training and other factors on the subjective rating of perceived exertion. **Acta Physiologica Scandinavica,** 83: 399-406 (See Pandolf 1978).

El-Rich M and Shirazi-Adl A (2005). Effect of load position on muscle forces, internal loads and stability of the human spine in upright postures. **Computer Methods in Biomechanics & Biomedical Engineering**. 8(6): 359-368.

Engelbrecht R and Manyuchi KT (2001). Ergonomic developments in forest engineering in the South African Forest Industry. **Ergonomics SA**, 1: 2-10.

Epstein Y, Rosenblum J, Burstein R and Swaka MN (1988). External load can alter the energy cost of prolonged exercise. **European Journal of Applied Physiology**. 57(2): 243-247.

Eston R and Reilly T (2001). **Kinanthropometry and exercise physiology laboratory manual: tests, procedures and data.** Volume 2: Exercise Physiology. Second Edition.

Evans WJ, Winsmann FR, Pandolf KB and Goldman RF (1980). Self-paced hard work comparing men and women. **Ergonomics**, 23(7): 613-621.

Feyen R, Liu Y, Chaffin D, Jimmerson G and Joseph B (2000). Computor-aided ergonomics: a case study of incorporating ergonomics analyses into workplace design. **Applied Ergonomics**. 31: 291-300.

*Filiare M, Vacheron JJ, Vanneuville G, Poumarat G, Garcier JM, Harouna Y, Guillot M, Terver S, Toumi H and Thierry C (2001). Influence of the mode of load carriage on the static posture of the pelvic girdle and the thoracic and lumbar spine in vivo. **Surgical and Radiologic Anatomy,** 23: 27-31 (See Motmans **et al.**, 2006).

Forsman M, Hansson G-A, Medbo L, Asterland P and Engström T (2002). A method for evaluation of manual work using synchronised video recordings and physiological measurements. **Applied Ergonomics,** 33: 533-540

Fowler NE, Rodacki ALF and Rodacki CD (2006). Changes in stature and spine kinematics during a loaded walking task. **Gait and Posture**. 23: 133-141.

Franco G and Fusetti L (2004). Bernardino Ramazzini's early observations of the link between musculoskeletal disorders and ergonomic factors. **Applied Ergonomics,** 35:67-70.

Gallagher S (2005). Physical limitations and musculoskeletal complaints associated with work in unusual or restricted postures: A literature review. **Journal of Safety and Research**. 36: 51-61.

Gamberale F (1985). The perception of exertion. **Ergonomics**, 28(1): 299-308.

Garg A, Chaffin DB and Herrin GD (1978). Prediction of metabolic rates of manual materials handling jobs. **American Industrial Hygiene Association Journal**. 39: 661-673.

Gerr F and Mani L (2000). Work-related low back pain. **Primary Care**. 27(4): 865-876.

Giefing DF, Grzywiński W and Kosak J (2003). Physical work load of workers during planting using different types of dibbles. **Electronic Journal of Polish Agricultural Universities,** 6 (1): 1-7.

Giguère D, Belanger R, Gauthier J-M and Larue C (1993). Ergonomics aspects of tree-planting using 'multipot' technology. **Ergonomics**, 36 (8): 963-972.

Goedecke JH, St Clair Gibson A, Grobler L, Collins M, Noakes TD and Lambert EV (2000). Determinants of the variability in respiratory exchange ratio at rest and during exercise in trained athletes. **American Journal of Physiology: Endocrinology and Metabolism,** 279 (6): E1325-1334

González-Alonso J, Calbet JAL and Nielsen R (1998). Muscle blood flow is reduced with dehydration during prolonged exercise in humans. **Journal of Physiology,** 513 (3): 893-905.

Gordon MJ, Goslin BR, Graham T and Hoare J (1983). Comparison between load carriage and grade walking on a treadmill. **Ergonomics**. 26(3): 289-298.

Goslin BR and Rorke SC (1986). The perception of exertion during load carriage. **Ergonomics**. 29(5): 677-686.

Grandjean E (1986). **Fitting the task to the Man: An ergonomic approach.** Taylor and Francis. London and Philadelphia.

Grego F, Vallier J-M, Collardeau M, Rosseu C, Cremieux J and Brisswalter J (2005). Influence of exercise duration and hydration status on cognitive function during prolonged cycling exercise. **International Journal of Sports Medicine,** 26 (1): 27-33.

Hagberg M and Wegman D (1987). Prevalence rates and odds ratios of shoulder-neck diseases in different occupational groups. **British Journal of Industrial Medicine,** 44 (9): 602-610.

Hagen KB, Magnus P and Vetlesen K (1998). Neck/shoulder and low-back disorders in the forestry industry: relationship to work tasks and perceived psychosocial job stress. **Ergonomics**. 41(10): 1510-1518.

Haisman MF (1988). Determinants of load carrying ability. **Applied Ergonomics** 19(2): 111-121.

Halkett J (2006). Unsafe Statistics. **Inwood Magazine,** 67: 30-32.

Hansson G-Å, Balogh I, Ohlsson K, Pålsson B, Rylander L and Skerfing S (2000). Impact of physical exposure of neck and upper limb disorders in female workers. **Applied Ergonomics**. 31:301-310.

Haslegrave CM (1994). What do we mean by a 'working posture'? **Ergonomics**. 37(4): 781-799.

Haslegrave CM, Tracy MF and Corlett EN (1997). Force exertion in awkward working postures – strength capability while twisting or working overhead. **Ergonomics,** 40 (12): 1335-1362.

Helander MG (1997). Forty years of IEA: Some reflections on the evolution of ergonomics. **Ergonomics,** 40 (10): 952-961.

Hong Y, Li JX, Wong ASK and Robinson PD (1998). Weight of schoolbags and the metabolic strain created in children. **Journal of Human Movement Studies,** 35 (4): 187-200.

Hughes AL and Goldman RF (1970). Energy cost of "hard work". **Journal of Applied Physiology,** 29 (5): 570-572.

Jafry T and O'Neill DH (2000). The application of ergonomics in rural development: a review. **Applied Ergonomics,** 31: 263-268.

Jiang BC (1986). Psychophysical modeling for combined manual-materials-handling activities. **Ergonomics,** 29 (10): 1173-1190.

Juul-Kristensen B, Fallentin N and Ekdahl C (1997). Criteria for classification of posture in repetitive work by observation methods: A review. **International Journal of Industrial Ergonomics,** 19: 397-411.

Kalis JK, Freund BJ, Joyner MJ, Jilka SM, Nittolo J and Wilmore JH (1988). Effect of β-blockade on the drift in O_2 consumption during prolonged exercise. **Journal of Applied Physiology,** 64: 753-758.

Kemper HCG, Kok MLJ, Maas S and Westra HG (1990). Validity of the use of heart rate in estimation of oxygen uptake in static and in combined static/dynamic exercise in man. **Journal of Physiology,** 420: 57P.

Keren G, Epstein Y, Magazanik A and Sohar E (1981). The energy cost of walking and running with and without a backpack load. **European Journal of Applied Physiology,** 46: 317-324.

Keyserling WM (2000). Workplace risk factors and occupational musculoskeletal disorders, part 2: A review of biomechanical and psychophysical research on risk factors associated with upper extremity disorders. **American Industrial Hygiene Association Journal,** 61 (2): 231-243.

Kirk PM, Sullman MJM and Parker RJ (1998). The physical demands of New Zealand forest work. **Proceedings of the Ergonomics Conference**, Cape Town, South Africa, 9-11 September 1998.

*Knapik J, Johnson R, Ang P, Meiselman H, Bensel C, Johnson W, Flynn R, Hanlon W, Kirk J, Harman E, Frykman P and Jones B (1993). Road march performance of special operations soldiers carrying various loads and load distributions. **Natick MA: US Army Research Institute of Environmental Medicine, Technical Report T14-93**. (See Knapik **et al.,** 1996).

Knapik J, Harman E and Reynolds K (1996). Load carriage using packs: A review of physiological, biomechanical and medical aspects. **Applied Ergonomics,** 27 (3): 207[216.

Knapik JJ, Reynolds KL and Harman E (2004). Soldier load carriage: historical, physiological, biomechanical and medical aspects. **Military Medicine** 169(1): 45-56.

Kogi K (1997). Low-cost ergonomic solutions in small-scale industries in developing countries. **African Newsletter on Occupational Health and Safety,** 7 (2): 31-33.

Koradecka D (1997). Ergonomics and safety in societies in transfer. **Ergonomics**. 40(10): 1130[1147.

Kroemer KHE and Grandjean E (1997). **Fitting the task to the human**. A textbook of occupational ergonomics. Fifth edition. Taylor and Francis, London.

Kumar S, Narayan Y and Bacchus C (1995). Symmetric and asymmetric two-handed pull-push strength of young adults. **Human Factors,** 37: 854-865.

Kumar S, Fagarasanu M, Narayan Y and Prasad N (2006). Measures of localized spinal muscle fatigue. **Ergonomics,** 49 (11): 1092-1110.

Kuo CF and Chu CH (2005). An online ergonomic evaluator for 3D product design. **Computers in Industry,** 56 (5): 479-492.

LaFiandra M and Harman E (2004). The Distribution of Forces between the Upper and Lower back during Load Carriage. **Medicine and Science in Sports and Exercise**, pp 460-467.

Lambert MI, Cheevers EJ and Coopoo Y (1994). Relationship between energy expenditure and productivity of sugar cane cutters and stackers. **Occupational Medicine**. 44: 190-194.

Laurensen B, Ekner D, Simonsen EB, Voigt M and Sjøgaard G (2000). Kinetics and energetics during uphill and downhill carrying of different weights. **Applied Ergonomics**, 31: 159-166.

Legg SJ (1985). Comparison of different methods of load carriage. **Ergonomics**, 28(1):197-212.

Legg SJ and Mahanty (1985). Comparison of five modes of carrying a load close to the trunk. **Ergonomics**. 28(12): 1653-1660.

Legg SJ, Ramsey T and Knowles DJ (1992). The metabolic cost of backpack and shoulder load carriage. **Ergonomics**, 35(9): 1063-1068.

Lilley R, Feyer A, Kirk P and Gander P (2002). A survey of forest workers in New Zealand. Do hours of work, rest and recovery play a role in accidents and injury? **Journal of Safety Research**. 33: 53-71.

Loewenson RH (1999). Women's occupational health in globalisation and development. **American Journal of Industrial Medicine**. 36(1): 34-42.

Lukmanji Z (1992). Women's workload and its impact on their health and nutritional status. **Progress in food and nutrition science**. 16: 163-179.

Lyons A-A (2001). **Reducing the Risk of Injuries in Tree Planters.** Human Kinetics Undergraduate Thesis, University of British Columbia.

Maas S, Kok NLJ, Westra HG and Kemper HCG (1989). The validity of the use of heart rate in estimating oxygen consumption in static and in combined static/dynamic exercise. **Ergonomics,** 42 (5): 761-766.

Mackie HW, Stevenson JM, Reid SA and Legg SJ (2005). The effect of simulated school load carriage configurations on shoulder strap tension forces and shoulder interface pressure. **Applied Ergonomics,** 36 (2): 199-206.

Madras DE, Cornwall MW and Coast JR (1998). Energy cost, perceived exertion and postural adjustments when treadmill walking with two types of backpacks. **Journal of Human Movement Studies,** 35 (5): 233-249.

*Malhotra MS and Sen Gupta J (1965). Carrying of schoolbags by children. **Ergonomics,** 8: 55-60. (See Legg and Mahanty, 1985).

Maloiy GMO, Heglund NC, Prager LM, Cavagna CA and Taylor CR (1986). Energy cost of carrying loads: have African women discovered an economic way? **Nature,** 319: 668-669.

Manyuchi KT, Pulkki RE and Ackerman P (2003). An Analysis of Occupational Health and Safety in Forest Harvesting in the South African Forest Industry. **Ergonomics SA**, 1: 2-17.

Marras WS and Granata KP (1997). Spine loading during trunk lateral bending motions. **Journal of Biomechanics,** 30 (7): 697-703.

Marras WS (2000). Occupational low back disorder causation and control. **Ergonomics**. 43(7): 880-902.

Martin PE and Nelson RC (1986). The effect of carried loads on the walking pattern of men and women. **Ergonomics**, (10): 1191-1202

*Martin TW, Zeballos RJ and Weisman IM (1991). Gas exchange during maximal upper extremity exercise. **Chest,** 99: 420-425 (See Cerny and Ucer, 2004).

McArdle WD, Katch FI and Katch VL (2001). **Exercise Physiology**. Fifth Edition. Baltimore: Williams and Wilkins.

*McIlroy MB, Marshall R and Christie RV (1954). The work of breathing in normal subjects. **Clinical Science,** 13: 127-136 (See Cerny and Ucer, 2004).

*Melhorn JM. (1998). Cumulative trauma disorders and repetitive strain injuries. The future. **Clinical Orthopaedics.** 351:107-126 (See Hansson **et al.,** 2000).

Meister D (2000). An outsider's view of cognitive ergonomics. **Proceedings of the XIVth Triennial Congress of the International Ergonomics Association and 44th Annual Meeting of the Human Factors and Ergonomics Association, 'Ergonomics for the New Millennium'**,. pp 561-563.

Meyers JM, Faucett J, Tejeda DG, Kabashima J, Miles JA, Janowitz I, Duraj V, Smith R and Weber E (2000). High risk tasks for musculoskeletal disorders in agricultural field work. **Proceedings of the XIVth Triennial Congress of the International Ergonomics Association and 44th Annual Meeting of the Human Factors and Ergonomics Association, 'Ergonomics for the New Millennium'.** pp 616-619.

Mirka GA, Kelaher, DP, Nay DT and Lawrence BM (2000). Continuous assessments of back stress (CABS): A new method to quantify low-back stress in jobs with variable biomechanical demands. **Human Factors**. 42 (2): 209-225.

Minetti AE, Moia C, Roi GS, Susta D and Ferretti G (2002). Energy cost of walking and running at extreme uphill and downhill slopes. **Journal of Applied Physiology,** 93: 1039-1046.

Mohan, D (1987). Injuries and the 'poor' worker. **Ergonomics**, 30(2): 373-377.

Motmans RREE, Tomlow S and Vissers D (2006). Trunk muscle activity in different modes of carrying schoolbags. **Ergonomics** 49(2): 127-138.

*NIOSH (1997). Musculoskeletal Disorders and workplace factors – a critical review of epidemiologic evidence for work-related musculoskeletal disorders of the neck, upper extremity and low back. U.S. Department of Health and Human Services. (See Coury **et al.**, 2000).

Noble BJ (1982). Clinical applications of perceived exertion. **Medicine and Science in Sports and Exercise** 14(5): 406-411.

Noble BJ, Borg GAV, Jacobs I, Ceci R and Kaiser P (1983). A category-ratio perceived exertion scale: relationship to blood and muscle lactates and heart rate. **Medicine and Science in Sports and Exercise** 15(6): 523-528.

Nordin M, Ortengren R and Andersson GBJ (1984). Measurements of trunk movements during work. **Spine,** 9 (5): 465-469.

Oborne DJ (1995). **Ergonomics at Work**. Third Edition. New York: John Wiley and Sons.

O'Neill DH (2000). Ergonomics in industrially developing countries: does its application differ from that in industrially advanced countries. **Applied Ergonomics**, 31: 631-640.

O'Neill DH (2005). The promotion of ergonomics in industrially developing countries. **International Journal of Industrial Ergonomics,** 35: 163-168.

Orloff, HA and Rapp, CM (2004). The effects of Load Carriage on Spinal curvature and Posture. **Spine** 29(12): 1325-1329.

Pandolf K (1978). Influence of local and central factors in dominating rated perceived exertion during physical work. **Perceptual and Motor Skills** 46: 683-698.

Padula RS and Coury HJCG (2003). Sagittal trunk movements during load carrying activities: a pilot study. **International Journal of Industrial Ergonomics**, 32: 181-188.

*Parker R and Kirk P (1994). Physiological workload of forest work. **LIRO Brief report**, 19(4): 1 – 7 (See Lilley **et al.,** 2002)

Pascoe DD, Pascoe DE, Wang YT, Shim D-M and Kim CK (1997). Influence of carrying book bags on gait cycle and posture of youths. **Ergonomics,** 40 (6): 631-641.

Passmore R and Durnin JVGA (1955). Human Energy Expenditure. **Physiological Review,** Volume 35 (4): 801-839.

Patla AE (1980). Effects of walking on various inclines on EMG patterns of lower limb muscles in humans. **Human Movement Science,** 5: 345-357.

Patton JF, Kaszuba J, Mello RP and Reynolds KL (1991). Physiological responses to prolonged treadmill walking with external loads. **European Journal of Applied Physiology**, 63: 89-93.

Petersson NF, Mathiassen SE, Bjoring G and Winkel J (2000). The accuracy of self-rating of exposure to repetitive work. **International Journal of Industrial Ergonomics,** 25: 239-246

Pierrynowski MR, Winter DA and Norman RW (1981). Metabolic measures to ascertain the optimal load to be carried by man. **Ergonomics,** (5): 393-399.

Pimental NA and Pandolf KB (1979). Energy Expenditure while standing or walking slowly uphill or downhill with loads. **Ergonomics,** 22(8): 963 – 973.

*Popkin BM (1989). Time Allocation of the Mothers and Child Nutrition. **Ecology Food and Nutrition,** 1: 1-14. (See Lukmanji, 1992).

Quesada PM, Mengelkoch LJ, Hale RC and Simon SR (2000). Biomechanical and metabolic effects of varying backpack loading on simulated marching. **Ergonomics,** 43:293-309.

*Ramazzini B (1713). **De morbis artifacum diatriba**. Baptistam Conzattum, Patavii. Revised and translated by Wilmer Cave Wright 1983 in The Classics of Medicine Library , Division of Gryphon Editions, New York. (See Franco and Fusetti, 2004).

*Renbourne ET (1954). The knapsack and pack. **Journal of the Royal Army Medical Corps,** 99: 1-15. (See Pierrynowski **et al.** 1981).

Roberts D (2003). Strategies for Tree-Planters – Decrease Illness and Injury, and Increase Productivity. **Report for Summit Reforestation and Forest Management,** Selkirk College, British Columbia Canada.

Robinson DG, Trites DG and Banister EW (1993). Physiological effects of work stress and pesticide exposure in tree planting by British Columbia silviculture workers. **Ergonomics,** 36(8): 951-961.

Rosa RR (1995). Extended workshifts and excessive fatigue. **Journal of Sleep Research, Supplement,** 4 (2): 51-56.

Rowell LG (1986). **Human Circulation: Regulation during physical stress.** New York: Oxford University Press

Sagiv M, Ben-Sira D, Sagiv A, Werber G and Rotstein A (1994). Left ventricular responses during prolonged treadmill walking with heavy load carriage. **Medicine and Science in Sports and Exercise,** 26 (3): 285-288.

Sagiv M, Ben-Gal S and Ben-Sira D (2000). Effects of gradient and load carried on human haemodynamic responses during treadmill walking. **European Journal Applied Physiology,** 83:47-50.

Saha PN, Datta SR, Banerjee PK and Narayane GG (1979). An acceptable workload for Indian workers. **Ergonomics,** 22 (9): 1059-1071.

Sanders, MS and McCormick, EJ (1993). **Human Factors in Engineering and Design** McGraw Hill Inc. Singapore

Santee WR, Allison WF, Blanchard LA and Small MG (2001). A proposed model for load carriage on sloped terrain. **Aviation Space and Environmental Medicine,** 72(6): 562-566.

Scott PA (1993). Ergonomic problems associated with industry in developing countries, with South Africa as a model. **Ergonomics SA,** 5 (1): 27-28.

Scott PA and Shahnavaz H (1997). Ergonomics training in Industrially Developing Countries: Case studies from "Roving Seminars". **Proceedings: 7th International Conference on Human-Computer Interaction,** 24-28 August, San Francisco, USA.

Scott PA (1999). The effect of a work-conditioning programme on manual labourers in South African industry. **International Journal of Industrial Ergonomics,** 24: 253-259.

Scott PA (2001). The key to humanizing the work environment and improving productivity in Industrially Developing Countries. Keynote address. **Proceedings: Humanizing work and work environment, International Indian Society's Ergonomics Conference,** 11-14 December 2001, Mumbai, India.

Scott PA and Christie CJ (2004a). A Preliminary field assessment of the energy expenditure of forestry workers in South Africa. **Proceedings: Human Factors and Ergonomics Society 48th Annual Meeting**, 20 – 24 September, New Orleans, USA.

Scott PA and Christie CJ (2004b). An indirect method to assess the energy expenditure of manual labourers in situ. **South African Journal of Science,** 100: 694-698.

Scott PA, Christie CJ and Renz M (2004). Two 'Micro' IDC Field investigations requiring 'Macro' interventions. **Proceedings: Human Factors and Ergonomics Society 48th Annual meeting** 20-24 September 2004, New Orleans, USA.

Scott PA, Mattison MC and Furney SE (2005). Mondi: Ergonomics Evaluation. **Consultancy Report.**

Scott PA and Renz MC (2006). An example of a combined field and laboratory investigation for effective ergonomics. **Applied Ergonomics,** 37 (6): 785-792.

Shahnavaz H (1987). Workplace injuries in the developing countries. **Ergonomics,** 30 (2): 397-404.

Shahnavaz H (1996). Making ergonomics a world-wide concept. **The Ergonomics Society Annual Conference,** 4-6 April 1995, University of Kent, Canterbury

Shoenfeld Y, Shapiro Y, Portugeeze D, Modan M and Sohar E (1977). Maximal backpack load for long distance hiking. **Journal of Sports Medicine**, 17:147-151.

Singleton WT (1986). **The Body at Work**. London: Cambridge Universtiy Press.

Slappendel C, Laird I, Kawachi I, Marshall S and Cryer C (1993). Factors Affecting Work-Related Injury Among Forestry Workers: A Review. **Journal of Safety Research**, 24: 19 – 32.

Snook SH, Ciriello M and Webster B (1999). Maximum acceptable forces for repetitive wrist extension with a pinch grip. **International Journal of Industrial Ergonomics.** 24:579-590.

Soule RG and Goldman RF (1969). Energy cost of loads carried on the head, hands and feet. **Journal of Applied Physiology**. 27(5): 687-690.

Soule RG, Pandolf KB and Goldman RF (1978). Energy expenditure of Heavy Load Carriage. **Ergonomics**, 21 (5): 373 – 381.

*Staudt F J (1993). **Tropical Forestry Handbook, Volume 2.** Laslo Pancel (Ed.) Springer-Verlag, Berlin. (See Engelbrecht and Manyuchi, 2001).

Straker LM, Stevenson MG and Twomey LT (1997). A comparison of risk assessment of single and combination manual handling tasks: 2. Discomfort, Rating of Perceived exertion and heart rate measures. **Ergonomics** 40(6): 656 – 669.

Strath SJ, Basset DR, Swartz AM and Thompson DL (2001). Simultaneous heart rate motion sensor technique to estimate energy expenditure. **Medicine and Science in Sports and Exercise,** 2118-2123.

Stuempfle KJ, Drury DG and Wilson AL (2004). Effect of load position on physiological and perceptual responses during load carriage with an internal frame backpack. **Ergonomics** 47(7): 784-789.

Sujatha T, Shatrugna V, Venkataramana Y and Begum N (2000). Energy expenditure on household, childcare and occupational activities of women from urban poor households, **British Journal of Nutrition**, 83 (5): 497-503.

Sullman MJM and Byers J (2000). An Ergonomic Assessment of Manual Planting *Pinus Radiata* Seedlings. **Journal of Forest Engineering,** 11(1): 53:62.

Sundström-Frisk C (1984). Behavioural control through piece-rate wages. **Journal of Occupational Accidents,** 6 (1-3): 49-59.

Todd AI (2002). Physiological and psychophysical responses of male and female soldiers to changes in marching speed, load and gradient. **Unpublished MScThesis,** Department of Human Kinetics and Ergonomics, Rhodes University, Grahamstown, South Africa.

Tortora GJ and Grabowski SR (2000). **Principles of Anatomy and Physiology.** Ninth Edition. New York: HaperCollins Publishers.

Trites DG, Robinson DG and Banister EW (1993). Cardiovascular and muscular strain during a tree planting season among British Columbia silviculture workers. **Ergonomics**. 36(8): 935 – 949.

Tucker K and Sanjur D (1988). Maternal employment and child nutrition in Panama. **Social Science and Medicine,** 26 (6): 605-612.

Urlings IJM, Nijboer ID and Dul J (1990). A method for changing attitudes and behaviour of management and employees to stimulate the implementation of ergonomic improvements. **Ergonomics**, 33(5): 629 – 637.

van der Beek AJ and Frings-Dresen MHW (1995). Physical workload of lorry drivers: A comparison of four methods of transport. **Ergonomics,** 38 (7): 1508-1520.

van Wely P (1970). Design and Disease. **Applied Ergonomics,** 1: 262-269.

Vogt L and Banzer W (1999). Measurement of lumbar spine kinematics in incline treadmill walking. **Gait and posture**, 9:18-23.

Voorbij AJM and Steenbekkers LPA (2001). The composition of a graph on the decline of total body strength with age based on pushing, pulling, twisting and gripping force. **Applied Ergonomics** 32: 287-292.

*Viry P, Creveuil C and Marcelli C (1999). Nonspecific back pain in children: A search for associated factors in 14-year-old schoolchildren. **Revue du Rhumatisme (English Edition),** 66 (7-9) 381-388 (See Young **et al.,** 2006).

Wareham NJ, Hennings SJ, Prentice AM and Day NE (1997). Feasibility of heart-rate monitoring to estimate total level and pattern of energy expenditure in a population-based epidemiological study: the Ely Young Cohort Feasibility Study 1994-95. **British Journal of Nutrition,** 78 (6): 889-900.

Wästerlund DS, Chaseling J and Burström L (2004). The effect of fluid consumption on forest workers' performance strategy. **Applied Ergonomics**, 35(1): 29-36.

Watt B and Grove R (1993). Perceived Exertion. Antecedents and Applications. **Sports Medicine** 15(4): 225-241.

Westgaard, RH and Winkel, J (1997). Review article: Ergonomic intervention research for improved musculoskeletal health: A critical review. **International Journal of Industrial Ergonomics**. 20: 463 – 500.

Westgaard RH and Åaras A (1984). Postural muscle strain as a causal factor in the development of musculo-skeletal illnesses. **Applied Ergonomics,** 15 (3): 162-174

Wilson JR and Corlett EN (1995). **Evaluation of Human Work.** Second Edition. London: Taylor and Francis.

Winsmann FR and Goldman RF (1976). Methods for evaluation of load-carriage systems. **Perceptual and Motor skills**, 43: 1211 – 1218

Wisner A (1985). Ergonomics in industrially developing countries. **Ergonomics.** 28 (8): 1213-1224

Workers Compensation Board of British Columbia (1996). **Preventing Tree Planting Injuries.**

World Health Organisation (1997). Gender and Health: A technical paper.

Wyndham CH, van der Walt WH, van Rensburg AJ, Rogers GG and Strydom NB (1971). The influence of body weight on energy expenditure during walking on a road and on a treadmill. **International Zeitschrift fur Angewandte Physiologie,** 29: 285-292.

Yoon H and Smith JL (1999). Psychophysical and physiological study of one-handed and two-handed combined tasks. **International Journal of Industrial Ergonomics,** 24 (1): 49-60.

Zalk DM (2001). Grassroots ergonomics: initiating an ergonomics program utilizing participatory techniques. **The Annals of Occupational Hygiene**, 45(4): 283-289.

BIBLIOGRAPHY

Apud E, Bostrand L, Mobbs ID and Strehlke B (1989). **Guidelines on ergonomic study in forestry.** Geneva, ILO.

*Bammer G. (1987). How technologic change can increase the risk of repetitive motions injuries. **Seminars in Occupational Medicine**. 2(1): 25-30 (See Coury **et al.**, 2000).

Bartel S, Niederman B and Waters TR (2000). Job hazards for musculoskeletal disorders for youth working on farms. **Journal of Agricultural Safety and Health**. 6(3):191-201.

Capodaglio P, Capodaglio EM and Bazzini G (1997). A field methodology for ergonomic analysis in occupational manual materials handling. **Applied Ergonomics**. 28(3): 203-208.

Chaffin DB (1987). Occupational biomechanics – a basis for workplace design to prevent musculoskeletal injuries. **Ergonomics**. 30(2): 321-329.

Chung H and Wang MJ. (2001). The effects of container design and stair climbing on maximal acceptable life weight, wrist posture, psychophysical, and physiological responses in wafer-handling tasks. **Applied Ergonomics**, 32: 593-598.

Charteris J, Scott PA and Nottrodt JW (1989). Metabolic and kinematic responses of African women headload carriers under controlled conditions of load and speed. **Ergonomics,** 32 (12): 1539-1550.

Chung MK, Lee YJ, Lee I and Choi KI (2005). Physiological workload evaluation of carrying soft drink beverage boxes on the back. **Applied Ergonomics**, 36 (5): 569-574.

Ciriello VM and Snook SH (1999). Survey of manual handling tasks. **International Journal of Industrial Ergonomics**, 23: 149-156.

Friedrich M, Cermak T and Heiller I (2000). Spinal troubles in sewage workers: epidemiological data and work disability due to low back pain. **International Archives of Occupational Environmental Health**. 73: 245-254.

Garg A and Moore JS (1992). Epidemiology of low-back pain in industry. **Occupational Medicine**. 7(4): 593 – 608.

Holt KG, Wagenaar RC, Kubo M, LaFiandra ME and Obusek JP (2005). Modulation of force transmission to the head while carrying a backpack load at different walking speeds. **Journal of Biomechanics,** 38: 1621-1628.

Kuiper JI, Burdorf A, Verbeek JHAM, Frings-Dresen MHW, van der Beek AJ and Viikari-Juntura ERA (1999). Epidemiological evidence on manual materials handling as a risk factor for back disorders: a systematic review. **International Journal of Industrial Ergonomics**, 24: 389-404.

Kumar S (1997). The effect of sustained load on intra-abdominal pressure and EMG characteristics of trunk muscles. **Ergonomics**. 40(12): 1312-1334.

Laessoe U and Voigt M (2004). Modification of stretch tolerance in a stooping position. **Scandinavian Journal of Medicine and Science in Sports**. 14(4): 239-244.

LaFiandra M, Holt KG, Wagenaar RC and Obusek JP (2002). Transverse plane kinematics during treadmill walking with and without a load. **Clinical Biomechanics.** 17:116-122.

Legg SJ, Barr A and Hedderley DI (2003). Subjective perceptual methods for comparing backpacks in the field. **Ergonomics**, 46 (9): 935-955.

Lyons J, Allsopp A and Bilzon J (2005). Influences of body composition upon the relative metabolic and cardiovascular demands of load-carriage. **Occupational Medicine**, 55(5): 380-384.

Marras WS, Lavender SA, Leurgans SE, Fathallah FA, Ferguson SA, Allread WG and Rajulu SL (1995). Biomechanical risk factors for occupationally related low back disorders. **Ergonomics**. 38(2): 377-410.

Marshall RN and Burnett AF (2004). A kinematic, kinetic and electromyographic comparison of stooped sheep shearing techniques and shearing with a sheep manipulator. **Applied Ergonomics**, Article in Press.

Marshall SW, Kawachi I, Cryer P, Wright D, Slappendel C and Laird I (1994). The epidemiology of forestry work-related injuries in New Zealand 1975-88: fatalities and hospitalisations. **New Zealand Medical Journal**. 107 (988): 434-437.

Mathiassen SE and Winkel J (1996). Physiological comparison of three interventions in light assembly work: reduced work pace, increased break allowance and shortened working days. **International Archives of Occupational Environmental Health**. 68(2): 94-108.

Mital, A (1999). Analysis of multiple activity manual materials handling tasks using *A Guide to Manual Materials Handling*. **Ergonomics**, 42(1): 246-257.

Monod H and Garcin M (1996). Use of physiological criteria for improving physical work conditions. **Journal of Human Ergology** 25(1): 29-38.

Nottrodt JW and Manley P (1989). Acceptable loads and locomotor patterns selected in different carriage methods. **Ergonomics**. 32(8): 945-957.

Reiser RF II and Dalton EA (2005). Effect of floor slope and load carriage on standing posture**. Biomedical Science Instrum,** 41: 25-30.

Silverstein BA, Fine LJ and Armstrong TJ (1986). Hand wrist cumulative trauma disorders in industry. **British Journal of Industrial Medicine** 43(11): 779 -784.

Vos HW (1973). Physical workload in different body postures, while working near to, or below ground level. **Ergonomics**. 16(6): 817 – 828.

Wieslander G, Norback D, Gothe CJ and Juhlin L (1989). Carpal tunnel syndrome (CTS) and exposure to vibration, repetitive wrist movements, and heavy manual work: a case-referent study. **British Journal of industrial Medicine** 46(1): 43-47.

Xu Y, Bach E and Orhede E (1992). Work environment and low back pain: the influence of occupational activities. **Occupation Environmental Medicine**. 54(10): 741-745.

Young IA, Haig AJ and Yamakawa KS (2006). The association between backpack weight and low back pain in children. **Journal of Back and Musculoskeletal Rehabilitation,** 19 (1): 25-33.

APPENDICES

APPENDIX A: GENERAL INFORMATION

Equipment checklist
Order of Procedures
Letter to Subject
Subject Consent Form

EQUIPMENT CHECKLIST

General

- Basic Stationary (clipboard, paper, pens, pencils, erasers, ruler, scissors)
- Data Collection Sheets
- Subject Information Sheets
- Subject Consent Forms
- Other (water, disinfectant, cotton wool)

Demographic data

- Toledo Scale
- Stadiometer
- Tape measure

Physical Measurements

- Digital camera (including batteries)

Physiological Measurements

- Polar heart rate monitor
- Quark b^2 (including syringe, gas cylinder, masks, computer)

Psychophysical Measurements

- Rating of Perceived Exertion Scale
- Body Discomfort Map and Scale

ORDER OF PROCEDURES

- Calibrate equipment before volunteers arrive
- Volunteers arrive
- Welcome and explanation and sign informed consents
- Habituation with treadmill
- Stature and mass
- Put on heart rate monitors and masks
- Sit volunteers down to rest

Unilateral carrying

Volunteer 1:

- Measure stature
- Attach Quark b^2
- Collect resting data
- While collecting resting set treadmill up for condition
- Stand them up, turn treadmill on and allow them to step on (mark)
- Walk for a little while till comfortable
- Pass the barrel to them and mark on computer
- RPE and heart rate every minute
- Mark every minute
- Photos at two minutes
- Photos just before four minutes
- At four minutes, after RPE and mark take barrel from subject
- Stop treadmill
- Let them sit down and collect resting data
- Detach Quark b^2
- Body discomfort
- Measure stature
- Sit them down with other volunteers

Repeat with each volunteer for number of unilateral conditions being completed in this session.

Back pack

Volunteer 1

- Measure stature
- Attach Quark b^2
- Collect resting data
- While collecting resting set treadmill up for condition
- Attach back pack onto back and allow them to adjust for comfort (mark)
- Turn treadmill on and allow them to step on when ready (mark)
- Walk for a little while till comfortable
- RPE and heart rate every minute
- Mark every minute
- Photos at two minutes
- Photo just before four minutes
- Last RPE at fourth minute and mark
- Stop treadmill (mark)
- Take back pack off
- Let them sit down and collect resting data
- Detach Quark b^2
- Body discomfort
- Measure stature
- Sit them down with other volunteers

Repeat with each volunteer for number of back pack conditions being completed in this session

LETTER OF INFORMATION

RHODES UNIVERSITY
DEPARTMENT OF HUMAN KINETICS AND ERGONOMICS

LABORATORY INVESTIGATION OF A LOAD CARRIAGE TASK OBSERVED IN FORESTRY

(Sheena E Furney)

Dear ________________

Thank you for volunteering to be a subject in this Master of Science research thesis. You will be part of a group of females who will participate in determining the physiological cost and biomechanical stressors associated with carrying different loads unilaterally and on the back while walking on different gradients.

The aim of this study is to establish whether carrying a specified load on one's back is physiologically and biomechanically less stressful than carrying these same loads unilaterally. A further objective is to determine to what extent the gradient affects these responses.

The testing will take place in the laboratory Department of Human Kinetics and Ergonomics. The testing will be supervised by a member of staff, and you will be required to sign an informed consent expressing your willingness to participate in the study. You will be required to perform 9 carrying conditions with different loads, on different gradients while walking on a treadmill. These loads you will carry both in your hand and on your back. It is essential that appropriate clothes are worn; please ensure that you are in comfortable clothes and shoes to facilitate movement and that you are wearing a spaghetti strap, or very thin strap top.

A risk that may be involved is that stiffness in the arms and back may ensue in the day(s) following the test, although this will try to be avoided through an adequate warm-up and stretching.

Please feel free to ask questions regarding the study and procedures of the testing. Your results will be given to you and explained at the completion of all the testing sessions. Please remember that you are permitted to stop or leave the study at any time, should you so wish. Thank you once again for volunteering to be a subject in my research project.

Yours Sincerely

Sheena Furney
(MSc student – Department of Human Kinetics and Ergonomics)

INFORMED CONSENT

RHODES UNIVERSITY
DEPARTMENT OF HUMAN KINETICS AND ERGONOMICS

Having been fully informed of the nature of the research entitled: **LABORATORY INVESTIGATION OF A LOAD CARRIAGE TASK OBSERVED IN FORESTRY**

I,____________________________ do hereby give my consent to act as a subject in this research project. I have read and fully understand the accompanying letter describing the potential risks and benefits associated with my participation. Outlined in the letter are the procedures, which have also been explained to me.

I realize the necessity to promptly report to the researcher any abnormality or distress and am aware that I may withdraw from participation as a subject at any time. In the event of personal injuries sustained I waive any legal recourse against the researcher or Rhodes University. This waiver shall be binding upon my heirs and legal representatives. I realize that my anonymity will be protected at all times but agree to having the information collected possibly used and published for statistical or scientific purposes. All my queries have been answered to my absolute satisfaction.

Volunteer: **NAME** ____________________
SIGNATURE ____________________ **DATE**: __________

Researcher: **NAME** ____________________
SIGNATURE ____________________ **DATE**: __________

Witness: **NAME** ____________________
SIGNATURE ____________________ **DATE**: __________

APPENDIX B: DATA COLLECTION

Rating of Perceived Exertion Scale
Instructions to Subject for RPE
Body Discomfort Scale
Instructions to Subject for Body Discomfort
Subject Demographic and Anthropometric Data Sheet
Data Collection Sheet

RATINGS OF PERCEIVED EXERTION

Borg's Scale for Ratings of Perceived Exertion

RATINGS OF PERCEIVED EXERTION

6	
7	**VERY, VERY LIGHT**
8	
9	**VERY LIGHT**
10	
11	**FAIRLY LIGHT**
12	
13	**SOMEWHAT HARD**
14	
15	**HARD**
16	
17	**VERY HARD**
18	
19	**VERY, VERY HARD**
20	

Borg G (1982). Psychophysical bases of perceived exertion. **Medicine and Science in Sports and Exercise**, 14(5): 377-381.

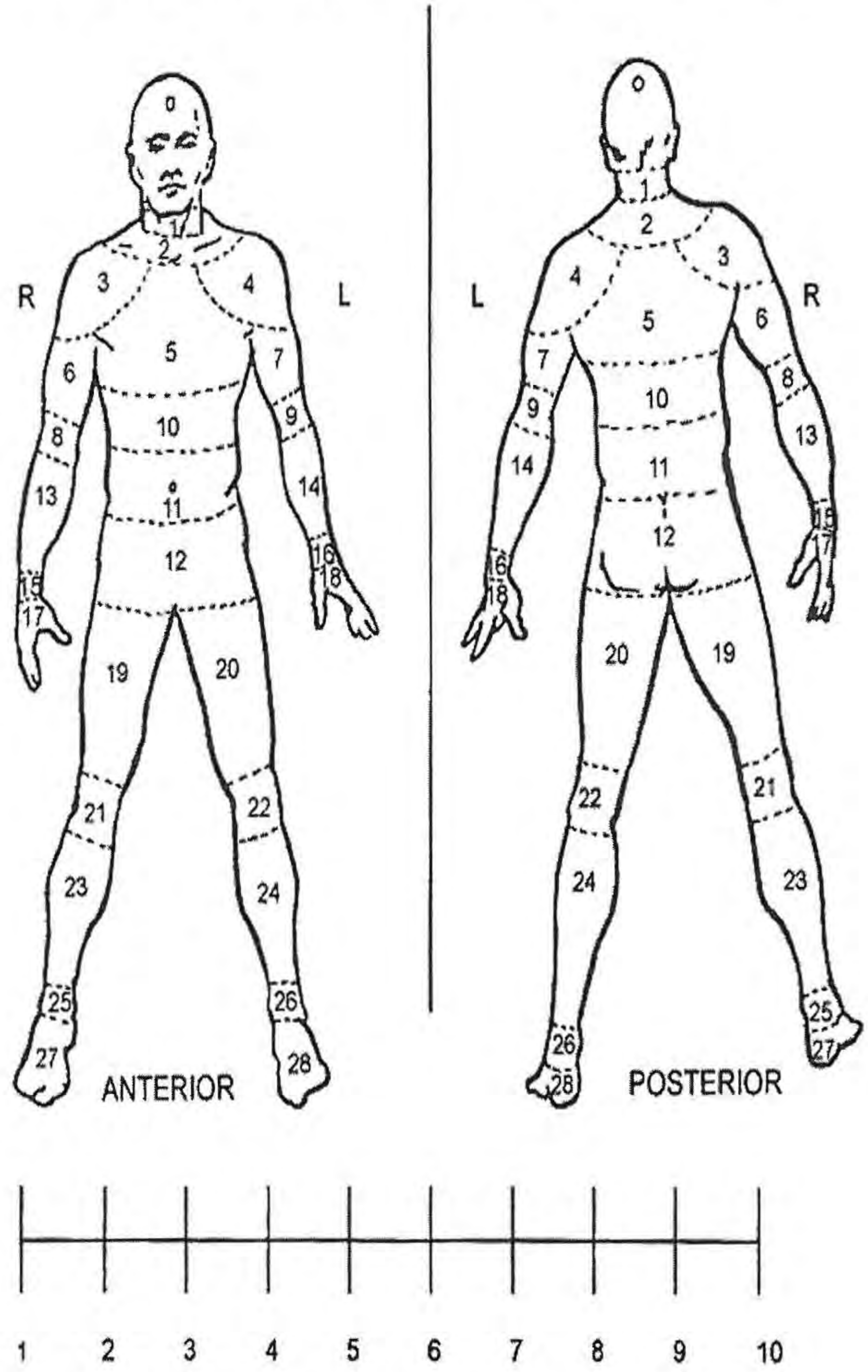
INSTRUCTIONS TO SUBJECT FOR RPE

While you are working we want you to try and estimate how hard you feel you are working, so your degree of perceived exertion. We will be doing this by using a scale called the Rating of Perceived Exertion scale or RPE. You will be asked to point to a number on the scale and this will correspond to how you are feeling. You will first be asked how you are feeling in terms of your heart and your lungs, so how hard your heart is working and how difficult or easy it is to breathe, this is called your "Central" RPE. Then we will ask you how your hands and wrists are feeling, this will be called your "Local" RPE. These two ratings will tell us how YOU are feeling and so your RPE rating will be different to everyone else in the group.

It is important that you are as objective as possible and do not over-estimate or under-estimate the degree of exertion or effort that you feel. You will be asked to give these ratings every 15 minutes during your work. A rating of six (6) will correspond to how you are feeling when you are sitting down quietly and are rested, and rating of twenty (20) reflects how you would feel if you were working at your maximum, at your very hardest, and so were at the point where you needed to stop.

BODY DISCOMFORT MAP AND RATING SCALE

BODY DISCOMFORT MAP AND RATING SCALE



INSTRUCTIONS TO SUBJECT FOR BODY DISCOMFORT

At the end of your work (or my testing time) you will be requested to identify if you felt any discomfort or pain in any part of your body while you were working. You will need to point to an area of the body (a site), on the body map, where you felt discomfort or pain, identifying whether it was the front or the back of your body. The sites on the map are numbered from 0-27.

After showing the sites you felt discomfort or pain you will be asked to identify how much pain or discomfort you felt, so the intensity of the discomfort. You will do this by pointing to a number at the bottom of the map. The numbers range from one (1) to ten (10), with one referring to 'minimal discomfort', and ten referring to 'extreme discomfort'. You will be asked to do this for every area of the body you stated as having felt discomfort.

Again please try being as objective as possible and not over-estimate or under-estimate the degree of discomfort or pain that you are feeling.

SUBJECT DEMOGRAPHIC AND ANTHROPOMETRIC DATA SHEETS

RHODES UNIVERSITY
DEPARTMENT OF HUMAN KINETICS AND ERGONOMICS
MASTER OF SCIENCE THESIS

LABORATORY INVESTIGATION OF A LOAD CARRIAGE TASK OBSERVED IN FORESTRY

(Sheena E Furney)

Name (for record purposes only)	
Subject Code	
Age	
Body Mass (kg)	
Stature (mm)	
BMI	

INJURIES: ____

____

____

____

DATA COLLECTION SHEETS

Volunteer:

Condition: ____________

Time	Heart rate (bts.min^{-1})	'Central' RPE	'Local' RPE	Comments
Reference		▨	▨	
30s		▨	▨	
1min				
1.30		▨	▨	
2 min				
2.30		▨	▨	
3 min				
3.30		▨	▨	
4 min				

Body Discomfort:

Area	Rating	Comments

Stature:__________

Comments: ____

____

____

APPENDIX C: SUMMARY REPORTS

Physiological Formulae and Variables
Quark b^2 Report
Statistica Printout
Papers published by the author relating directly and indirectly to this research

PHYSIOLOGICAL FORMULAE AND VARIABLES

Heart rate (HR) in bt.min^{-1}
The number of cardiac contractions per minute

Breathing Frequency (F_B) in br.min^{-1}
Number of breaths per minute

Tidal Volume (V_T) in L
The volume of air inspired and expired with every breath

Minute Ventilation (V_E) in L.min^{-1}
The total volume of air inspired every minute

VE = Breathing Frequency x Tidal Volume

Oxygen Consumption (VO_2) in mlO2.kg^{-1}.min^{-1}
The amount of oxygen consumed by the body each minute during a particular activity

$$\frac{\text{ml.kg-1 x body mass}}{1000} = \text{L.min-1}$$

Energy expenditure (EE)

VO_2 (L.min^{-1}) x 20.1 = EE (kJ.min^{-1})
kJ.min^{-1}/4.186 = EE (kcal.min^{-1})

Respiratory Quotient (RQ)
Rate of CO_2 volume produced to O_2 volume utilised

$$RQ = \frac{VCO_2}{VO_2}$$

Standard Deviation (SD)
68% of scores in a normal distribution fall within 1 SD of the mean

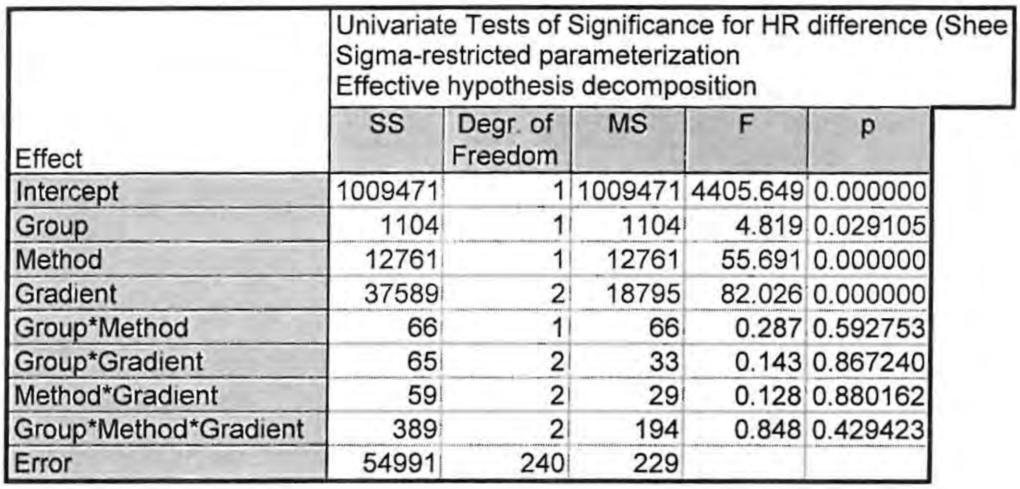
Coefficient of Variation (CV) in %
Measures in the relative variability of scores, allowing for comparisons of different data

$$CV = \frac{SD}{\text{Mean}} \times 100$$

QUARK b^2 PRINTOUT

T	Rf	HR	VT	VE	VO2	VCO2	VO2/Kg	EEm	npRQ
hh:mm:ss	b/min	bpm	L	l/min	ml/min	Ml/min	ml/min/Kg	Kcal/min	---
00:00:08	12.07243	67	0.32556	3.930297	47.12848	30.19203	0.780273	0.205872	4.572421
00:00:13	12.2825	66	0.39802	4.888674	103.5811	70.34487	1.714919	0.470399	0.53573
00:00:18	11.78782	64	0.447007	5.269233	139.1221	93.56174	2.303345	0.634372	0.582375
00:00:23	11.82499	63	0.479665	5.672029	161.8216	108.77	2.679165	0.739572	0.600093
00:00:28	11.87178	63	0.494973	5.876213	176.7778	116.8005	2.926785	0.80641	0.592666
00:00:34	11.7325	62	0.533754	6.262273	202.1238	135.271	3.346421	0.925728	0.615275
00:00:40	11.18151	61	0.551104	6.162177	205.9409	136.0156	3.409618	0.941163	0.605017
00:00:45	11.09878	61	0.566412	6.286486	210.3212	139.7142	3.482138	0.962413	0.611539
00:00:51	10.88929	61	0.558248	6.078925	196.5446	133.0535	3.25405	0.901763	0.623544
00:00:56	10.8735	61	0.572536	6.225471	197.7181	137.0559	3.273479	0.911202	0.645623
00:01:02	10.57455	61	0.587844	6.216189	199.554	139.9422	3.303873	0.921771	0.656966
00:01:08	10.66477	62	0.614379	6.55221	212.2579	150.502	3.514204	0.983195	0.670574
00:01:14	10.50788	62	0.613358	6.445096	203.221	147.4542	3.364586	0.945054	0.69018
00:01:20	10.41667	62	0.632749	6.591136	210.8715	149.877	3.49125	0.977148	0.672463
00:01:25	10.1833	62	0.63479	6.464258	203.2142	143.5645	3.364473	0.940189	0.664891
00:01:29	11.13173	62	0.625605	6.964064	221.4906	150.2332	3.667064	1.017954	0.632995
00:01:33	11.84366	63	0.642955	7.614939	226.7073	153.9352	3.753432	1.042388	0.635253
00:01:36	13.82488	65	0.692962	9.580123	311.1578	214.9367	5.15162	1.43927	0.663368
00:01:38	16.26898	69	0.685818	11.15756	357.5019	254.3789	5.918906	1.66449	0.691619
00:01:41	18.99937	76	0.72562	13.78633	441.3006	332.7645	7.306302	2.080521	0.743771
00:01:44	20.13423	84	0.802162	16.15092	524.0353	418.1213	8.676081	2.501179	0.793979
00:01:48	19.71091	91	0.859314	16.93786	570.6758	468.2366	9.448275	2.740803	0.819087
00:01:52	18.226	96	0.79706	14.52721	456.6789	381.9151	7.560909	2.200117	0.836409
00:01:58	15.40041	99	0.894013	13.76817	466.2467	379.5792	7.719316	2.233578	0.811597
00:02:02	14.24501	98	0.840944	11.97926	408.2698	318.4476	6.759433	1.93716	0.772349
00:02:07	13.14636	96	0.829718	10.90777	399.0788	290.8711	6.607265	1.86792	0.713756
00:02:11	12.95896	94	0.81543	10.56712	420.1066	283.8926	6.955407	1.939166	0.654415
00:02:16	12.68499	93	0.850129	10.78388	454.1309	297.6745	7.518723	2.085637	0.633443
00:02:20	13.39884	93	0.8338	11.17195	498.1292	314.9059	8.247172	2.27431	0.609724
00:02:25	13.1406	93	0.945041	12.41841	586.4902	363.594	9.710102	2.670738	0.600062
00:02:31	12.46365	94	1.012398	12.61818	594.3672	364.912	9.840516	2.702318	0.593805
00:02:35	12.90323	95	1.000152	12.90518	607.9743	369.6621	10.0658	2.759948	0.587842
00:02:38	13.18102	95	0.966473	12.7391	585.0575	347.8962	9.686383	2.645765	0.572352
00:02:43	12.89214	95	0.999131	12.88093	592.095	347.2914	9.802897	2.671762	0.563812
	14.60617	94	0.888983	12.88257	511.6669	353.3571	8.471306	2.3736	0.683045
00:02:48	13.0719	95	0.971576	12.70034	575.1742	336.5766	9.522751	2.594116	0.561577
00:02:53	13.16945	96	1.14201	15.03964	716.0589	429.9936	11.85528	3.24583	0.583033
00:02:57	13.29198	96	1.175689	15.62723	754.4128	461.0526	12.49028	3.430251	0.595372
00:02:59	14.54193	96	1.169565	17.00773	830.0422	511.8982	13.74242	3.78097	0.602827
00:03:03	15.39251	96	1.165483	17.93971	896.6534	559.9915	14.84525	4.093987	0.612198
00:03:07	15.61687	96	1.194059	18.64745	944.2172	597.5515	15.63274	4.321502	0.621634
00:03:12	15.98295	96	1.061385	16.96407	849.9066	538.7546	14.0713	3.889884	0.621421
00:03:17	14.94024	97	1.145072	17.10764	874.0588	554.1718	14.47117	4.000865	0.621917
00:03:22	13.35113	97	1.257334	16.78683	876.6014	559.1914	14.51327	4.016774	0.626074
00:03:26	12.86449	98	1.283868	16.51631	853.5719	548.9462	14.13199	3.916494	0.631265
00:03:30	13.04915	99	1.310403	17.09965	884.9513	574.4266	14.65151	4.067465	0.638054

STATISTICA PRINTOUT



Univariate Tests of Significance for HR difference (Shee
Sigma-restricted parameterization
Effective hypothesis decomposition

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	1009471	1	1009471	4405.649	0.000000
Group	1104	1	1104	4.819	0.029105
Method	12761	1	12761	55.691	0.000000
Gradient	37589	2	18795	82.026	0.000000
Group*Method	66	1	66	0.287	0.592753
Group*Gradient	65	2	33	0.143	0.867240
Method*Gradient	59	2	29	0.128	0.880162
Group*Method*Gradient	389	2	194	0.848	0.429423
Error	54991	240	229		

PAPERS PUBLISHED BY THE AUTHOR

(Directly and indirectly related to the research)

James J, Cripwell A and Furney S (2005). Pushing vs. Pulling Strength: Effect of Handle Height and Practical Ergonomics Applications. **Proceedings of the Fourth International Cyberspace Conference on Ergonomics**, 15 September-15 October.