PHYSIOLOGICAL AND PSYCHOPHYSICAL RESPONSES OF MALE SOLDIERS TO CHANGES IN MARCHING GRADIENT, SPEED AND LOAD

BY

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THESIS

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ABSTRACT

The present study sought to investigate the effects of changes in gradient, under apparently optimal combinations of speed and load, on selected physiological, psychophysical and biophysical responses of military personnel. Subjects (n = 32) were required to march under level (0%), downhill (-10%) and uphill (+10%) conditions. Under each gradient, subjects marched with the following speed-load combinations: 4 $km.h^{-1}$ carrying 50 kg, 5 $km.h^{-1}$ carrying 35 kg and 6 $km.h^{-1}$ carrying 20 kg, a total of nine experimental conditions. Subjects were required to march for six minutes under each condition.

Physiological responses (HR, VO_2, R, Br, V_E, V_T, EE) indicated that subjects were not overly taxed by the three speed-load combinations during level marching, which elicited submaximal demands. Furthermore, the results revealed that downhill marching with heavy loads results in similar responses to level marching, while lighter loads may result in significant reductions in physical demands compared to level marching. The physiological responses to uphill marching revealed that subjects were severely physically taxed under these conditions, regardless of speed-load combination. It is unlikely that soldiers would be able to maintain these intensities for an extended period without undue fatigue. It is evident from the psychophysical responses (Rating of Perceived Exertion and Body Discomfort) that subjects perceived the heavy load conditions, regardless of gradient, to be the most stressful on the cardiovascular and muscular systems. The positive gradient conditions also elicited elevated RPE and Body Discomfort responses, while lighter load downhill conditions were perceived to result in the least strain.

DEDICATION

As an expression of my love and gratitude for his wisdom, sacrifices and encouragement, I would like to dedicate this thesis to my father, the late Martin Todd, an exceptional parent.

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INTRODUCTION

INTRODUCTION

The demands of many military objectives require soldiers to complete route marches as quickly as possible with minimum fatigue and discomfort (Johnson **et al.**, 1995). However, such marches are conducted over diverse terrain and gradients (uphill and downhill), with foot soldiers often carrying heavy loads at high walking speeds. Poor combinations of walking speed and load result in excessive physical and psychological demands on the soldier. Furthermore, failure to adjust speed and load to changes in gradient will exacerbate these already stressful demands. Soldiers who have been excessively physically taxed will be fatigued and prone to a high incidence of injuries. Reynolds **et al.** (1990) found that the debilitation of the soldier through fatigue and injury has a deleterious effect on combat-readiness and ultimately, mission effectiveness.

Walking gradient, together with walking speed and load carriage, have long been identified as being among the main determinants of energy expenditure during walking (Givoni and Goldman, 1971; Pimental and Pandolf, 1979; Knapik **et al.**, 1996). Therefore for soldiers to perform post-march requirements effectively, an understanding of the metabolic and perceptual responses to changes in gradient is essential. Pivarnik and Sherman (1990) have identified a lack of studies investigating the energy cost of negative gradient walking, an aspect of many military operations. Furthermore, such marches are rarely performed at moderate speeds and without a load, making it important to assess what effect these two factors have on the energy expenditure - walking gradient relationship.

The psychophysical factors associated with any job impact on motivation, satisfaction and willingness to work, consequently affecting performance whether in military, industrial or recreational settings. It is hence important to assess the psychological responses of individual soldiers to task demands, thus improving an understanding of how they are likely to respond to the pressures placed on them in the military. The Rating of Perceived Exertion (RPE) scale, developed by Borg (1970), is an effective psychophysical indicator, allowing an objective measure of a subjective experience. Differential ratings for “Local” and “Central” responses increase understanding of the individual’s perception of task demands and ability to cope.

Soldiers, workers and recreational hikers are differentially taxed by the same task demands due to differences in stature and muscle mass. Knapik (1989) found that soldiers (regardless of sex) of greater stature, muscle mass and aerobic capacity have the ability to carry heavier loads at higher speeds, over varying slopes, without any added energy expenditure. Hence, under enforced march rates, these individuals will be able to complete the march with relatively lower energy expenditure and less fatigue, while soldiers of a more gracile morphology are predisposed to complete critical post-march tasks in a condition of greater fatigue. Such differences in morphology are particularly pertinent for the South African National Defence Force (SANDF), which may exhibit wide ethnic diversity within a single unit. This diversity has a substantial effect on the variability in the psychological and physical capabilities and limitations of the individuals within that unit. The implications of this are differentiated levels in fatigue rate and ability to perform crucial post-march activities, resulting in a decrement in the overall military efficiency.

With female participation in the SANDF infantry, sex-based differences are becoming an increasingly important consideration. Haisman (1988) argued that women are at a disadvantage in load carriage tasks due to lower body weight, higher body fat, lower VO_{2max} and lower muscle strength compared to men. Therefore, it was contended by Martin and Nelson (1986) that females should carry lower absolute loads than males for biomechanical and physiological reasons. Despite this, soldiers are generally required to perform uniformly regardless of sex or individual differences in physique. Reducing differential effects of this on post-march combat-readiness is therefore, a central concern for the military ergonomist.

STATEMENT OF THE PROBLEM

The objective of this research was to investigate the relationship between walking gradient and energy expenditure, plus the perceptual responses to these changes in gradient. There will be changes in energy expenditure depending on the walking gradient. Therefore, identification of the effects of walking uphill and downhill on selected biophysical, physiological and psychological factors are of considerable relevance within military, industrial and recreational settings.

Furthermore, factors such as load carriage and walking speed result in a concomitant adjustment in metabolic and perceptual responses. There is a need to establish the combined effect of changes in gradient, load carried and walking speed on energy expenditure (particularly in the case of the ethnically diverse and largely unstudied population of the new SANDF) and to establish optimal loads and speeds to be maintained in order to minimise fatigue and injury. In addition speed-load combinations which are similar during level marching, may not elicit similar responses under gradient marching.

RESEARCH HYPOTHESIS

While increases in gradient are expected to increase the physiological and perceptual demands on backpack carriers, negative gradients are expected to decrease these demands. Furthermore, speed-load combinations which may be optimal under level marching, may not constitute minimal energy expenditure under incline and decline marching.

STATISTICAL HYPOTHESES

1 (a) H_o: μ C;M $_1$ = μ C;M $_2$……………..9

H_a: μ C;M $_1 \neq \mu$ C;M $_2$……………..9

Where: C;M = Cardiovascular and Metabolic responses (HR; VO_2 and derived energy-cost measures; R).

1 (b) H_o: μ V $_1$ = μ V $_2$…………………..9

H_a: μ V $_1 \neq \mu$ V $_2$…………………..9

Where: V = Ventilatory measures (V_E; V_T; Br).

2 H_o: $\mu\ P_1 = \mu\ P_2$………………9

H_a: $\mu\ P_1 \neq \mu\ P_2$………………9

Where: P = Psychophysical responses (RPE; BD).

3 H_o: $\mu\ K_1 = \mu\ K_2$………………9

H_a: $\mu\ K_1 \neq \mu\ K_2$………………9

Where K = Kinematic responses (Cadence; Step length)

DELIMITATIONS

A sample of 40 male subjects was selected from a group of volunteer foot-soldiers from the Grahamstown military base, Sixth Battalion, South African Infantry (6SAI). Five years of research by the Department of Human Kinetics and Ergonomics, Rhodes University has lead to the development of optimal speed-load combinations to be used while walking on the level. Three similar combinations were selected for the present study in order to evaluate the effect that increasing and decreasing gradient has on selected biophysical, physiological and psychophysical responses to apparently optimal combinations of speed and load.

There were nine different gradient, speed and load combinations used as the basis for experimentation. Clothing worn during experimentation was standard military uniform for all subjects. The subjects were required to perform all nine conditions (six minutes per condition), which were randomly assigned. These were 4 $km.h^{-1}$ with a 50 kg load at gradients of 10%, 0% and –10%, 5 $km.h^{-1}$ with a

35 kg load at gradients of 10%, 0% and –10% and 6 $km.h^{-1}$ with a 20 kg load at gradients of 10%, 0% and –10%.

LIMITATIONS

When an investigation involves individual physiological and psychological responses it is impossible to control all factors impinging on the results due to the network causality of such an investigation. However, every effort was made to ensure the rigorous control of as many of the influencing factors as possible. The following limitations still remained and should be taken into consideration when examining the results:

1. Subjects were not randomly selected by the researchers, but were volunteers from the Grahamstown military base. Although every effort was made to motivate the subjects throughout the experiment, this factor could not be evaluated objectively.

2. Other than voluntary compliance with the request to maintain normal eating, drinking and exercise habits during the course of the experiment, there was no control over these external factors.

3. Although clear and detailed instructions on the use of the perceptual scales was given to each group, the researchers are still required to presume that the verbal categories are appraised in a similar manner by all subjects. The problems associated with any "self report" scale remains, and the validity of the scales must be appraised in this light.

CHAPTER II

REVIEW OF LITERATURE

INTRODUCTION

Increased mechanisation has not alleviated the physical strain experienced by foot-soldiers. Knapik **et al.** (1996) identified technological developments as being determining factors in the progressive increase in the soldiers' load, with the need for greater firepower and protection requiring soldiers to carry more heavy equipment. After completing a demanding march, foot-soldiers are required to execute highly complex military objectives effectively, and then make a rapid retreat. In order for these tasks to be executed efficiently it is essential that soldiers are mentally and physically alert and prepared for the task at hand. However, military conditions often require soldiers to carry heavy loads at high walking speeds, over various gradients and still be combat efficient.

There are many factors that will affect the energy expenditure associated with marching. These include body weight (Cotes, 1969), weight and distribution of load carried (Soule and Goldman, 1969), weight of footwear (Jones **et al.**, 1984), speed (Pandolf **et al.**, 1977), gradient (Evans **et al.**, 1980), terrain (Haisman and Goldman, 1974), sex (Haisman, 1988) and age (Rodgers, 1995). Despite comprehensive studies identifying the deleterious effects of placing excessive demands on military personnel, combat-readiness after enforced marches in which sub-optimal loads and speeds over varying gradients are maintained, remains an unresolved military concern (Charteris, 1998).

SEX-RELATED DIFFERENCES

Females were first accepted in combat roles in the United States military in 1976. Protzman (1979) noted that this change resulted in only minimal essential adjustments to training schedules to accommodate female participation. However, there is substantial evidence illustrating significant differences in the physical capabilities and limitations of males and females (Jones **et al.**, 1993), which will have an associated effect on military efficiency. It has been argued that the average female has "a smaller inherent aerobic power and less muscular strength than a man, reflecting sociocultural influences, physical size, body composition, and hormonal milieu" (Shephard, 2000; p:19).

Bhambhani and Maikala (2000) argued that when carrying the same absolute loads "women are more susceptible to fatigue and are at a greater risk of cardiovascular complications than men." Despite differences in sex and morphology, all members of a platoon are required to carry the same load at the same speed over varying gradients. Military personnel are hence differentially taxed by the task requirements, resulting in a concomitant variability in post-march performance and overall military efficiency.

In general, females will be at greater risk than males in load carriage tasks due to lower body weight, VO_{2max} and muscle strength and a higher percentage body fat (Vogel and Patton, 1978). Protzman (1979) argued that males have a higher capacity for physical performance and are therefore likely to accomplish military tasks "with fewer injuries or diseases and less apparent stress". Martin and Nelson

(1986) argued that due to biomechanical and physiological differences between males and females, females should carry lower absolute loads than males.

Despite these obvious differences in biomechanical and physiological capabilities during loaded marching, military conditions often stipulate that these factors cannot be accounted for and all members of a platoon are required to perform uniformly and optimally regardless of sex. There is hence a strong argument that workloads should be made relative to individual capabilities, thereby ensuring that individuals are equally taxed, promoting military, industrial and recreational efficiency.

ENERGY EXPENDITURE

Equation for Predicting Energy Expenditure

Energy expenditure has been shown to be directly affected by load carried, walking speed, body mass, gradient and terrain (Patton **et al.**, 1991). As a result, prediction equations of the energy expenditure associated with walking were developed as early as 1920 by Cathcart and associates. In the 1970's prediction equations were developed by researchers such as Givoni and Goldman (1971) and Pandolf **et al.** (1977) to determine energy expenditure, while walking with loads. These equations provide useful information regarding the physical severity and potential fatigue that would result from military tasks.

Givoni and Goldman (1971) developed the following equation:

$$M = \eta(W + L)[2.3 + 0.32 (V-2.5) + G(0.2 + 0.07(V-2.5))]$$

Where:

M = Metabolic cost, Watts	η = terrain factor, defined as 1.0 for treadmill walking
W = body weight, kg	L = external load, kg
V = walking speed, $km.h^{-1}$	G = slope (grade), %

This prediction equation is limited to walking speeds between 0.7 $m.s^{-1}$ (2.52 $km.h^{-1}$) and 2.5 $m.s^{-1}$ (9 $km.h^{-1}$). Furthermore, the equation is only valid as long as the product of load carried and velocity is no larger than the numerical value of 100. A product that exceeds this value will result in an under prediction of energy expenditure. The reliability of the equation is dependent on several assumptions, the first being that metabolic cost rises progressively with an increase in speed, a point accepted in the literature (Hughes and Goldman, 1970; Givoni and Goldman, 1971). Further assumptions are that the metabolic cost of walking is proportional to total weight (body weight and load) and a function of walking speed, and that any external load being carried should be kept near to the body's center of mass. Myles and Saunders (1979) criticised Givoni and Goldman's equation for its reliance on the assumption that speed and weight are interchangeable, requiring that under heavy loads there is a reciprocal change in speed to compensate without any added metabolic cost.

The equation was therefore revised in 1977 by Pandolf **et al.** to include walking at any speed up to 2.4 $m.s^{-1}$ (8.64 $km.h^{-1}$) at which point it becomes more efficient to run than to walk. It was also revised to include loads of up to 70 kg and gradients from 0 to 25%.

The Pandolf **et al.** (1977) equation is:

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

Where:

M = Metabolic cost, Watts	η = terrain factor, defined as 1.0 for treadmill walking
W = body weight, kg	L = external load, kg
V = walking speed, $km.h^{-1}$	G = slope (grade), %

The Pandolf **et al.** (1977) equation was criticised by Pimental and Pandolf (1979) for placing too much emphasis on the effects of speed at slow walking speeds and being too sensitive to changes in load. They also criticised the equation for its lack of ability to predict the energy cost of downhill walking. The difficulty of predicting energy expenditure remains apparent today: Bunc and Dlouhá (1997) reported that the problem of predicting energy cost of walking, from the basic mechanical and physiological principles, remains unsolved.

Workloads

Saha **et al.** (1979) defined an acceptable workload as “the level of physical activity that can be sustained for an eight hour work shift whilst remaining in a physiological steady state and without fatigue or discomfort”. When individuals are allowed to self-pace, the energy expenditure selected is lower than in the case of an enforced pace (Zarrugh and Radcliffe, 1978). Knapik **et al.** (1996) argued that self-paced work intensities are dependent on several factors including the load carried, level of aerobic fitness (VO_{2max}) and distance to be covered.

Goldman (1965) investigated self-selected workloads of military personnel and found that regardless of variations in load or terrain, men tended to voluntarily work at an energy expenditure of 29.8kJ.min^{-1}. Hughes and Goldman (1970) argued that men will select an energy expenditure of approximately 494 W, which represents 40-50% of their VO_{2max}. Later Evans **et al.** (1980) found a mean energy expenditure for males, higher than Hughes and Goldman, of 549 W. It has also been argued that since workloads higher than 50% of VO_{2max} result in lactic acid accumulation from anaerobic metabolism (Åstrand and Rodahl, 1977), individuals select a workload as close to their anaerobic threshold as possible therefore meeting the energy demands aerobically.

It was contended by Evans **et al.** (1980) that self-selected workloads of 45% of VO_{2max} are reasonable for hard work to be sustained for 1 to 2 hours. In a study by Levine **et al.** (1982), untrained and trained individuals were required to march for 3.5 hours, and when both groups were combined there was a self-selected energy expenditure of approximately 40% of VO_{2max}. For an eight-hour work shift, Saha **et al.** (1979) argued that a workload of 35% of VO_{2max} could be considered reasonable, corresponding to an energy expenditure of 18.0 kJ.min^{-1} and a heart rate of 110 bt.min^{-1}. Shapiro **et al.** (1973) recommended that adjusting work intensity to individual VO_{2max} will minimise muscle enzyme leakage and muscle damage.

Therefore self-selected workloads are dependent on work duration as well as load carriage (Evans **et al.**, 1980). Haisman (1988) found that there is a decrease in self-selected work rates (energy expenditure) as the task demands (load carriage) get larger. Levine **et al.** (1982) claimed that as the duration of exercise increases from 1 to 6.5 hours, there is a corresponding reduction in self-selected workloads from 46 to 35% of VO_{2max}. Haisman (1988) argued that as load carriage increases, self-selected walking speed and energy cost decrease (see Table I).

Table I: **Load carried, self-selected walking speed and energy cost.**

Load (kg)	0	20	30	40	50	60
Speed ($km.h^{-1}$)	8.0	6.5	5.8	5.2	4.3	3.7
Speed ($m.s^{-1}$)	2.2	1.8	1.6	1.4	1.2	1.0
Energy Cost ($kJ.min^{-1}$)	41	33	32	31	28	27

Adapted from Haisman, 1988

Self-selected workloads are of military importance, as Levine **et al.** (1982) pointed out that a well-trained individual will be able to walk at his own pace with a higher energy expenditure and to maintain that pace for a longer period of time than an untrained individual. This is applicable as soldiers of varying levels of fitness are required to march for prolonged periods at an enforced pace, therefore differentially taxing the various members of the platoon. By matching individuals by aerobic fitness, variations in fatigue and differences in energy expenditure will be significantly reduced.

It is argued by Epstein **et al.** (1988) and Patton **et al.** (1991) that there is an increase in energy expenditure over time. Patton and co-workers (1991) contended that at high loads and/or walking speeds, prolonged (> 2 hours) marching will increase energy expenditure. These authors asserted that in order to prevent an increase in VO_2 over time (physiological drift) when carrying loads of

31.5 and 49.4 kg, marching speed should not exceed speeds of 1.35 $m.s^{-1}$ (4.86 $km.h^{-1}$) and 1.1 $m.s^{-1}$ (3.96 $km.h^{-1}$) respectively. These speed-load combinations are similar to those selected in the present study (4 $km.h^{-1}$ carrying 50 kg and 5 $km.h^{-1}$ carrying 35 kg): therefore it could be expected that there would be no rise in the physiological responses to these conditions over time.

Casaburi **et al.** (1987) and Kalis **et al.** (1988) postulated that increased body temperature, increased minute ventilation, reduced mechanical efficiency, shift in substrate utilisation and, when exercise intensity is over 50% of VO_{2max} then increased blood lactate levels, all contribute to an increase in energy expenditure as time progresses. Another contributing factor during load carriage is the reduction in mechanical efficiency as a result of altered locomotor biomechanics as the subject adjusts to the weight of the load (Patton **et al.**, 1991).

Contrasting to the contentions of Epstein **et al.** (1988) and Patton **et al.** (1991), it was put forward by Sagiv **et al.** (1994) that there is no change in energy expenditure over time, while Kirk and Schneider (1992) found that only minute ventilation increased over time during load carriage. However, an individual cannot be expected to carry a heavy load at high walking speeds for prolonged periods without any decrements in efficiency and an increase in the likelihood of fatigue. Although a workload may not overly strain an individual in the short term, prolonged exertion may result in the same workload being considered to be too high. In the present study responses were measured for only six minutes under any condition. Therefore ‘physiological drift’ would not have occurred, which must be taken into account particularly at high workloads, as over time, individuals may become more susceptible to fatigue and injury.

In accordance with Evans **et al.** (1980), speed-load combinations for this study were selected to represent workloads of approximately 45% of VO_{2max}, as soldiers are seldom required to march for more than a couple hours. Scott and Charteris (1999) and Christie (2001) found the following speed-load combinations did not overly strain SANDF personnel: 3.5 $km.h^{-1}$ with a load of 50 kg; 4.5 $km.h^{-1}$ with a load of 35 kg and 5.5 $km.h^{-1}$ with a load of 20 kg. Therefore, three similar speed and load combinations (4 $km.h^{-1}$ with a load of 50 kg, 5 $km.h^{-1}$ with a load of 35 kg and 6 $km.h^{-1}$ with a load of 20 kg) were used in the present study in order to investigate the effect of marching gradient, as these workloads were found to be acceptable for level walking, but have not been investigated while marching over undulating terrain. It was hypothesised that these combinations would result in higher workloads under uphill conditions and lower workloads under downhill conditions than under level conditions and may be excessive, resulting in fatigue and injury.

SPEED AND LOAD CARRIAGE FACTORS

Effect on Gait Patterns

Increasing the velocity of walking has a marked effect on resulting gait patterns. Charteris **et al.** (1986) and Charteris (1998) support the theory of a progressive speed-related tendency for a reduction in single support time, absolute contact time and double support time. Hence a greater percent of stride time is given to single support, and it follows that a smaller percent of stride time is given to the double support phase. The result is an accompanying decrease in contact time as a whole. The effect of these responses demonstrated by Charteris (1998) is to dramatically reduce the time that the entire plantar surface of the foot is in contact with the floor. This period provides the greatest amount of stability throughout the walking cycle, and is therefore of particular importance during heavy load carriage, as balance and stability are vital components of load carrying ability.

Minetti **et al.** (1995) argued that at any given walking speed the step frequency chosen is one that minimises energy expenditure. Rodgers (1995) defined this frequency as the number of steps per minute when walking as naturally as possible. In a study by Winter (1991) the natural cadence for males was found to vary between 101 and 122 st.min^{-1}, while Zatsiorky **et al.** (1994) found the mean frequency from several studies to be 111.5 st.min^{-1}. Murray **et al.** (1964) and Kirtley **et al.** (1985) found that increasing natural step frequency (cadence) results in an increase in walking speed, and vice versa. The relationship between progression rate and step frequency has been found to be curvilinear, although it can be considered essentially linear within a limited speed range (Vilensky and Gehlsen, 1984).

The critical step frequency (highest frequency with a double support phase, i.e. walking) varies between 175 and 200 st.min^{-1} (Zatsiorky **et al.**, 1994). Once step frequency has reached this level walking is transformed into running. According to Thorstensson and Robertson (1987) the critical speed where running becomes more economical than walking is approximately 7.2 km.h^{-1} (2 m.s^{-1}), although there is a large variation in this speed due to differences in individual lower limb length.

Shorter-legged individuals tend to adopt a natural frequency that is higher than those adopted by long-legged individuals. Therefore, in order to maintain the same high velocity, shorter-legged individuals will be required to sustain a higher cadence than the long-legged individual. Consequently transition speed will be lower in individuals with short legs, due to selection of different natural frequencies. Minetti **et al.** (1994) argued that when transition speed is freely chosen, humans tend to start running while it is still more economical to walk. It is thus essential when investigating the relationship between cadence and step length at various walking speeds, that lower extremity length be taken into consideration (Zatsiorky **et al.**, 1994).

Table II: **Gait characteristics of males and females under natural conditions**

	Speed ($km.h^{-1}$)	Speed ($m.s^{-1}$)	Step Frequency ($st.min^{-1}$)	Step Length (m)
Males	5.232	1.45	111.4	0.78
Females	4.896	1.36	116.9	0.70

Adapted from Zatsiorky **et al.**, (1994)

The mean step length as found by Zatsiorky **et al.** (1994) from several gait kinematics studies for males was 0.78 m. Elble **et al.** (1991) argued that the relationship between step length and cadence is linear over a wide range of walking speeds and that step length will be chosen in proportion to step frequency (Dean, 1965; Zarrugh and Radcliffe, 1978). Zatsiorky **et al.** (1994) identified this relationship to have “a deep physiological significance”, fundamental in determining an optimal walking pattern. In other words, it is vital in determining an optimal speed, step length and cadence in order to obtain minimal energy expenditure per unit of distance traversed.

Holt **et al.** (1991) and Bunc and Dlouhá (1997) agreed that frequency and stride length have a consequential effect on metabolic cost. However, Zatsiorky **et al.** (1994) recognised that the stride length/frequency relationship has not been comprehensively studied and is still a matter of debate. More recently it has been argued by Bunc and Dlouhá (1997) that a low step frequency combined with a long stride length results in higher energy cost than a high frequency with a short stride length. These authors postulated that this may be caused by subjects losing their dynamic equilibrium, rendering them unstable. Holt **et al.** (1991) reasoned that higher frequencies allow subjects to make better use of the elastic energy return than the lower frequencies, since there is a limited time period in which elastic energy can be utilised.

A study by Charteris **et al.** (1986) on headloading found that in an attempt to balance, the position of the load and the mass of the load combine to produce a walking pattern distinguished by a longer double-support phase and a short, quick swing at a faster pace at the same velocities. For backpack loading, Kinoshita (1985) found similar increases in double-support as load increased. Further studies by Martin and Nelson (1986) found that load increments (in a backpack) up to 40% of body mass resulted in a decreased stride length and swing time and an increase in stride rate and double-support time. In contrast, Pierrynowski **et al.** (1981) contended that carrying loads of up to 34 kg results in no apparent change in gait patterns, while Charteris (1998) found that cadence was unaffected by increments of load up to 50% of body mass.

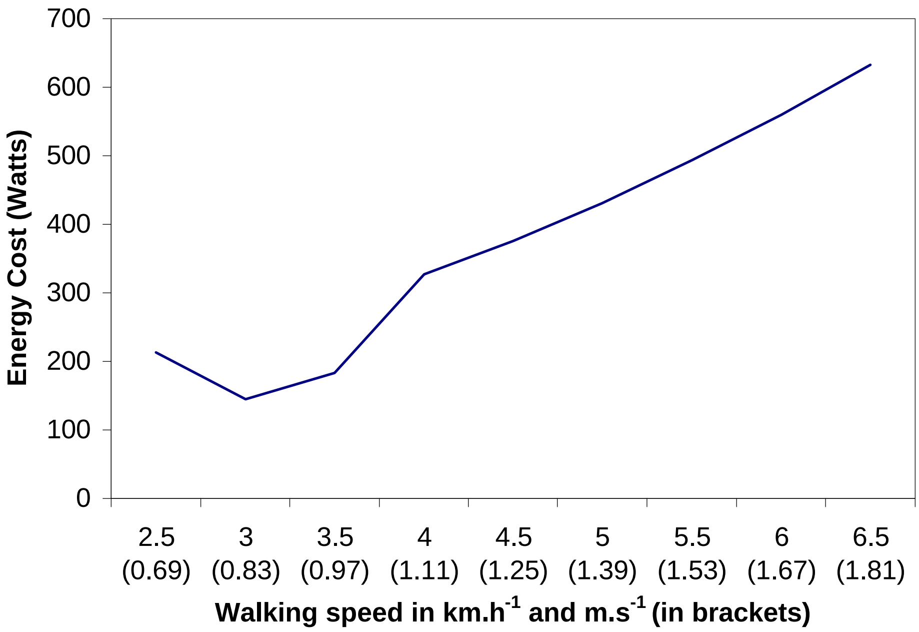
There is hence a discrepancy between loads carried as headloading and backpacking, which is of relevance to the current study. Although headloading is a more efficient method of load carriage, backpacking is a widely used form of load carriage in recreational (hiking), military (foot troops) and industrial (crop sprayers) settings. Therefore backpack loading is more applicable to *in situ* conditions.

Optimal Speed

There is an obvious incentive for route marches to be completed as quickly as possible. However, a walking speed above what is physiologically sound will result in soldiers being excessively taxed by the task demands. Reynolds **et al.** (1990) found that an increase in walking speed from 3.96 $km.h^{-1}$ to 5.76 $km.h^{-1}$ increased the number of injuries experienced by 65%. Ensuring effective utilisation of the available energy will reproduce an optimal performance, allowing for the maintenance of a high intensity without negatively affecting the utilisation of energy sources (Daniels, 1985). Since walking speed plays an important role in ensuring combat readiness, the attainment of an optimal walking speed is an imperative goal to be achieved.

Daniels **et al.** (1977) investigated the relationship between VO_2 and velocity and found a linear relationship. However, Daniels (1985) later contended that studies on blood lactic acid accumulation such as Nagle **et al.** (1970) indicate that although there is a linear relationship between velocity and VO_2, there may not be a linear relationship between velocity and energy expenditure. Daniels (1985) further argued that the departure from linearity of the VO_2 – velocity relationship at very fast and slow velocities “seems a valid hypothesis worthy of testing”.

According to Pimental and Pandolf (1979) an increase in walking speed from zero to 2.8 km.h^{-1} results in an increase in energy expenditure. They argued that these increases are not necessarily linear in nature and may exhibit periods of sharp peaks. Contrastingly, as far back as 1920, Cathcart and associates investigated the optimal marching speed with respect to energy expenditure. They disputed that energy expenditure is initially high and then decreases to an optimal, thereafter increasing again with further increases in speed. Similarly, Bunc and Dlouhá (1997) found an initially high energy expenditure, decreasing to an optimal energy expenditure at a walking speed of approximately 4 km.h^{-1}. Once walking speed increases above 4 km.h^{-1} energy expenditure starts to increase again.



Adapted from Haisman (1988)

FIGURE 1: **Energy cost of increased walking speed carrying a load of 30 kg.**

Goldman and Iampietro (1962) and Soule **et al.** (1978) found large variability in the energy expenditure of slow walking speeds and attributed it to the inefficiency of such walking speeds. Bunc and Dlouhá (1997) postulated that the high energy expenditure associated with “low-velocity bipedal locomotion” is the result of problems in maintaining balance, exacerbated under loaded conditions (Soule **et al.**, 1978). Workman and Armstrong (1963), Zarrugh and Radcliffe (1978) and Bunc and Dlouhá (1997) all support arguments of a U-shaped relationship between energy expenditure and walking speed. Haisman (1988) found that once walking speed is above 4 $km.h^{-1}$, there is a linear relationship between speed and energy expenditure.

Givoni and Goldman (1971) found an initially non-linear relationship between energy expenditure and speed. Later, Soule **et al.** (1978) and Bunc and Dlouhá (1997), found a decrease in energy expenditure to an optimal before it starts to increase again with further increases in speed. Early studies by Bobbert (1960) and Margaria **et al.** (1963) asserted that there is a curvilinear increase in energy expenditure with increasing speed. In a study by Pimental **et al.** (1982) an increase in walking speed from 2.41 $km.h^{-1}$ (0.67 $m.s^{-1}$) to 4.03 $km.h^{-1}$ (1.12 $m.s^{-1}$) resulted in a 27% increase in energy expenditure, supporting the findings of the aforementioned authors. Williams (1987) lends further support to an increasing curvilinear relationship between energy expenditure and walking speed, both in absolute terms and relative to stature.

It is contended by Pearce **et al.** (1983) that efficiency of walking can be expressed as “the least metabolic cost per unit travelled’. Laurent and Pailhous (1986) and

Kadaba **et al.** (1990) investigated freely-chosen walking speeds selected by males, and obtained velocities that varied between 4.68 and 5.04 $km.h^{-1}$. These freely-chosen values do not coincide with the optimal walking speed of 4 $km.h^{-1}$ found by Bunc and Dlouhá (1997). Therefore freely chosen speeds do not necessarily concur with those that are optimal to minimise energy expenditure.

It was argued by Margaria **et al.** (1963) and McArdle **et al.** (1996) that the oxygen consumption per kilogram of body weight will be 0.2 $l.min^{-1}$, regardless of speed. However, the argument that short and tall individuals will be equally taxed at any given walking speed is questionable. Williams (1987) found that there was no difference in the VO_2 responses of the two stature groups under absolute or relative walking conditions. Williams (1987) argued that stature as a whole has no effect on the energy expenditure of walking and differences in stature will not have a detrimental effect on the determination of the relationship between walking speed and energy expenditure. However, under running conditions, it was found that tall individuals tended to expend less energy due to a fewer number of strides per unit of distance. Therefore, lower limb length is an important factor to be taken into consideration when investigating the energy expenditure responses to a specific walking speed.

Load Carriage

Throughout the history of mankind, loads have been transported using carrying devices such as yokes, rucksacks and backpacks (Kinoshita, 1985). Even with the development of complex technology, this basic form of transportation remains an indispensable resource. Under military conditions, loads often have to be carried for prolonged periods, placing high demands on the physical performance capacity of soldiers (Borghols **et al.**, 1978). Knapik **et al.** (1990) noted that the soldiers' load is progressively rising due to increased need of firepower and armoured protection, while Reynolds **et al.** (1990) showed that field soldiers are often required to carry loads as high as body weight. It has long been recognized (Colonel **et al.**, 1944) that prolonged marches with large loads may result in a number of clinical disorders. Furthermore, Renbourn (1954) and Devas (1975) argued that heavy loads are a prominent cause of incapacity to foot-soldiers, therefore negatively impacting military efficiency, resulting in unwanted injury and financial costs.

Haisman (1988) argued that the determinants of load carrying ability are age, anthropometry, body composition, aerobic and anaerobic power, muscle strength and sex. Other factors including load-related factors such as the dimensions and placement of the load, terrain, gradient, climate and clothing worn will all impinge on load carrying ability. Although the load borne has been shown to have little or no influence on energy expenditure when standing (Borghols **et al.**, 1978), Bhambhani **et al.** (1997) argued that load carriage has a significant effect on heart rate, cardiac output and VO_2, when walking. Lloyd and Cooke (2000) found similar increases in oxygen consumption when comparing loaded to unloaded walking. Bobet and Norman (1984) found that a 20 kg load increased heart rate by 8-10 bt.min^{-1}, while Duggan and Haisman (1992) found that a load of approximately 37 kg resulted in an increase in energy expenditure of 35%.

Schleusing and Ohl (1967) investigated the effect of carrying 10 kg and 20 kg loads and found that a 20 kg load gave rise to higher energy expenditure than a 10 kg load. They postulated that increases in energy expenditure are not proportional to increases in load, but are dependent on other factors such as type of activity. A later study by Quesada **et al.** (2000) argued that increments in load carriage of 15% of body weight resulted in proportional increases in energy expenditure of approximately 5-6%.

Keren **et al.** (1981) and Epstein **et al.** (1987) proposed that the crossover point of efficiency between walking and running is not only dependent on step frequency but also on the weight of the load carried. Epstein **et al.** (1987) contended that the increased energy expenditure associated with load carriage is due to an external load causing a forward shift in the centre of mass, thereby altering efficiency and increasing energy expenditure. Gordon **et al.** (1983) found that the tendency to lean forward was observed in all subjects in an attempt to bring the centre of mass back over the base of support. Therefore, to minimise the effect of load carriage, it is important to carry loads as close to the trunk, and therefore the centre of mass as possible, optimising efficiency and stability.

Malhotra **et al.** (1962) asserted that during exercise such as marching, there is a linear relationship between body weight and energy expenditure. Several authors have argued that there is also a linear relationship between load carried and energy expenditure (Datta and Ramanathan, 1970; Borghols **et al.**, 1978). There is substantial evidence (Bobbert, 1960; Goldman and Iampietro, 1962; Givoni and Goldman, 1971; Soule **et al.**, 1978) that load carriage results in an increase in energy expenditure equivalent to that associated with carrying additional body weight. The results of Datta **et al.** (1973) support the findings of Goldman and Iampietro (1962) that the energy cost per unit weight is the same regardless of the distribution of the weight between body weight and load. Soule **et al.** (1978) argued that as long as the load is carried close to the centre of mass and is well balanced, loads of up to 70 kg result in added energy expenditure, similar to that of added body weight.

Epstein **et al.** (1988) agreed that small loads result in an increase in energy expenditure, similar to that of increasing body weight. However, Bobbert (1960) and Epstein **et al.** (1988) contended that heavy load carriage does affect energy expenditure per kilogram. These authors argued that over time physical fatigue results in changes in locomotor biomechanics, with muscle fatigue requiring the recruitment of greater muscle mass, in so doing, increasing energy expenditure. Åstrand and Rodahl (1977) argued that increases in energy expenditure associated with workloads greater than 50% of VO_{2max} (above which heavy load carriage is likely to be) are due to anaerobic metabolism and lactic acid production, reducing efficiency of performance.

Renbourn (1954) and Schoenfeld **et al.** (1978) argued that energy expenditure would increase disproportionately when load carried exceeds 40-45% of body weight. It has been found that at high velocities (Hughes and Goldman, 1970) and inclines (Durnin and Passmore, 1967), heavier loads tend to result in a disproportionate increase in energy expenditure. Several authors (Saltin and Stenberg, 1964; Hughes and Goldman, 1970; and Epstein **et al.**, 1988) have argued that maximal loaded walking efficiency will be achieved at a speed of 1.25 to 1.39 $m.s^{-1}$ (4.5 to 5 $km.h^{-1}$) with a load of 40-50% of body weight.

Although it was found by Malhotra **et al.** (1962), Soule **et al.** (1978) and Charteris **et al.** (1989) that the energy cost of moving body weight plus a load increases concomitantly with increments in load, it is hypothesised that high loads must have a curvilinear relationship with energy expenditure as reported by Renbourn (1954), Pimental and Pandolf (1979) and Maloiy **et al.** (1986). Therefore, the notion of "free-ride" with regard to heavy load carriage is an important factor to investigate in order to establish what loads should be carried to optimise efficiency.

Goldman (1965), Hughes and Goldman (1970) and Haisman (1988) all found an optimal load between 30 and 33 kg, while Pandolf **et al.** (1977) found an optimal load of 20 kg. Pierrynowski **et al.** (1981) found an optimal load of 40 kg when only the load mass was taken into consideration, but when body mass was taken into account there was an optimal load of only 7 kg. They surmised that "the issue of the 'optimum' load to be carried is complicated and confused because the value cited depends upon the experimental conditions imposed upon the subjects, the manner of presentation of the data, and whether there is a non-linearity in the metabolic rate/load curve."

Haisman (1988) asserted that the upper limit of load carriage should be 30 kg, but recognised the need to make loads relative to body weight, as absolute loads would differentially tax different individuals. For example, comparing an individual weighing 58 kg (5th percentile for the British infantry, Gooderson, 1976) to an individual of 91 kg (95th percentile), it is unlikely that these two individuals would be equally taxed by the same absolute load. Knapik (1989) identified that variations in soldier height and weight are important factors in load carriage. Soldiers with a greater height and muscle mass may have the ability to carry a heavier load without any added energy expenditure. There are many studies supporting the need to make individual loads relative to body weight (Cathcart **et al.**, 1923; Marshall, 1950; Kinoshita, 1985; Scott and Ramabhai, 2000). Relative loads will ensure that all members of a platoon are equally taxed by the task demands, and therefore, will perform post-march tasks more efficiently and with fewer injuries. Therefore, any load carriage system should promote stability, bring the centre of gravity of the load as close to that of the body as possible and make use of large muscle mass (Legg, 1985), as well as be relative to body weight.

Walking Speed and Load Carriage

Hughes and Goldman (1970) and Knapik **et al.** (1993) found a linear relationship between walking speed and load carriage, with walking speed adjustment being a function of the load carried. As load carriage is increased there is a reciprocal drop in the corresponding walking speed, thereby ensuring that energy expenditure does not increase.

Myles and Saunders (1979) argued that, even though a heavy load may be carried at a slower speed with no added energy expenditure, there is an increased cost on the cardiopulmonary system and the heavier load is perceived by the subjects as being ‘harder work’. They contended that higher loads result in a greater amount of muscular strain and the restriction of chest movements, thereby affecting minute ventilation and breathing frequency.

Soule **et al.** (1978) found that increases in walking speed are associated with greater increases in energy expenditure than increases in load carriage. An increase in walking speed from 3.2 to 6.4 $km.h^{-1}$ resulted in a 51-56% increase in energy expenditure, depending on the load carried. Whilst an increase in load from 35 to 70 kg only resulted in an increase in energy expenditure of 25%.

Hughes and Goldman (1970) investigated the optimal combinations of load and speed. They argued that a load of 40 kg should be carried at a walking speed of 5 $km.h^{-1}$, and a 30 kg load at a speed of 5.6 $km.h^{-1}$, because these combinations result in the lowest energy expenditure per kilogram and distance covered. Quesada **et al.** (2000) found that marching overuse injuries (resulting from poor combinations of walking speed and load) result in “substantial pain, impair function and subsequently impede performance”. It is important to minimise such injuries by optimising walking speed and load carried.

GRADIENT FACTORS

Effects on Gait Patterns

Gait patterns selected by individuals are freely chosen and not mechanically predetermined, regardless of whether walking speed is self-selected or imposed (Zatsiorky **et al.**, 1994). This gait pattern is chosen in order to enhance body stability by optimising several fundamental aspects of gait, such as double support time, step width, foot clearance, and prevention of foot slip at heel strike. Zatsiorky

et al. (1994) argued that once these requirements have been met, the determinants of the required gait pattern are step length and minimisation of energy expenditure. Holt **et al.** (1991) and Bunc and Dlouhá (1997) agreed that stride frequency and stride length have a consequential effect on metabolic cost.

Locomotion on sloping ground results in alterations in overall body posture and imposes critical demands on ground clearance during the swing phase of the step cycle. It is therefore critical that the locomotor system can easily adapt to these changes in gradients (Patla, 1986). Recently, Aminian **et al.** (1995), Kuster **et al.** (1995) and Sun **et al.** (1996) have identified that there is limited data available on the correlation between the incline of the ground and gait patterns.

Wall **et al.** (1981) found that under an enforced pace there was no change in cadence, stride time and length or pelvic rotation during uphill walking. However, under normal conditions (no speed constraints) the obvious response to increases in positive gradient would be to walk slower and to take smaller steps. This is supported by Sun **et al.** (1996) who found a significant decrease in cadence, walking speed and step length with increasing slope. Conversely, Wall **et al.** (1981) found that even under self-selected speeds, there was no change in step length. This has been attributed to the fact that the main adjustments in gait to positive gradients are increased knee and thigh flexion at heel strike. Wall **et al.** (1981) argued that knee flexion reduces step length, while hip flexion increases step length, thereby counteracting any changes in step length. Therefore, within the military setting, it is important to account for individual variability in gait pattern responses to varying gradients. Failure to adjust will have a deleterious effect on the efficiency of individual walking patterns, thereby increasing energy expenditure and reducing military effectiveness.

During level walking there is a continual conversion of potential energy to kinetic energy and *vice versa*, with the energy cost of walking being derived from the “incomplete reciprocity between them” (Wall **et al.**, 1981). However, when walking uphill, the incline results in less lowering of the center of mass compared to the preceding lift. The concomitant result is a reduction in the reutilisation of kinetic energy and a consequential increase in metabolic cost (Veicsteinas **et al.**, 1979).

There is controversy in the literature as to the exact nature of the gait responses of normal walkers in downhill walking. Simpson **et al.** (1991), Kuster **et al.** (1995) and Vogt and Banzer (1999) found that for downhill gradients of up to –19% there was no change in stride time or stride length. Furthermore, Sun **et al.** (1996) found no changes in cadence and walking speed with increases in negative gradients. Contrastingly, for gradients of up to -20%, Wall **et al.** (1981) found significant changes in stride time and length compared to level and uphill walking. Wall **et al.** (1981), Kawamura **et al.** (1991) and Sun **et al.** (1996) found decreases in stride time and length with increases in negative gradient, regardless of whether speed was controlled or not. The decrease in step length during downhill walking has been attributed to an increased frictional demand, which increases the likelihood of slipping. According to Sun **et al.** (1996) reduced step length will reduce the frictional demand and thereby increase stability, reducing the chance of slipping.

Therefore, both positive and negative gradients have an adverse effect on the efficiency of gait patterns and hence result in an increase in the metabolic cost of walking. An understanding of the physical and physiological responses to positive and negative gradients will allow appropriate adjustments in walking speed and/or load carried to be made. These adjustments will ensure that foot soldiers are not excessively taxed by the task demands, therefore optimising their ability to perform post-march tasks.

Physiological Determinants

It has long been accepted that there are many factors that influence the energy expenditure of walking, such as body weight, load carried, terrain, speed and incline (Margaria, 1976). Poor combinations of walking speed and load carriage, and the failure to adjust one or both to changes in walking gradient will place high demands upon the physical performance capacity of individuals (Borghols **et al.**, 1978). Considering that there are limited stores available to overcome frictional and gravitational demands during walking, the identification of the energetic constraints to human locomotion is critical (Frederick, 1985). Staab **et al.** (1992) found that factors such as hill length, steepness and location all influence the severity of a hill and need to be accounted for in order to perform optimally.

There is little argument that positive gradients result in an increase in energy expenditure (Pandolf **et al.**, 1977; Kirk and Schneider, 1992; Laursen **et al.**, 2000, Sagiv **et al.**, 2000, Santee **et al.**, 2001). Montoye **et al.** (1985) investigated a wide range of walking gradients and found a linear relationship between oxygen uptake and positive treadmill gradients of up to 18%. Similarly, Gordon **et al.** (1983) found a linear relationship between walking gradients and heart rate responses, with an approximate 43% increase in heart rate with an increase in gradient from 5% to 20%. Kirk and Schneider (1992) found that a gradient of only 3% significantly increased heart rate, minute ventilation, and ratings of perceived exertion. More recently, Sagiv **et al.** (2000) found that a gradient of 10% increased heart rate to 169 $bt.min^{-1}$. Nagle **et al.** (1990) argued that progressive uphill walking requires increasing energy expenditure, due to an increase in vertical work and added work required to displace the centre of mass against gravity.

Patla (1986) investigated muscle activity during inclined walking and found a linear relationship between average EMG values and incline. As incline increases, there is a reciprocal increase in biceps femoris, vastus lateralis, rectus femoris and the tricep surae muscle activation, during the various phases of the walking pattern. This has been attributed to an additional power requirement in order to raise the body further than during level walking (Patla, 1986; Sun **et al.**, 1996). Therefore the combination of reduced reutilisation of kinetic energy and increased muscle activation during uphill walking results in a substantial increase in energy expenditure.

Although loads of up to 20 kg during level walking have little effect on energy expenditure, Laursen **et al.** (2000) found that walking uphill with a 10 kg load increased energy turnover by more than 70% and a load of 20 kg almost doubled energy turnover. Goldman and Iampietro (1962) investigated the effect of load carried and walking gradient on energy expenditure, and found a linear relationship between walking gradient and energy expenditure up to gradients of

9%, even under loaded conditions. They argued further that the energy cost per unit weight (body weight plus load carriage) is constant for any given gradient and speed.

Gordon **et al.** (1983) also investigated the effect of load carriage on the metabolic responses to grade walking. They found that the relationship between energy expenditure and gradient remained linear, but that the responses were significantly higher with load carriage, and the slope of the curve significantly steeper. In other words, for the same vertical power, the RPE and heart rate responses were consistently lower in the unloaded conditions. It was contended by Gordon **et al.** (1983) that RPE and heart rate responses to 10 minutes of walking under loaded conditions, is comparable to 5 minutes of walking with added gradient.

However, not all studies have indicated a linear relationship between energy expenditure and walking gradient, when load carried is taken into consideration. Bobbert (1960) argued that there is a curvilinear relationship between energy cost and walking gradients of 0 to 12 degrees. To a lesser extent, Pimental and Pandolf (1979) found that under more strenuous conditions, the same increase in gradient will increase energy expenditure by a greater amount.

Legg **et al.** (1992) investigated different load carriage systems at various gradients and found an increase of 21% in heart rate and a 32% increase in oxygen consumption with an increase in grade to only 5%. Sagiv **et al.** (2000) investigated various loads (25 and 35 kg) and gradients (0, 5 and 10%) at a walking speed of 5 $km.h^{-1}$ and found that gradient had a substantial effect on both heart rate and oxygen consumption. These authors found that changes in gradient had a greater effect on energy expenditure than did changes in load carriage. An increase in load carriage from 25 to 35 kg at a gradient of 10% did not significantly alter energy expenditure, whilst an increase in gradient from 5 to 10% did have a significant effect on energy cost.

Substantial increases in heart rate responses to grade walking were also found by Pimental and Pandolf (1979). Pandolf **et al.** (1977) found that for a young, healthy 70 kg male carrying a load of 40 kg at a walking speed of 1.34 $m.s^{-1}$ (4.83 $km.h^{-1}$), increasing the gradient to 16%, results in an energy expenditure that is considered to be outside the physiological range for young, healthy men. Scott and Charteris (1999) investigated a similar walking speed (4.5 $km.h^{-1}$) and load carriage (35 and 50 kg) on the level and found that neither condition excessively strained subjects with an oxygen consumption of 56% of VO_{2max}. It was suggested by Kirk and Schneider (1992) that as long as speed is held constant, small increases in gradient greatly increase the difficulty of load carriage. It is therefore clear that gradient has a substantial impact on the resulting energy expenditure.

Table III: **Energy expenditure (Watts) of grade walking with various loads at a speed of 1.34 $m.s^{-1}$ (4.82 $km.h^{-1}$).**

		Gradient (%)				
		0	4	8	12	16
Load (kg)	0	294	425	556	687	819
	20	362	531	700	868	1037
	40	473	679	886	1092	*

Adapted from Haisman (1988)

* Outside of physiological range

Gradient and load carriage are however, not the only two factors that will affect energy expenditure; walking speed is also a vital aspect to be considered. Margaria (1968) investigated the effect of gradient on energy expenditure at various walking speeds and found that there was a substantial increase in energy cost with increases in gradient and speed. Pimental and Pandolf (1979) found an increase in energy expenditure of 30% when walking speed was increased from 0.5 $m.s^{-1}$ to 0.9 $m.s^{-1}$ at a gradient of +10% with a load of 20 kg, whilst increasing the load to 40 kg did not further alter energy expenditure. These authors argued that energy expenditure is more sensitive to gradient and load carriage at high walking speeds, than in conditions of slow walking speed,.

However, the data on negative gradients are less conclusive, and according to Davies and Barnes (1972) and Pimental and Pandolf (1979) have not been adequately studied. Even though downhill walking forms a substantial part of any march, Robergs **et al.** (1997) argued that there is limited research on the physiological and energy expenditure responses to such gradients. When compared to uphill walking, the energy expenditure of walking downhill has shown increases (Pimental and Pandolf, 1979; Duggan and Haisman, 1992), decreases (Margaria, 1968; Nagle **et al.**, 1990) and no difference (Pivarnik and Sherman, 1990).

Laursen **et al.** (2000) found heart rate and oxygen consumption values for all downhill conditions to be lower than those for level or uphill conditions, indicating a significant reduction in energy cost when walking downhill, even under loaded conditions. Pimental **et al.** (1982) and Robergs **et al.** (1997) found similar trends in oxygen consumption responses to downhill walking and running respectively. Pimental **et al.** (1982) argued that decreases in energy expenditure are caused by gravity helping to move the load in a downward direction, therefore requiring the recruitment of fewer muscle fibres. Contrastingly, they do acknowledge that this response may not be elicited when an enforced pace is required. By maintaining a specified pace, there is added energy expenditure in resisting the pull of gravity. This is illustrated by Pimental and Pandolf (1979) who found that there was greater energy expenditure for a negative gradient of 10% with a load of 40 kg at an enforced speed of 0.9 $m.s^{-1}$ (3.2 $km.h^{-1}$) than for level walking under the same conditions. This is particularly applicable to the military, where troops are often required to maintain a set pace, thereby reducing the positive effects of gravity during downhill walking. The testing protocol of the present study will also require the subjects to walk at an enforced pace, therefore it is important that this factor is taken into consideration.

Pivarnik and Sherman (1990) investigated the effect of negative grades at a walking speed of 4.8 $km.h^{-1}$ and found that declines of up to 10% had no significant effect on heart rate or VO_2. They argued that although negative treadmill grades result in a higher amount of eccentric work, metabolic and cardiovascular demands are not reduced. Studies by Pimental and Pandolf (1979) and Duggan and Haisman (1992) contended that not only are the demands not reduced but in fact they may increase. Pimental and Pandolf (1979) argued that the surprising increase in energy expenditure associated with negative gradients is due to the involvement of the back and leg muscles in resisting the downward pull of gravity.

The greater involvement of the leg muscles during negative grade walking is supported by several studies (Byrnes **et al.**, 1985; Schwane **et al.**, 1983; Schwane **et al.**, 1987) of extensor muscle soreness associated with downhill walking and running, not experienced on the level. Byrnes **et al.** (1985) and Schwane **et al.** (1987) both found elevated levels of muscle-specific enzymes and proteins such as creatine phosphokinase, creatine kinase and myoglobin after downhill running. It is asserted by Komi and Viitasalo (1977) and Schwane **et al.** (1983) that delayed-onset of muscle soreness is due to the increase in eccentric muscle contractions associated with negative gradients.

During downhill walking the body is continually being lowered, therefore the centre of mass requires less mechanical work to be lifted than during level walking. Kuster **et al.** (1995) found that this was reflected in a 50% lower muscle power generation at the ankle during push off. This ankle plantarflexor action accounts for up to 80-85% of the energy generation during normal walking (Winter, 1983). It could therefore be expected that there would be a reduction in energy expenditure during negative gradient walking. However, physiological studies have not shown this to be the case (Pivarnik and Sherman, 1990). It is argued by Wall **et al.** (1981) that the lowering of the centre of mass compared to the preceding lift results in an increased muscular effort in doing negative work. Even though negative (eccentric) work is metabolically less costly, Kuster **et al.** (1995) found that there was an increase in the mechanical power requirements at the knee joint during early stance, six times larger than for level walking. This results in an increase in the work done by the knee extensors, greater than the reduction in work done by the plantar flexors and therefore an increase in energy expenditure. Duggan and

Haisman (1992) found an increase in the metabolic cost of walking with a load of 27.09 kg from 532 W during level walking to 833 W during downhill walking. There is substantial evidence (Cotes and Meade, 1960; Pimental and Pandolf, 1979; Pahud **et al.**, 1980) that at similar positive and negative gradients, the energy expenditure associated with negative work is greater than that associated with positive work.

Pimental and Pandolf (1979) investigated the effect of added load at both positive and negative gradients on energy expenditure. There was an increase in energy expenditure during both downhill and uphill walking with loads of 20 and 40 kg at a walking speed of 3.2 $km.h^{-1}$. However, the energy expenditure associated with a positive slope of 10% was approximately 53% higher than that achieved during the equivalent negative slope, regardless of the load carried. Laursen **et al.** (2000) investigated cardiovascular and metabolic responses to unloaded and loaded uphill and downhill walking. These authors found that the lowest heart rate and oxygen consumption were achieved during downhill walking (-8%), unloaded, with a mean heart rate of 73 $bt.min^{-1}$ and oxygen consumption of 0.5 $l.min^{-1}$. The highest heart rate and oxygen consumption were achieved during uphill walking (8%), carrying a 20 kg load asymmetrically, with a heart rate of 130 $bt.min^{-1}$ and an oxygen consumption of 2.1 $l.min^{-1}$.

It is contended by Davies and Barnes (1972) and Pimental **et al.** (1982) that at similar levels of oxygen consumption, higher heart rates were achieved during downhill walking than during uphill walking. This has been attributed to the greater amount of eccentric work required during downhill walking, which elicits a pressor response (as in isometric exercise), with vasoconstriction resulting in an increase in mean arterial pressure and an increase in heart rate (Petrofsky **et al.**, 1981). A further factor influencing the heart rate – oxygen consumption relationship is the greater increase in muscle and core temperature during eccentric exercise than during concentric exercise (Pahud **et al.**, 1980).

It was disputed by Margaria (1968) and Wanta **et al.** (1993) that the energy cost of walking downhill approximates a U-shape when plotted against gradient. There is an initial decrease in energy cost and then a gradual increase. This is supported by Santee **et al.** (2001) who argued that the net cost of downhill walking will reach a minimum and then increase, as work is required to maintain stability. Margaria (1968) found that the minimum energy expenditure occurred at a gradient of -9%, while more recently Santee **et al.** (2001) found that the minimum VO_2 values occurred at a –8% gradient. However, Wanta **et al.** (1993) found optimal gradient to show a significant amount of variation (between -6% and -15%), depending on individual walking characteristics and walking speed. These authors hypothesised that at the optimal point, the centre of mass is no longer elevated against gravity during the positive phase of the step cycle, minimising energy expenditure. They argued that any further increases in negative gradient will result in an increase in the braking component in resisting gravity, reducing step length and increasing energy expenditure.

This large variation and the use of non-standardised protocols, for example, some studies used various walking speeds (Pivarnik and Sherman, 1990), others loads (Duggan and Haisman, 1992; Laursen **et al.**, 2000), and some just gradient

(Nagle, 1990; Wanta **et al.**, 1993), may account for the lack of consensus on the relationship between negative gradients and energy expenditure. Within the army setting it is hence important to adjust walking speed and/or load carried to changes in gradient in order to maintain energy expenditure within acceptable limits and thereby optimise overall performance.

PERCEPTUAL RESPONSES

Although the primary focus of the present study was on the metabolic responses to various walking gradients, Fleishman **et al.** (1984) contended that physical effort is a complex factor that cannot be explained by any single physiological parameter. Furthermore, Borg (1970) has argued that humans react to environmental stimuli as they perceive them and not how they really are, and hence, it is important to have an understanding of the relationship between the objective and subjective measurements. Fleishman **et al.** (1984) argued that one's physical capabilities and psychological perceptions of a task interact at all levels of performance. The physical workload affects psychological motivation, fatigue, satisfaction and willingness to work, while the performer uses psychological signals to determine physiological work pace. These authors contended that the physical and psychological factors function 'reciprocally in cueing muscular and cardiovascular effort in relation to feelings of workload, exertion and fatigue'. In the military context cognisance must be taken of the fact that although a platoon marches as one unit, this unit is comprised of unique individuals with their own physical and psychological strengths and weaknesses. Individual perceptions of the task demands are an essential aspect of ensuring optimal performance and hence obtaining military efficiency.

Rating of Perceived Exertion

In 1970, Borg developed a scale for the Rating of Perceived Exertion (RPE), constructed so as to increase linearly with intensity of physical exertion. Birk and Birk (1987) argued that perceived exertion is a rating of the effort made during exertion which integrates signals from the peripheral working muscles and joints, from the central circulatory and pulmonary systems and from the central nervous system. Thus perception of exertion is a complex interaction of all these influencing factors, eliciting a gestalt rating. Borg (1982) argued that perceived exertion is “the single best indicator of the degree of physical strain”.

The RPE scale has values ranging from 6 to 20, which reflect heart rates of 60 to 200 bt.min^{-1}. In other words, a rating of 13 would represent a heart rate of approximately 130 bt.min^{-1}. Hence the RPE scale consists of a 15-point numerical scale, with every second number having a verbal anchor. The reliability of the scale is dependent on the subjects’ understanding of the concepts of the personalised rating and, of course on fidelity of introspection. It is therefore essential that the researcher provides subjects with specific instructions about the use of the scale (Refer to Appendix B). The diverse ethnic backgrounds and languages of the South African National Defence Force increases the difficulty associated with ensuring a conceptual understanding of the RPE scale.

Borg (1982) found high correlations between RPE and heart rates (r = 0.8-0.9), as well as with other physiological variables. More recently, Walker **et al.** (1996) found that not only is RPE highly correlated with heart rate but also with power output and was found to be reliable over repeated tests. RPE can also be highly correlated with other factors such as ventilatory threshold and lactate threshold (Hetzler **et al.**, 1991).

Ekblom and Goldbarg (1971) proposed a two-factor model of perceived exertion associated with physical work. They put forward a “Local” factor, which is associated with feelings of strain involving the working muscles and/or joints and a “Central” factor associated with feelings involving the cardiopulmonary systems. In the present investigation, a Local rating, from the working muscles and joints of the lower spine, and a Central rating, from the cardiopulmonary system, were measured. It was argued by Robertson **et al.** (1979) that during cycle ergometry the Local rating of perceived exertion (legs) was higher than the Central rating. An earlier study by Pandolf **et al.** (1975) of level and grade walking supports the dominance of local muscular factors in the exertional perception. Knuttgen **et al.** (1982) lend further support to local sensations from the exercising muscles and joints dominating the sensory process.

Gamberale (1985) proposed that RPE should be used to complement the circulatory responses during exercise. Due to the complex nature of any exertional environment, an evaluation of the metabolic, biomechanical and perceptual responses rather than just the physiological and biophysical will ensure that any subtle differences that may exist are detected. This will enable an integrated understanding of all factors impinging on performance, thereby allowing fine changes in walking speed and\or load carriage to maintain energy expenditure at an optimal, specific to the requirements of the task at hand.

Body Discomfort Scale

Another tool to assess individual reactions to physically demanding tasks has been developed by Corlett and Bishop (1976). This scale uses the perception of muscular pain as a measure, however it is recognized by Corlett and Bishop (1976) that pain is experienced as specific and localized pain, therefore the more appropriate term ‘discomfort’ was used. The scale makes use of a body map dividing the body into 27 segments, which allows for the identification of the site(s) of discomfort. Once the subjects have identified the site(s) of discomfort, they are able to rate the intensity of discomfort using the discomfort scale, with a rating of 1 indicating ‘very comfortable work’ and a rating of 10 indicating ‘ very uncomfortable work’ (see Appendix B, pp: 171).

CHAPTER III

METHOD

INTRODUCTION

The success of any military objective, no matter how sophisticated the technology used, is dependent on the human operator. Foot soldiers are often required to march substantial distances before the execution of military objectives. Individual variability plus load, walking speed and gradient are all determinants of the energy expenditure associated with such marches. Not only will individuals be differentially taxed by the same task, but the lack of adjustment in speed and load to environmental factors (such as gradient of the terrain), will result in excessively high workloads being placed on soldiers.

The ethnic diversity in the SANDF has resulted in a substantial variability not only in soldier morphology and physical strength, but also socio-cultural background. These factors all contribute to a substantial range in soldier capabilities, which ultimately impact on overall military effectiveness. Despite this diversity, soldiers are required to perform tasks as a group and function quickly and effectively as a unit.

The aim of the present study was to investigate the relationship between gradient and energy expenditure, and the effect of walking speed and load carriage on this relationship. The attainment of least energy expenditure per unit distance covered is of vital military importance, and acknowledging the human element it is also important to take individual perceptions into account in order to enhance performance and hence maximise military proficiency. Walking speed and load carriage adjustments to the environmental conditions, especially changes in gradient, need to be investigated, taking cognisance of morphological, perceptual and practical issues relevant to the current demographics of the SANDF. The present study therefore included morphological, kinematic, physiological and perceptual responses to marching, ensuring an integrated, holistic investigation.

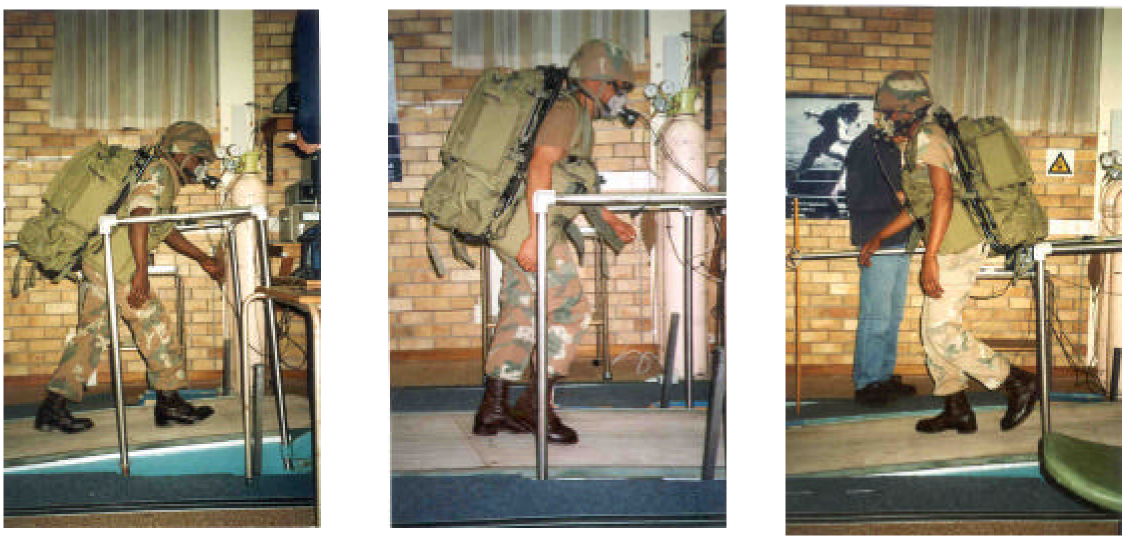
PILOT STUDY

Prior to the main study, several preliminary investigations were conducted on a treadmill in the Ergonomics laboratory of Rhodes University. Appropriate speeds, loads and gradients were established. Speed and load combinations were selected from those found by Christie (2001) to be considered submaximal when walking on the level. A range of gradients was tested and 10% incline and decline gradients were deemed realistic and sufficient to elicit the required terrain effects. The pilot phase ensured experimenter familiarity with the equipment and rating scales to be used and facilitated clarification of the testing protocol.

EXPERIMENTAL DESIGN

Several authors (Pandolf **et al.**, 1977; Gordon **et al.**, 1983; Laursen **et al.**, 2000) have argued that there is an increase in energy expenditure with an increase in gradient. Legg **et al.** (1992) showed how an increase in gradient to only 5% had a marked effect on heart rate and oxygen consumption, while Pimental and Pandolf (1979) found similar increases in energy expenditure on a positive gradient of 10%. There is controversy in the literature as to whether negative gradients will decrease or increase energy expenditure. Laursen **et al.** (2000) and Santee **et al.** (2001) found that the most economical gradient was a negative gradient of 8%. It was contended by Wanta **et al.** (1993) that energy expenditure would be optimal at a gradient between –6 and –15%. Such changes in energy expenditure will have a concomitant affect on soldiers' ability to perform. Hence the attainment of ideal combinations of the influential factors is of obvious military importance. In the present study, the three walking gradients selected were 10, 0 and –10%.

The effect of walking speed and load carriage on energy expenditure is affected by changes in gradient. An investigation by Christie (2001) found that walking speeds of 3.5 $km.h^{-1}$, 4.5 $km.h^{-1}$ and 5.5 $km.h^{-1}$ with loads of 20 kg, 35 kg and 50 kg respectively, did not excessively strain SANDF military personnel. However these 'optimal' speed-load combinations were only investigated under level marching conditions and changes in gradient were not considered. Pandolf **et al.** (1977), under similar conditions (4.83 $km.h^{-1}$ with a load of 40 kg) increased walking gradient to 16% and found that it was outside the physiological range of young, healthy men. Pimental and Pandolf (1979) argued that energy expenditure is more sensitive to gradient and load carried at fast walking speeds than at slow walking speeds. Therefore, in the present study three walking speed and load carriage combinations similar to those found to be optimal by Scott and Christie (2000) and Christie (2001) were selected: 4 $km.h^{-1}$ with a load of 50 kg; 5 $km.h^{-1}$ with a load of 35 kg and 6.0 $km.h^{-1}$ with a load of 20 kg.



A B C

FIGURE 2: **Three test conditions showing the uphill (A), level (B) and downhill (C) gradients.**

Thus, three different gradients and three different walking speed and load carriage combinations were selected for the present investigation. These are outlined in Table IV below. From these variables, nine different combinations of gradient, speed and load were utilised as the basis for experimentation.

Table IV: **Gradient, speed and load combinations**

Condition	Gradient (%)	Speed ($m.s^{-1}$)	($km.h^{-1}$)	Load (kg)
1	0	1.11	4.0	50
2	0	1.39	5.0	35
3	0	1.67	6.0	20
4	-10	1.11	4.0	50
5	-10	1.39	5.0	35
6	-10	1.67	6.0	20
7	+10	1.11	4.0	50
8	+10	1.39	5.0	35
9	+10	1.67	6.0	20

In order to ensure small numbers at each testing session, subjects were placed into 8 groups: M_1 to M_8, with five members in each group. Two groups were tested per day, with one group being tested in the morning and the other in the afternoon.

The investigation therefore involved nine experimental conditions, each lasting six minutes. During each condition several physiological and psychophysical variables were measured, allowing the researcher to study the effect of changes in gradient and speed-load combination on the various parameters investigated. Two-way ANOVAs were calculated to determine whether there were significant differences between the various conditions. These were computed for the assessment of the physiological, biomechanical and the psychophysical responses to changes in gradient.

	GRADIENT		
SPEED-LOAD	-10%	0%	+10%
4 km.h^{-1}; 50 kg			
5 km.h^{-1}; 35 kg			
6 km.h^{-1}; 20 kg			

Various physiological and psychophysical data

TECHNIQUES; INSTRUMENTS USED

Prior to the experiment, basic demographic information was gathered. These data included age, military experience and several anthropometric measurements. Rodgers (1995) showed that factors such as age and experience substantially affect physiological and psychological responses to any task. Furthermore, variability in mass, stature and lower limb length influence individual responses to loaded marching. Therefore these measurements must be taken into account when considering any marching activity.

Body Mass – Toledo Scale

Oxygen consumption (and energy expenditure measures derived therefrom) are directly related not only to load, speed and grade, but also to the individual's body weight. McInnis and Balady (1999) argued that larger body weights result in greater absolute VO_2 ($ml.min^{-1}$). In order to make pertinent comparisons between individual subjects of diverse weight, individual responses in this project are made relative to body weight (i.e. VO_2 measured in $ml.kg^{-1}.min^{-1}$).

A previously calibrated TOLEDO electronic scale was used to measure body mass to the nearest 0.01 kg. Subjects were required to stand still with equal weight distribution while the readings were recorded manually. Each subject was measured wearing minimal clothing and then full army uniform, but without the load to be carried.

Stature and Limb Length

Since energy expenditure required to maintain a specific walking speed is directly related to stature and more specifically lower limb length (Williams, 1987), both measurements were obtained using the Harpenden stadiometer and anthrometer. Stature was measure from the vertex in the mid-sagittal plane to the floor. Subjects were required to stand erect, barefooted with the visual axis parallel to the surface of the floor. Lower extremity length was measured from the greater trochanter to the floor on the lateral side of the limb. The greater trochanter was located by palpation while abducting the hip.

Body Composition – Bioelectrical Impedance Analysis

Buskirk and Taylor (1957), Poehlman (1989) and McInnis and Balady (1999) reported lean body mass (LBM) to be highly correlated with VO_{2max}. McInnis and Balady (1999) argued that individuals with a high LBM are able to work at a given rate for longer with a heavier load. There are several techniques available to assess body composition, including bioelectrical impedance analysis (BIA), the technique used in the present study.

BIA has been used since the 1970's as an indirect method of determining fat content (Van Loan, 1990). Eckerson **et al.** (1996) commented that the portable, rapid and non-invasive characteristics of BIA, as well as the use of only four electrodes on well-defined landmarks make this a popular technique. It was argued by Eston **et al.** (1993) that BI is a reliable measure in normal adults, obese adults and in children. BIA functions on the principle that when a constant low-level alternating current is applied to any biological structure, the structure produces an impedance to the spread of the current, dependent on the frequency of the current.

Subjects were required to be barefoot and to remove all jewellery before lying in a supine position on a non-conductive surface with arms and legs abducted at an angle of 30-45° from the trunk. The BI unit used consists of four electrodes which were placed on the dorsal surface of right hand and foot. The hand electrodes were placed as follows: the sensing electrode on the mid-dorsum of the wrist on a line bisecting the ulnar styloid. The current electrode on the mid-dorsum of the hand, midway between the proximal meta carpal-phalangeal joint and the sensing electrode. The foot electrodes were placed as follows: the sensing electrode on the mid-dorsum of the ankle on a line bisecting the medial malleolus. The current electrode on the mid-dorsum of the foot, midway between the proximal metatarsal phalangeal joint and the sensing electrode. Care was taken that the sensor and current electrodes were at least 55 mm apart to ensure that there was no interference between electrodes artificially increasing the resistance. The data from the BI unit were manually recorded for each subject at the first testing session. Calculations of body fat mass (kg and %), lean body mass (kg and %), body mass index (BMI) and Reciprocal Ponderal Index (RPI) were all relevant variables in the present study.

Any military operation should be conducted as efficiently as possible with minimal effort. An assessment of cardiorespiratory provides important information about the energy expenditure and workloads soldiers are exposed to. The assessment of workloads placed on soldiers will identify any need for adjustment of walking speed and/or load to the environmental conditions.

Maximal Oxygen Consumption (VO_{2max})

Cardiovascular endurance is traditionally measured via maximal oxygen uptake (VO_{2max}). However, submaximal tests are often used to provide an accurate estimation of maximal oxygen uptake, particularly when working with large, diverse populations such as the SANDF, who are unfamiliar with laboratory testing. An estimated VO_{2max} test was considered necessary to determine the percentage of assumed maximal workload experienced by each subject under each of the various walking speed, load and gradient combinations presented.

The Modified Bruce Protocol was utilised in the present study as the submaximal treadmill test to predict maximal oxygen consumption. This protocol employs increments in both walking speed and gradient, every three minutes. The test uses an end-point based on a predetermined heart rate (HR) at 85% of predicted maximal HR reserve (i.e. [(maximal HR - resting HR) (0.85)] + resting HR). All subjects were fitted with a telemetric Polar Heart Rate Monitor prior to testing in order to monitor this variable. Outlined below are the speed and gradient increments according to the Bruce Protocol.

Table V: **Submaximal Bruce Protocol for estimation of maximal oxygen consumption.**

Stage	**Speed**		**Grade**
	($m.s^{-1}$)	**($km.h^{-1}$)**	**(%)**
1	0.75	2.7	10
2	1.11	4.0	12
3	1.50	5.4	14
4	1.86	6.7	16
5	2.22	8.0	18
6	2.44	8.8	20

On the completion of each stage heart rate and perceptual ratings were recorded until subjects either reached their predetermined HR, or requested to stop.

To calculate the predicted VO_{2max} from the Bruce Protocol the following prediction equation was utilised based on exercise duration:

VO_{2max} (in $ml.kg^{-1}.min^{-1}$) = 14.8 – (1.379 $\times$ time in min) + (0.451 $\times$ time^2) – (0.012 $\times$ time^3).

Jopke (1981) identified the Bruce protocol to be the most commonly used treadmill protocol, a good choice for young subjects and elite athletes. Ward **et al.** (1998) found that individual differences in height and age did not affect the reliability of the Bruce Protocol. Furthermore they argued that running or walking during the later stages did not alter predicted VO_2 values.

Polar Heart Monitor

Heart rate monitoring has been used as an indirect method of assessing energy expenditure and has been compared to other methods such as indirect calorimetry (Ceesay **et al.**, 1989), and the doubly labelled water method (Racette **et al.**, 1995). Vuori (1998) argued that ambulatory heart rate monitoring is an objective, reliable and feasible evaluation of cardiovascular strain. Furthermore it is an easy to use, non-obtrusive and socially acceptable method of cardiac assessment in a variety of conditions. It is accepted that heart rate bears a close relationship to energy expenditure and cardiac strain (Ceesay **et al.**, 1989; McArdle **et al.**, 1996; Moon and Butte, 1996). These authors argued that during submaximal exercise there is a linear relationship between oxygen consumption and heart rate, and hence heart rate can be used to estimate oxygen uptake. However, since VO_2 was measured in the present study and the fact that the above heart rate-oxygen consumption relationship is not universally established, the purpose of heart rate measurements in the present study were purely for assessing cardiac strain.

Cardiovascular responses to the various conditions were recorded using the Polar Accurex Plus and Polar Sports Tester heart rate monitors. The monitor has three components: the watch, electrode strap and a transmitter. The heart watch is a display unit allowing the various functions to be programmed and is also a data-logger. The watch was kept close to the subject to ensure that it remained within the range of the transmitter. However, the display was kept out of view of the subjects to ensure natural responses. The electrode strap was placed around the 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 midcentre of the chest. The electrode picks up the electrical activity of the heart, stored as a measure of heart rate. Good contact between the skin and the transmitter is essential and can be achieved by moistening the conductive electrode straps with water or an electro-conducting gel.

In order to obtain a base-line, 'reference' heart rate was recorded during the preliminary testing procedures. Subjects were required to sit quietly until heart rate stabilized. Because anticipation of any task is highly likely to result in an increase in heart rate, 'anticipatory' heart rates were recorded immediately prior to each experimental condition. The heart rate monitors were programmed to record heart rate every 15 seconds, and heart rate was manually recorded from the watch display during the 3rd and 6th minute of experimentation, and again at the completion of each trial.

Metabolic and Cardiorespiratory Variables

An assessment of the metabolic requirements of military tasks such as marching gives an objective indication of the physical strain experienced by the soldier. An understanding of these responses will allow for modifications to be made to the loads carried and speed of marching, whilst taking environmental factors such as gradient of the terrain into account.

THE METAMAX

A portable ergospirometry unit, such as the MetaMax, when properly calibrated, provides sufficient data to allow for a complete assessment of the lungs, heart, circulatory and metabolic activity under stress. The MetaMax measures gas concentrations to within 0.03%, and ventilation accuracy to within approximately 4%.

The subjects' cardiovascular and respiratory responses to the various conditions were all recorded using this Portable Metabolic Testsystem (MetaMax), which consists of a base unit, mask and volume transducer. It makes use of a Triple-V volume transducer to assess the ventilatory volumes, a Zirconium sensor to analyse O_2 and an infra-red sensor for CO_2. The base unit is a portable device consisting of the complete electronics for measurement and processing of the physiological responses over a given period. The processing unit consists of several microprocessors that control sensors and mechanical components also in the processing unit. The sensors require specific working temperatures, hence the device was switched on for at least 15 minutes before measurement took place.

The face mask was used in conjunction with the Triple-V volume transducer for the defined exchange of expiratory gas with the base unit. The face mask is a single piece moulded from translucent silicone rubber, attached securely and comfortably to the face using the head cap assembly (a polyester net with stretch velcro and locking clips). Various mask sizes (large, medium and small) were available to guarantee the optimal fitting of the mask to the each test subject's face and to control all expiratory exchange through for analysis. Prior to each experimental condition, the subjects were fitted with the face mask and their helmets were placed over the head cap. Resting responses were collected for one minute prior to each condition.

Energetic data were collected continuously over the six minutes, with event markers at minutes two to three and minutes five to six. This was done to identify whether steady state had been reached or not. The parameters of interest were: breathing frequency (Br), tidal volume (V_T), minute ventilation (V_E), oxygen consumption (VO_2), and respiratory exchange ratio (R). Energy expenditure in kilojoules per minute was calculated by multiplying absolute VO_2 by 20.1 ($ml.min^{-1} \times 20.1 = kJ.min^{-1}$). Kilocalories per minute were calculated by dividing the kilojoules per minute by 4.186 ($kJ.min^{-1} \div 4.186 = kcal.min^{-1}$).

The response data received by the base unit can be stored in several ways, namely: integrated data logger, telemetry or a direct link to a personal computer (PC). The integrated data logger ensures the portability of the system, with a large storage capacity of about 8.5 hours recording duration. However, in the present study, as subjects were only required to walk on a treadmill for six minutes, the MetaMax was easily accessible to a direct link and storage with a PC. The PC was connected to the base unit via a serial link cable and data were transferred to the

PC using the appropriate command from the Microsoft Windows MetaMax Capture program.

The base unit analysed the oxygen and carbon dioxide content of the air moved, and the results were stored on the PC. These responses enabled assessment of the physical demands placed on the subjects by the various walking gradient, speed and load combinations in the nine experimental conditions.

Psychophysical Parameters

The perceptual responses to physical activity reflect each subject's personalised reaction to the task demands, aiding in the understanding of individual perceptions of the demands of loaded marching. In order to fully understand the factors influencing any soldier's performance, acknowledgement of the human element is essential. These perceptual ratings allow assessment of what each individual soldier 'feels' while performing the required task, by locating sites and intensity of physical strain. Therefore Borg's universally used RPE scale (Borg, 1970) and Corlett's Body Discomfort Scale (Corlett and Bishop, 1976) were included.

RATING OF PERCEIVED EXERTION SCALE (RPE)

The conceptual basis and the use of the RPE scale were carefully explained to subjects prior to testing (see Appendix B). A clear understanding of the use of the scale is essential in order to obtain valid perceptual ratings from the subjects. Ratings of Local RPE, based on feelings of strain experienced in the muscles and/or joints of the lower limbs, and Central RPE referring to overall feelings of cardiovascular strain were obtained immediately prior to the third and sixth minutes of each condition and recorded manually onto data sheets.

BODY DISCOMFORT SCALE

The Body Discomfort Scale identifies specific areas of the body that are perceived as experiencing discomfort or pain. The scale consists of a Body Map and a 10-point scale. The Body Map is divided into 27 different segments, with a rating on the 10-point scale of 1 denoting Minimal Discomfort and 10 denoting Extreme Discomfort (see Appendix B). On the completion of each six-minute condition, subjects were required to identify both the site and the intensity of any discomfort/pain experienced. The subjects were asked to point to the site(s) of discomfort on the body map and to rate the intensity of each identified site. Each subject was allowed to select up to two areas of discomfort for each condition, which were manually recorded on data sheets.

SUBJECT CHARACTERISTICS

The initial sample consisted of 40 SANDF foot-soldiers from the Grahamstown military base. During four weeks of experimentation, there were several subjects who, for various reasons (injury, poor health or an inability to complete the required tasks), were unable to fulfil the requirements of the study. The final number of subjects was therefore 32, a number which it was felt did little to reduce the statistical power of the experiment.

Army Medical Personnel cleared all subjects for participation after a full medical examination. Each subject was fully informed as to the exact nature of the project and each was given verbal and written information about the testing procedures (Appendix A). Subjects were then free to give their voluntary, written informed consent to the testing protocol. The testing protocol had prior approval of the Rhodes University Ethics Committee, a pre-condition for commencement of the project.

TABLE VI: **Demographic information (n = 32) of the group, means, with standard deviations in brackets.**

Variable	Subjects (n=32)
Age (years)	26.4 (5.4)
Military Experience (years)	3.2 (2.5)
Stature (mm)	1727 (67)
Lower Limb Length (mm)	861.5 (46.3)
Mass (kg) Minimal clothing	67.6 (7.3)
Mass (kg) Full uniform	70.7 (7.4)
Body Fat (%)	14.9 (3.5)
LBM (%)	85.1 (3.5)
BMI ($kg.(m^2)^{-1}$)	22.7 (2.0)
RPI ($mm.kg^{0.333}$)	424 (34.5)

LBM – Lean Body Mass; BMI – Body Mass Index (minimally clothed); RPI – Reciprocal Ponderal Index (minimally clothed).

The mean age of the group was 26.4 (±5.5) years, with the youngest subject being 19 years and the oldest, 37 years. A summary of the demographic data is presented in Table VI. The group as a whole had a mean stature of 1727 (±67) mm and mass of 67. 6 (±7.3) kg in minimal clothing; 70.7 (7.4) kg when in full military uniform. There was a mean percentage body fat of 14.9 (±3.5) %, and therefore a lean body mass of 85.1 (±3.5) %. The body mass index of the group was 22.7 (±1.97) kg.$(m^2)^{-1}$, within the ACSM (1986) recommended range of 20-24.9 kg.$(m^2)^{-1}$. The linearity of the group, as depicted in the RPI attests to their relative muscularity and non-obese morphology.

Individual differences in lower limb length impact on cadence and step length and therefore have a concomitant impact on locomotor energy expenditure. Thus it is important to take limb length into consideration. The present group exhibited a mean limb length of 862 (±46) mm.

HABITUATION

Cybex Trotter 900T and Quinton 611 motorized treadmills were used in the present study to closely control walking velocity and gradient. The Cybex Trotter 900T was used during the Bruce Protocol, whilst the Quinton 611 treadmill was used for the experimental conditions as it was better designed for negative gradient walking. The differences between overground and treadmill walking underlie the necessity to habituate subjects to treadmill walking (Van Ingen Schenau, 1980; Wall and Charteris, 1980; Gordon **et al.**, 1983; Alton, 1998).

There are two components to habituation as identified by Wall and Charteris (1980), an initial accommodation of 'faltering balance-regaining' experienced during the first 10 seconds of exposure to treadmill walking, and a gradual habituation involving the establishment of a stable, essentially normal gait pattern. Charteris and Taves (1976) and Wall and Charteris (1980) found that the kinematic variability associated with habituation is still prevalent after ten to fifteen minutes of treadmill walking. It is therefore imperative that subjects are habituated to treadmill walking, particularly if unaccustomed to the treadmill, as was the case in the present study.

FIGURE 3: **Subjects being habituated to treadmill walking, and gaining familiarity with the wearing of a face mask.**

As none of the subjects had had any previous experience in a laboratory situation, all were familiarised with the laboratory during the initial briefing session. Subjects were habituated to walking on the Quinton treadmill in one laboratory and to the Cybex Trotter 900T, in another laboratory close by. Subjects were shown how to get on and off the treadmill and during three habituation sessions were exposed to walking at various speeds, with and without loads at various positive and negative gradients. In all, each subject experienced a total of an hour's exposure to treadmill walking.

TESTING PROTOCOL

Subjects reported to the laboratory on five separate occasions prior to experiment proper. These sessions were used to familiarise them with laboratory equipment and testing as well as to gather anthropometric measurements, provide treadmill habituation, and to conduct the predicted VO_{2max} test (see Appendix A for testing schedule).

Two groups of five subjects were required to complete experimental conditions each week, over a four-week period. In other words 10 subjects were required over a five day period, in which anthropometric measures were made and all experimental conditions were completed. The first two days were used to familiarise subjects with laboratory conditions, to habituate them to treadmill walking and to take anthropometric measurements. The next three days involved exposure to all nine experimental conditions, each subject being required to complete three conditions per day, with at least an hour's break between each condition. This involved 18 minutes of walking per day, an exposure level unlikely to strain the subjects or result in fatigue. One group was tested in the mornings while the other group was tested in the afternoons. Once an individual was assigned to a group he was required to be present at the same time of day throughout the experiment to minimise diurnal effects.

On arrival at the laboratory, subjects were fitted with a Polar Heart Rate Monitor, battle jacket, helmet and relevant backpack. The face mask was fitted and attached to the portable MetaMax for the recording of resting data for one minute. The subject was then required to straddle the treadmill and once the required speed and gradient had been selected and the treadmill had started gathering momentum, ‘anticipatory’ heart rate was recorded. The subject was then required to step onto the treadmill and to hold on until balance had been obtained. Each subject was then required to walk for six minutes under each condition whilst attached to the portable ergospirometer. This allowed subjects to reach steady state, where oxygen demand and oxygen supply are matched and ventilatory and cardiovascular responses are kept at a fairly constant level.

Cardiorespiratory and metabolic responses were recorded throughout the six-minute period, and event-markers were activated at minutes two and three, and at minutes five and six. Cadence was measured using a cadence meter during the 3^{rd} and 6^{th} minutes. Ratings of Central and Local RPE were recorded immediately prior to the 3^{rd} and 6^{th} minutes. On completion of each six-minute trial, subjects straddled the treadmill and were then asked to identify sites and intensity of discomfort on the Body Discomfort Scale.

FIGURE 4: **Subjects providing responses to Rating of Perceived Exertion and Body Discomfort scales.**

STATISTICAL ANALYSIS

All experimental data were downloaded to a STATSGRAPHICS (Version 6.1) statistical package. As a first step basic descriptive statistics relative to the variables assessed were gathered, providing general information concerning the sample (See example, Appendix C). The 0.05 level of probability was employed throughout the statistical treatment of the results. Therefore, there were still five chances in a hundred that a Type I error (rejecting a true hypothesis) could have been committed. The chances of committing a Type II error (failing to reject a false hypothesis) are dependent on the number of subjects. The 32 subjects in the present study should limit this probability.

Related student t-tests were calculated to determine whether there were any differences between the third and sixth minute to establish whether steady state had been achieved. Two-way ANOVAs were calculated to determine differences with each increment in gradient and speed-load combination, and between each condition. All analyses of variance were conducted on data collected during the sixth minute of each condition.

CHAPTER IV

RESULTS AND DISCUSSION

INTRODUCTION

Substantial military research (Cathcart **et al.**, 1923; Johnson **et al.**, 1995; Christie, 2001) has focused on the effects of walking speed and load carriage on performance. Knight and Caldwell (2000) identified several obvious manifestations of excessive loads including energetic effects, muscular fatigue and kinematic and inertial consequences. While walking speed and load carriage are two key components in energy expenditure determination, in order to ensure that foot marches are completed with minimum fatigue and injury, consideration of other external factors, such as the terrain traversed is necessary. A change in slope (either positive or negative) may result in an adjustment in gait kinematics, physical stressors and psychological demands placed on individuals within a platoon. Therefore changes in either the walking speed, load carried or both, need to be considered when soldiers are required to march over undulating terrain.

The present study investigated the effect of changes in gradient using three 'optimal' speed-load combinations proposed by Scott and Christie (2000) for level walking. These three speed and load combinations, namely 4 $km.h^{-1}$ carrying 50 kg, 5 $km.h^{-1}$ carrying 35 kg and 6 $km.h^{-1}$ carrying 20 kg, were analysed under uphill (+10%), level (0%) and downhill (-10%) gradients, resulting in a total of nine different experimental conditions.

In order to clarify the various speed and load combinations used, the following designations are used throughout:

Table VII: **Designation of Speed-Load combinations**

Speed-Load Combination	Designation	Conditions
4 $km.h^{-1}$; 50 kg	**SS-HL** (Slow Speed-Heavy Load)	1, 4 and 7
5 $km.h^{-1}$; 35 kg	**MS-ML** (Moderate Speed-Moderate Load)	2, 5 and 8
6 $km.h^{-1}$; 20 kg	**FS-LL** (Fast Speed-Light Load)	3, 6 and 9

CARDIOVASCULAR RESPONSES

Cardiac Responses

The cardiac responses prior to, during and immediately after each test condition were measured on all 32 subjects. Since factors such as emotional state and anticipation of an event significantly influence the cardiovascular system, obtaining true resting values for heart rate is very difficult. Therefore a “Reference” heart rate was used as the baseline measure. A Reference heart rate of 62 (±7.3) $bt.min^{-1}$ was recorded. Immediately prior to each test condition, an “Anticipatory” heart rate was recorded. Thereafter “Working” heart rates were recorded during the third and sixth minute of each test condition. A “Recovery” heart rate was measured 45-60 seconds after the completion of each condition, to give an indication of recovery rate.

The anticipatory heart rates measured were substantially higher than the reference heart rate, indicating that there is an elevation in heart rate preceding participation in a demanding task. Furthermore anticipatory heart rate showed substantial differences between the various experimental conditions (see Table VIII); they were highest under all three incline conditions, ranging between 105 and 108 $bt.min^{-1}$, indicating that subjects were most anxious in expectation of these conditions. The anticipatory heart rates were also elevated for the SS-HL combination (104 $bt.min^{-1}$), regardless of the gradient, signifying an increase in anticipation when having to carry heavy loads. The lowest anticipatory heart rate of 92 $bt.min^{-1}$ was obtained prior to subjects walking with the FS-LL combination on the level, indicating that subjects were least apprehensive under these conditions.

In order to assess whether subjects had obtained steady state or not, related Student t-tests were conducted on working heart rate responses of the 3rd and 6th minutes. Significant differences between minute three and minute six were found under all conditions, except with the FS-LL combination under downhill marching (Condition 6). It is therefore argued that for the other eight conditions, subjects had not reached steady state and that, over the duration of these test conditions, demands continued increasing. This is evident in all the uphill conditions where subjects were working close to maximal exertion, with heart rates reaching 172 $bt.min^{-1}$. McArdle **et al.** (1996) have suggested that it is only after at least four minutes that steady state is achieved. However, the severity of some of the conditions in the present study precluded continuation beyond six minutes. Therefore, on balance, the decision was to analyse the responses at the six-minute mark, when under light stress conditions, steady state was most likely to have been achieved, and under heavy stress conditions undue fatigue would not yet have set in.

TABLE VIII: **Heart rate (bt.min^{-1}) responses to changes in gradient with three combinations of speed and load (means, with SD in brackets).**

Speed Load	Condition	Gradient	Anticipatory HR	Working HR 3rd min	Working HR 6th min	P<0.05	Recovery HR
4km.h^{-1} 50kg SS-HL	4	**-10%**	103 (9)	126 (17.3)	133* (18.3)		119 (19.5)
	1	**0**	101 (11.5)	130 (14.4)	136* (16.7)		119 (15.7)
	7	**+10%**	107 (11.1)	163 (13.4)	172* (13.3)		154 (17.6)
5km.h^{-1} 35kg MS-ML	5	**-10%**	97 (9.6)	110 (12.9)	113* (13.7)		98 (14.3)
	2	**0**	98 (11.5)	119 (15.1)	122* (15.3)		106 (15.3)
	8	**+10%**	108 (14.3)	161 (12)	170* (12)		153 (17.5)
6km.h^{-1} 20kg FS-LL	6	**-10%**	98 (11.1)	104 (10.8)	106 (10.3)		92 (13.9)
	3	**0**	92 (12.2)	116 (11.7)	119* (11.9)		101 (11.5)
	9	**+10%**	105 (10.9)	159 (13.7)	168* (13.5)		147 (17.6)

HR = Heart Rate (bt.min^{-1}).
* Denotes a significant difference (P<0.05) between 3rd and 6th minute.
] Denotes a significant difference (P<0.05) between gradients (Working HR 6th minute).

LEVEL MARCHING

Under the level marching conditions there was no significant difference between working heart rates for the two lighter load-faster speed combinations (with a mean heart rate of 121 bt.min^{-1}, 62% of age predicted maximum). In comparison the SS-HL combination heart rate response (136 ± 16.7 bt.min^{-1}) was significantly higher (p=0.0000), eliciting an increase of 11.4%, indicating that subjects were working significantly harder under this condition (see Figure 5).

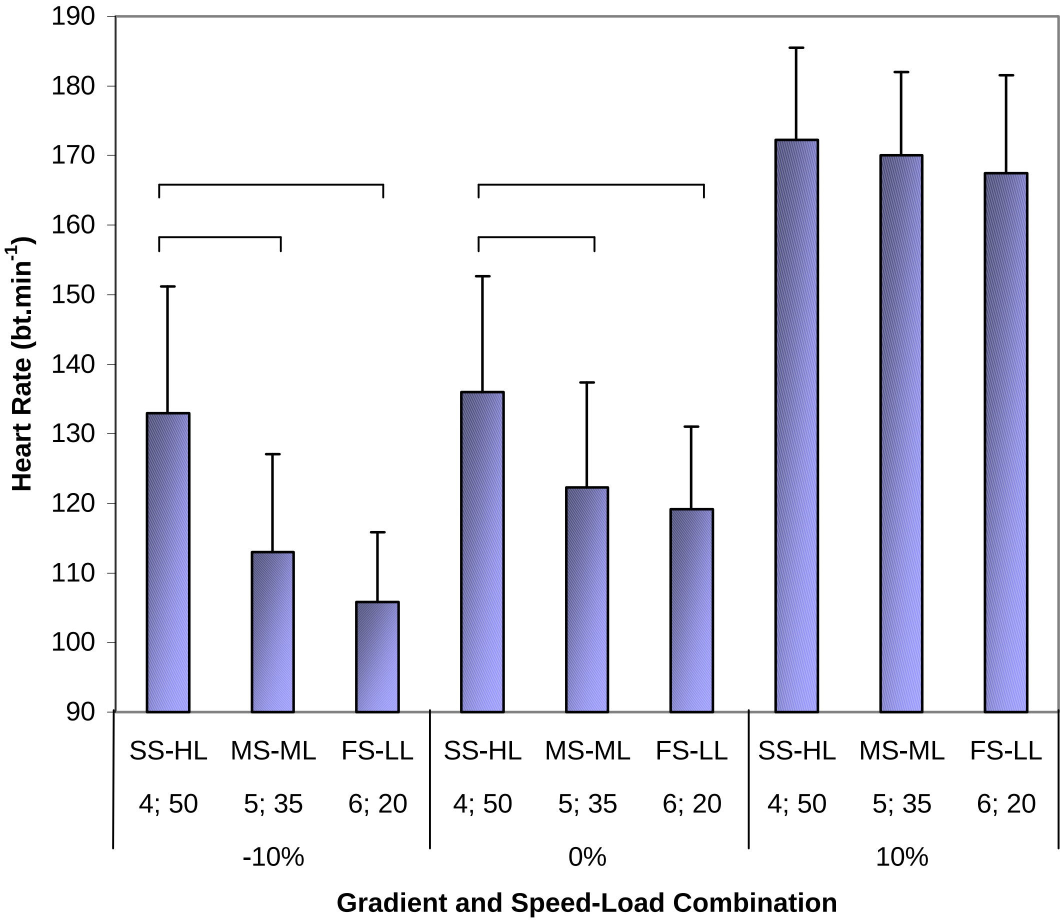


FIGURE 5: **Heart rate responses under three different gradients.**

Longitudinal bars link conditions with significant differences (p<0.05) between speed-load combinations under downhill and level gradients.

DOWNHILL MARCHING

The SS-HL decline response (133 bt.min^{-1}) was 18% higher than those of the other two faster speed-lighter load declines (mean of 110 bt.min^{-1}). This was probably due to the marked gait pattern adjustments caused by the combination of negative gradient and heavy load (50 kg), which resulted in greater muscle fibre recruitment.

Relative to level marching, the negative slope resulted in decreased working heart rates for the two faster speed – lighter load combinations, although only the FS-LL combination was significantly lower (p = 0.000). These downhill conditions (Condition 5 and 6) elicited the two lowest heart rates recorded for all nine conditions, with a 10.9% (FS-LL combination) and 7.4% (MS-ML combination) reduction from the equivalent level walking conditions. There was no difference between level and downhill marching with the SS-HL combination (see Table VIII), with a heart rate of 68.6% of maximal age-predicted heart rate, similar to the 70.1% recorded under level marching.

UPHILL MARCHING

The heart rate responses under the three uphill gradient conditions were all significantly higher than the level marching heart rate responses (see Conditions 7-9 in Table VIII). The ten percent gradient march (mean heart rate of 170 $bt.min^{-1}$) resulted in a 21-29% increase in heart rate in comparison to the equivalent level conditions. This represents 88% of age-predicted maximum heart rate, indicating that after only six minutes, exertional heart rates were rapidly approaching maximal values.

There were no significant differences between the speed-load combinations when walking uphill, another indication that subjects were stressed to near maximum levels (see Figure 5). Similar responses were found by Sagiv **et al.** (2000) where a heart rate of 169 $bt.min^{-1}$ was elicited when walking at 5 $km.h^{-1}$ carrying 35 kg on a positive slope of 10%, virtually identical to the responses recorded in the present study under the same conditions (Condition 8). These authors argued that the high heart rates associated with gradient walking are due to the alteration of locomotor biomechanics causing a reduction in mechanical efficiency in comparison to level marching.

Changes in gradient had a substantial effect on heart rate responses, with the lowest heart rate (106 ±10.3 $bt.min^{-1}$) obtained while marching downhill with the FS-LL combination (Condition 6) and the highest (172 ±13.3 $bt.min^{-1}$) while marching uphill with the SS-HL combination (Condition 7), a difference of 66 $bt.min^{-1}$ between the two conditions.

Oxygen Consumption

The commencement of physical exertion requires the recruitment of muscle fibres and therefore an increased oxygen demand to provide the required energy (McArdle **et al.**, 1996). In the present project, oxygen consumption was measured throughout the six minutes of each condition. However, for the purpose of the study, the mean oxygen consumption values in the 3rd and 6th minutes were analysed.

McArdle **et al.** (1996) argued that in weight-bearing activities, heavier individuals will have a higher oxygen consumption and that as much as 69% of the variation in VO_2 can be attributed to differences in body mass, rendering comparisons of absolute oxygen consumption values meaningless. Therefore, in order to compare oxygen consumption responses across subjects, assessments were made relative to body mass ($ml.kg^{-1}.min^{-1}$), to minimise the effects of inter-individual variability in oxygen consumption.

Before any marching conditions were examined subjects were required to complete a submaximal predictive VO_{2max} test (Bruce protocol). A mean predicted VO_{2max} of 38.6 (±7.3) $ml.kg^{-1}.min^{-1}$ was recorded. This value appears very low (considering that the ACSM (1989) found sedentary individuals to have a VO_{2max} of between 40 and 45 $ml.kg^{-1}.min^{-1}$), since the subjects were actively involved soldiers from an infantry battalion in the SANDF. However, it was similar to the predicted VO_{2max} values (42 $ml.kg^{-1}.min^{-1}$) found by Christie (2001) in a comparable group from the SANDF.

A possible contributing factor to these low figures may be the lack of familiarity with laboratory and testing conditions, which might have elevated heart rates resulting in a spuriously lower VO_{2max} than expected. Ward **et al.** (1998) argued that although age and stature do not influence the validity of the Bruce protocol, there may be a learning effect influencing the results. However, other factors such as the socio-economic status and pandemic health issues faced by the SANDF infantry, are more likely to have negatively impacted on the predicted VO_{2max} values, which were 18% lower than the values reported by Wyndham (1975) on African miners.

TABLE IX: **Oxygen consumption ($ml.kg^{-1}.min^{-1}$) responses to changes in gradient with three different combinations of speed and load (means, with SD in brackets).**

Speed Load	Condition	Gradient	VO_2 3rd min	VO_2 6th min	p<0.05
$4km.h^{-1}$;50kg SS-HL	4	**-10%**	20.1 (3.2)	21* (3.9)	]]
	1	**0**	23.8 (3.3)	24.5* (3.8)	]
	7	**+10%**	36.3 (3.9)	39.5* (4.5)	
$5km.h^{-1}$;35kg MS-ML	5	**-10%**	17.2 (2.8)	17.1 (2.7)	]]
	2	**0**	23.1 (3.1)	22.9 (3.3)	]
	8	**+10%**	38.3 (4.3)	41.2* (5.2)	
$6km.h^{-1}$;20kg FS-LL	6	**-10%**	17.4 (2.5)	16.9* (2.1)	]]
	3	**0**	23.1 (2.9)	22.9 (2.8)	]
	9	**+10%**	39.5 (4.1)	42.1* (5.6)	

* Denotes a significant difference ($p<0.05$) between 3rd and 6th minute.
] Denotes a significant difference ($p<0.05$) between gradients.

Related Student t-tests were conducted to determine whether oxygen consumption between minutes three and six were different (Table IX). Under the three SS-HL combinations there was an increase in oxygen consumption over time regardless of the slope. However, with the MS-ML and FS-LL combinations it was only marching under the 10% incline that elicited a significant increase ($p = 0.000$), while the FS-LL combination showed a significant decrease in oxygen consumption from minute three to minute six under the 10% decline. Thus steady state was achieved after six minutes when walking under level and downhill gradients with the FS-LL and MS-ML combinations. The lack of steady state evidenced under the positive gradient conditions and with the SS-HL combination reiterates the high demands placed on the individual when marching uphill and when carrying heavy loads.

LEVEL MARCHING

When walking on the level, changes in speed-load combination did not affect oxygen consumption (Table IX; Figure 6), confirming the findings of Christie (2001) who proposed that these combinations of speed and load are comparable in terms of demands placed on subjects. The mean oxygen consumption (23.5 $ml.kg^{-1}.min^{-1}$) for the three level conditions is higher than that found by Christie (2001). Although the loads used in the present study were the same as those used by Christie, due to military requirements these loads were each carried at 0.5 $km.h^{-1}$ faster than in the aforementioned study. It is argued that this marginal increase in speed at least partially accounts for the higher VO_2 levels.

The highest oxygen consumption recorded for level marching was in response to the SS-HL combination (Condition 1) and measured 24.5 (±3.8) $ml.kg^{-1}.min^{-1}$. This represents 63.5% of the predicted VO_{2max}, substantially higher than the 45-50% level recommended in the literature (Evans **et al.**, 1980; Levine **et al.**, 1982; Christie, 2001) as being an acceptable workload for an 8-hour shift. The other two level walking conditions also exhibited an oxygen consumption above 50% of VO_{2max}. As soldiers are seldom required to march continuously for more than a few hours, the fact that oxygen consumption exceeded the acceptable level for eight-hour work shifts is reasonable under these circumstances.

DOWNHILL MARCHING

Laursen **et al.** (2000) reported that oxygen consumption responses were lower under negative gradients than the comparable level conditions. The present study found similar results, as the responses recorded under the three decline conditions were lower than the level conditions. The lowest oxygen consumption of 16.9 (±2.1) $ml.kg^{-1}.min^{-1}$ was achieved marching downhill with the FS-LL combination.

Although the SS-HL combination (21 $ml.kg^{-1}.min^{-1}$) showed a 15% decrease compared to the equivalent level condition, it was significantly higher than the other two downhill conditions (mean of 17 $ml.kg^{-1}.min^{-1}$). This could be attributed to the increased eccentric muscular involvement in having to resist the effects of gravity, particularly considering that the average total mass moved under this condition was 121 kg (average body mass plus that of the load carried). The nominal decrease in VO_2, together with no change in heart rate associated with this combination, indicates that when marching downhill the load carried influences energetic efficiency more than does walking speed.

In contrast to the SS-HL combination there were 25 and 27% decreases with the MS-ML and FS-LL combinations respectively when compared to level marching. These two conditions resulted in an oxygen consumption of 44% of predicted VO_{2max}, acceptable for an 8-hour work shift.

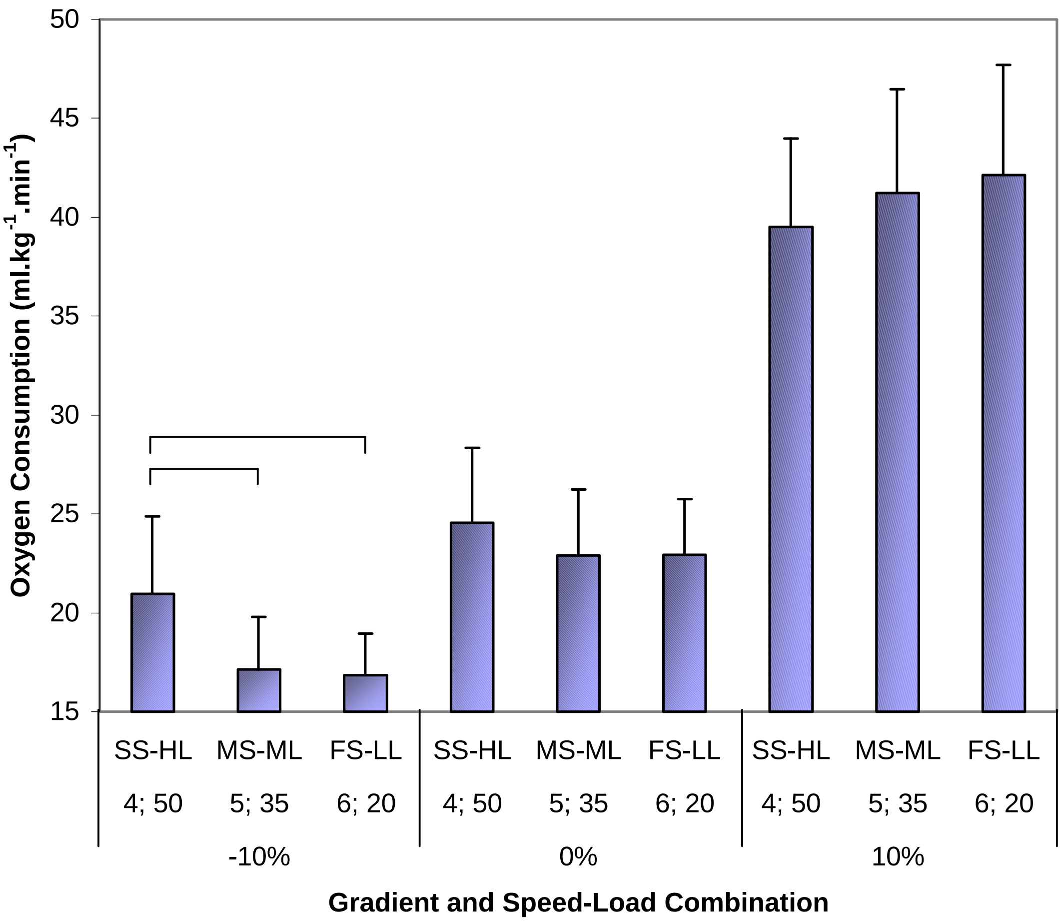


FIGURE 6: **Oxygen consumption responses under three different gradients.**

Longitudinal bars link conditions with significant differences ($p<0.05$) between speed-load combinations under negative gradient marching. Note: All +10% results were significantly elevated.

UPHILL MARCHING

Incline marching resulted in significant increases in oxygen consumption, relative to level walking, regardless of speed-load combination (Table IX). The highest oxygen consumption (42.1 ±5.6 $ml.kg^{-1}.min^{-1}$) was recorded with the FS-LL combination. There were increases of 37.9, 44.5 and 45.6% with the SS-HL, MS-ML and FS-LL combinations respectively when slope was increased from zero to 10%, an average increase of 42.7% attributable to incline walking. As there was no significant difference between these three conditions, the oxygen consumption results for these three conditions have been combined. The mean oxygen consumption was 38 $ml.kg^{-1}.min^{-1}$ in the 3rd minute and 41 $ml.kg^{-1}.min^{-1}$ in the 6th minute, approximately 98% and 106% of the predicted maximal values respectively. These results imply that subjects were working to their maximum capacity in the uphill conditions.

Respiratory Exchange Ratio (R)

The ratio of oxygen consumed to the carbon dioxide produced, where the exchange of oxygen and carbon dioxide at the lungs no longer reflects the oxidation of specific foods in cells, is known as the respiratory exchange ratio (McArdle **et al.**, 1996). At rest the respiratory exchange ratio could be expected to be well below 1.00, but during intense exercise it is likely to rise to above 1.00. An individual may be considered to be exercising maximally when the respiratory exchange ratio exceeds 1.15. Respiratory exchange ratio was measured during the 3rd and 6th minute of each test condition in the present study.

Related Student t-tests revealed a significant increase between the 3rd and 6th minutes of exertion under eight of nine test conditions; only the MS-ML combination marching downhill (Condition 5) showed no change. These increases indicate that there was an increased production of carbon dioxide over time, particularly in the moderate to low intensity conditions where oxygen consumption remained relatively stable over time as illustrated in Table X.

TABLE X: **Respiratory exchange ratio responses to changes in gradient with three different combinations of speed and load (means, with SD in brackets).**

Speed Load	Condition	Gradient	R 3rd min	R 6th min	p<0.05
$4km.h^{-1}$ 50kg SS-HL	4	**-10%**	0.96 (0.05)	0.98* (0.04)	
	1	**0**	0.95 (0.05)	0.97* (0.04)	
	7	**+10%**	1.08 (0.09)	1.09* (0.08)	
$5km.h^{-1}$ 35kg MS-ML	5	**-10%**	0.95 (0.05)	0.96 (0.05)	
	2	**0**	0.92 (0.05)	0.96* (0.04)	
	8	**+10%**	1.05 (0.08)	1.07* (0.08)	
$6km.h^{-1}$ 20kg FS-LL	6	**-10%**	0.94 (0.05)	0.96* (0.06)	
	3	**0**	0.90 (0.05)	0.95* (0.04)	
	9	**+10%**	1.03 (0.07)	1.07* (0.07)	

* Denotes a significant difference ($p<0.05$) between 3rd and 6th minute.
] Denotes a significant difference ($p<0.05$) between gradients.

LEVEL MARCHING

During level marching there was no significant difference between speed-load combinations, once again illustrating the comparability of these conditions. There was a mean respiratory exchange ratio of 0.96 for level marching. All three conditions resulted in a respiratory exchange ratio lower than 1.00, indicating the submaximal demands these conditions placed on the subjects.

DOWNHILL MARCHING

Marching down a negative gradient did not result in any significant changes in the respiratory exchange ratio, compared to level marching. As was the case in the level gradient, the negative slope with the SS-HL combination resulted in a nominally higher respiratory exchange ratio than occurred with the other two speed-load combinations. There was no significant difference between speed-load combinations during downhill marching, therefore the respiratory exchange ratio was combined for all three conditions, and a mean ratio of 0.97 was recorded.

UPHILL MARCHING

Significant changes in the respiratory exchange ratio were evident when subjects were required to march uphill (Table X). The results with the SS-HL combination revealed the highest ratio (1.09), compared to 0.97 with the same combination on the level. The other two speed-load combinations resulted in elevated R values of 1.07, indicating the high intensity imposed by marching uphill. Considering that, at a respiratory exchange ratio above 1.15, subjects are at maximum, the uphill conditions can be assumed to be unlikely to be maintained for any extended period of time.

In summary, Brouha (1967) argued that the mean heart rate over an 8-hour industrial work shift should not exceed 110 $bt.min^{-1}$, since intensities greater than this will result in cumulative fatigue. However, soldiers are seldom required to march for extended periods without a break. Therefore, responses marginally higher than 110 $bt.min^{-1}$ would be unlikely to have a fatigue effect in a military setting. In the present study the intensities encountered while walking downhill and on the level, which elicited mean heart rates of 117 and 126 bt.min^{-1} respectively, could be considered to impose submaximal demands, unlikely to physically over-tax conditioned foot soldiers who are customarily provided frequent rest-breaks during long route marches.

However, the positive gradient resulted in significantly higher demands, which soldiers would be unlikely to sustain over an extended period. An increase in the gradient to 10% (5.7°) raised heart rate to almost 90% of the maximal age-predicted level. Patla (1986) and Sun **et al.** (1996) argued that subjects walking uphill are required to do a greater amount of work in supporting/carrying the body and the load. In the present study subjects were required to lift their own body weights (mean 70.7 kg) plus a load ranging from 20 to 50 kg (total loads of 90 to 120 kg), which not only has to be moved horizontally, but also lifted vertically against gravity.

With respect to hypothesis 1 (a), although when marching at a slow speed carrying a heavy load, a negative slope of 10% seemingly did not affect heart rates compared to level walking, at higher speeds carrying lighter loads there was a substantial decrease in heart rate in the downhill conditions. However the decreases in heart rate associated with downhill walking (7-11%) were not as substantial as the increases recorded under the uphill conditions (21-29%). Within the military context these changes in heart rate need to be addressed and compensatory steps taken.

The results show that when required to walk downhill, the load carried will affect oxygen consumption (and therefore energy expenditure) more than will speed, while marching uphill will have the converse effect. There needs to be an adjustment in either the speed and/or the load when inclines and declines in terrain are encountered in order for soldiers to be able to complete the march with minimum fatigue and injury, thereby optimising their post-march capabilities. However, the present findings stress that when soldiers encounter undulating terrain, adjustments in one factor (either speed or load) may not be sufficient to prevent changes in oxygen consumption, as a negative gradient is not likely to counteract the increases in VO_2 resulting from a positive gradient, if walking speed and load carried are held constant.

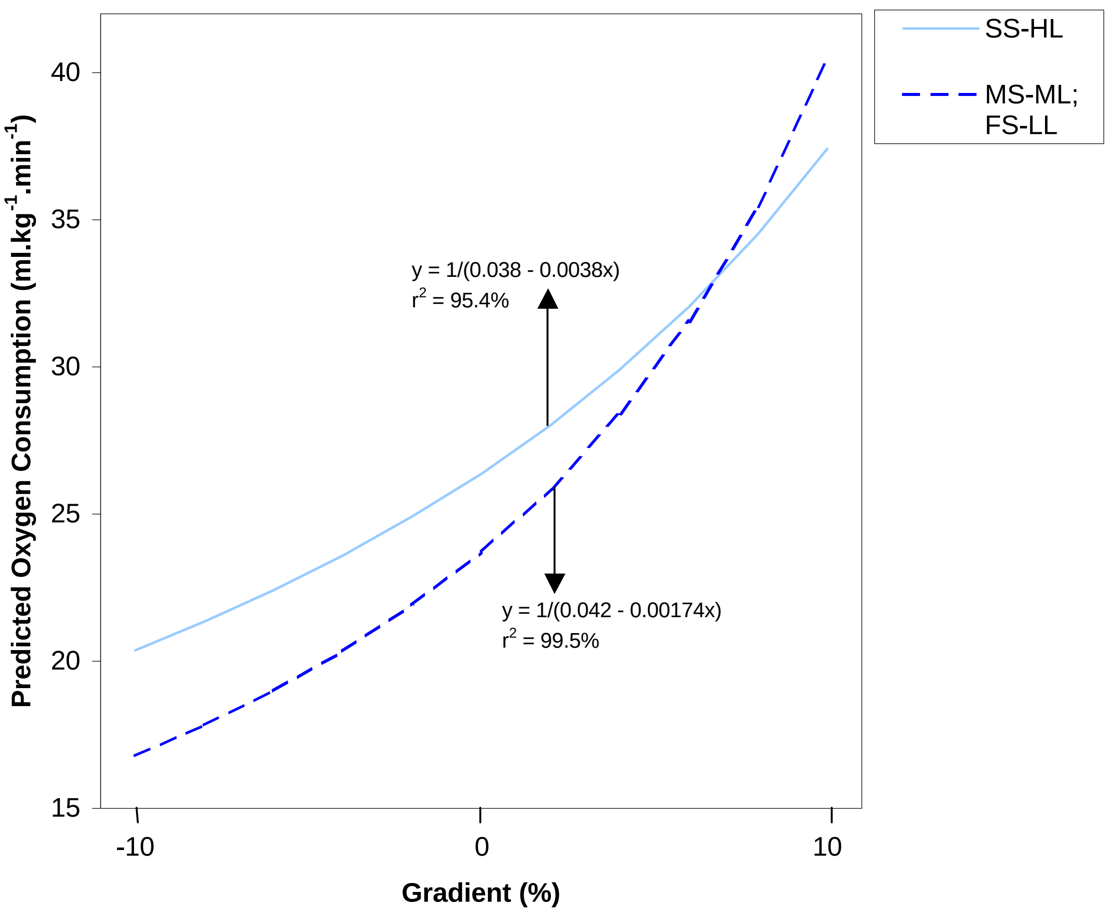


FIGURE 7: **Regression equations to predict oxygen consumption with three different speed-load combinations.**

Regression equations were developed to predict the oxygen consumption for gradient walking with loads (see Figure 7). The equations relative to the MS-ML and FS-LL speed-load combinations were almost identical, particularly at moderate gradients, the greatest error being only 2.4% at the extremes of the gradients tested, and were therefore combined as one equation to predict the oxygen consumption for walking speeds of 5 to 6 $km.h^{-1}$ carrying loads of 20 to 35 kg. However, with the SS-HL combination, the equation was significantly different, due mainly to the elevated VO_2 values when walking downhill with a heavy load.

VENTILATORY RESPONSES

Breathing Frequency and Minute Ventilation

When humans start physical activity there is an immediate increase in energy expenditure, resulting in the need for an increase in the oxygen supply to the working muscles and the removal of carbon dioxide from the muscles. Recent studies (Gonzalez **et al.**, 1999; Harty **et al.**, 1999) have found that breathing frequency restrictions can have a detrimental effect on ability to provide oxygen and to remove carbon dioxide, and therefore also on ability to perform optimally. Heavy load carriage, as was imposed in the present study, may result in such restrictions, causing an impairment in marching ability as well as having a deleterious effect on post-march efficiency.

When related Student t-tests were conducted on the breathing frequency and minute ventilation data, it was established that there was a significant difference ($p<0.05$) between the 3rd and 6th minute for seven of the nine conditions for both variables. Only walking downhill at 5 km.h^{-1} (35 kg) and at 6 km.h^{-1} (20 kg) showed no significant difference (see Table XI). As with the other responses discussed previously, the SS-HL combination appears to indicate a more demanding workload with no steady state being reached under any slope. The relatively stable responses found under two of the negative gradient conditions appear to support the submaximal demands these conditions placed on the subjects.

TABLE XI: **Breathing frequency (br.min^{-1}) and Minute Ventilation (l.min^{-1}) responses to changes in gradient with three combinations of speed and load (means, with SD in brackets).**

Speed Load	Condition	Gradient	Br 3rd min	Br 6th min		V_E 3rd min	V_E 6th min	p<0.05
4km.h^{-1} 50kg SS-HL	4	**-10%**	36.2 (8.8)	39.9* (10)		35.2 (5.9)	37.6* (7.1)	
	1	**0**	35.8 (9.6)	38.6* (11.1)		38.4 (8.5)	41.5* (7.9)	
	7	**+10%**	39.5 (9.6)	46* (11.1)		61.4 (11.1)	70.9* (13)	
5km.h^{-1} 35kg MS-ML	5	**-10%**	34.9 (9.4)	36.1 (10.9)		30.3 (4.9)	30.4 (5.4)	
	2	**0**	33.3 (9.6)	35* (9.5)		36 (5.8)	37.1* (5.9)	
	8	**+10%**	37.2 (10.2)	42.2* (11.9)		62 (10)	69.5* (14.1)	
6km.h^{-1} 20kg FS-LL	6	**-10%**	31.6 (10.2)	31.7 (10.7)		29.3 (5)	28.9 (4.5)	
	3	**0**	31.1 (9.3)	32.4* (10.1)		35.1 (6.1)	36.7* (6.8)	
	9	**+10%**	36.7 (10.9)	39.4* (11.9)		61.6 (15.7)	70.6* (14.8)	

* Denotes a significant difference (p<0.05) between 3rd and 6th minutes.
] Denotes a significant difference (p<0.05) between gradients.

The lowest breathing frequency (31.7 ±10.7 $br.min^{-1}$) and minute ventilation (28.9 ±4.5 $l.min^{-1}$) were recorded while marching downhill with the FS-LL combination. While the highest for both variables was evident when walking uphill with the SS-HL combination.

LEVEL MARCHING

At rest, normal breathing frequency is approximately 12 $br.min^{-1}$ and normal minute ventilation approximately 6 $l.min^{-1}$ (McArdle **et al.**, 1996). Both of these variables will increase in response to exercise in order to meet metabolic requirements. The results of the present study indicate that under level marching conditions there was an increase in breathing frequency to 35.3 $br.min^{-1}$ (an increase of 66% from rest) and an increase in minute ventilation to 36.9 $l.min^{-1}$ with the two faster speed – lighter load combinations (an increase of 84%) and to 41.5 $l.min^{-1}$ with the SS-HL combination.

During level marching changes in speed-load combination had no significant effect on breathing frequency, but there was a significant change in minute ventilation. The SS-HL combination (Condition 1) was found to result in significantly higher minute ventilation responses (11% higher) than the MS-ML and FS-LL combinations (as illustrated in Figure 8), indicating that subjects were working harder under this condition.

DOWNHILL MARCHING

Table XI shows the effect of a change in gradient on breathing frequency and minute ventilation. The negative slope resulted in no significant changes in breathing frequency with any speed-load combination. Since there was no significant difference between speed-load combinations breathing frequency for the downhill conditions was meaned (35.9 $br.min^{-1}$), and found to be similar to that recorded for level marching.

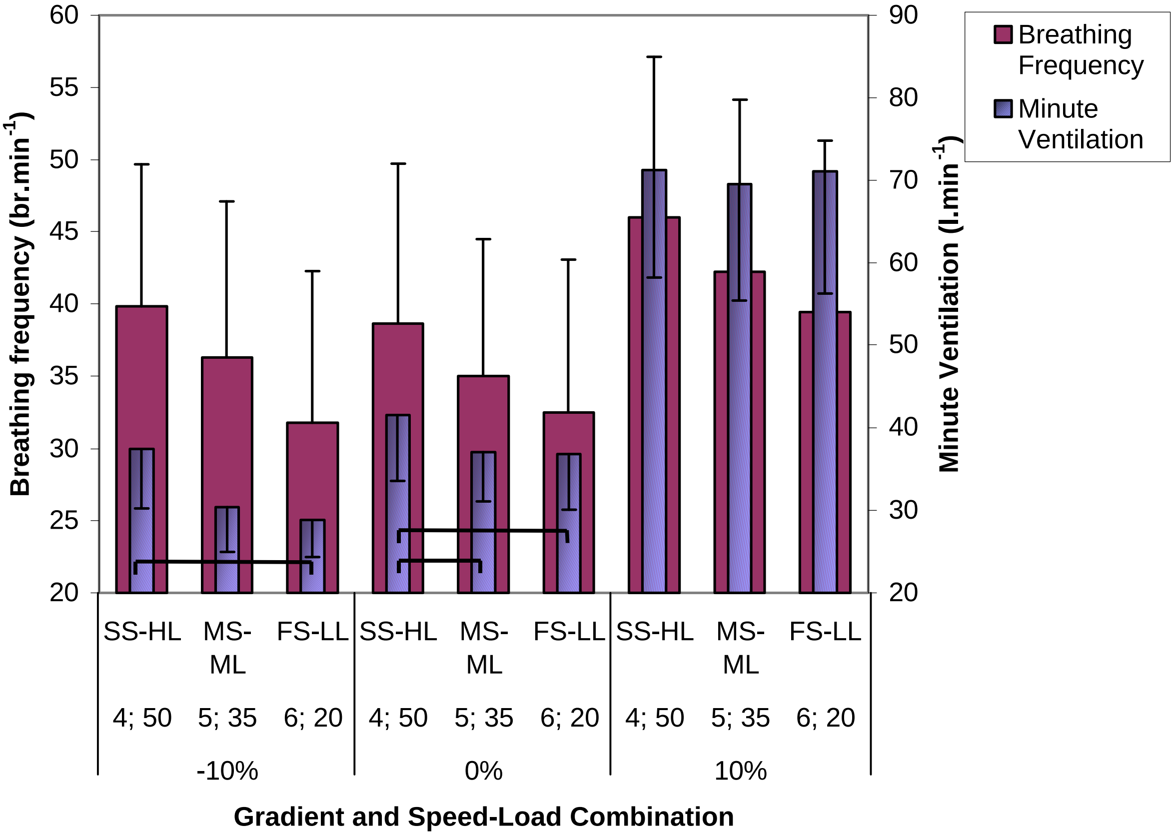


FIGURE 8: **Breathing frequency and minute ventilation responses under three different gradients.**

Longitudinal bars link conditions with significant differences ($p<0.05$) between speed-load combinations under downhill and level gradients.

Minute ventilation responses showed no significant difference with the SS-HL and MS-ML combinations, but there was a significant difference with the FS-LL combination (a decrease of 21% under downhill marching). A change in speed-load combination during negative gradient walking, only showed minute ventilation to be different with the SS-HL combination being significantly higher than the FS-LL combination (an increase of 23%).

UPHILL MARCHING

There was an increase in both breathing frequency and minute ventilation at all three speed-load combinations under uphill marching. The mean breathing frequency under the positive gradient (all three conditions were similar – see Figure 8) was 42.5 $br.min^{-1}$, an increase of approximately 17% compared to level walking, although these increases were not seen to be statistically significant. However, significant increases were recorded for minute ventilation responses under positive slope marching, with an increase to a mean of 70.6 $l.min^{-1}$ (a range of only 1.4 $l.min^{-1}$ between conditions), an increase of 45% compared to the equivalent level conditions.

A change in speed-load combination under uphill gradient marching did not result in any significant changes in either breathing frequency or minute ventilation. This may be due to the subjects being near maximal exertion under all three uphill conditions, thereby negating any differences between speed-load combinations. These results indicate the substantial demand that uphill marching places on the respiratory system in order to provide sufficient movement of air to facilitate oxygen consumption and carbon dioxide removal.

Tidal Volume

Tidal volume responses remained relatively stable over time, with related Student t-tests revealing very few differences in tidal volume over time. The only condition to show a significant increase in tidal volume was incline marching with the FS-LL combination, while the SS-HL combination (downhill) and the MS-ML combination (level) both showed significant decreases in tidal volume over time (see Table XII). It would appear that after three minutes of exercise, regardless of exercise intensity, tidal volume had generally stabilized and was unlikely to increase further as time progressed.

TABLE XII: **Tidal volume ($l.br^{-1}$) responses to changes in gradient with three combinations of speed and load (means, with SD in brackets).**

Speed Load	Condition	Gradient	V_T 3rd min	V_T 6th min	p<0.05
4km.h^{-1} 50kg SS-HL	4	**-10%**	1 (0.22)	0.97* (0.22)	
	1	**0**	1.14 (0.21)	1.12 (0.21)	
	7	**+10%**	1.59 (0.26)	1.57 (0.26)	
5km.h^{-1} 35kg MS-ML	5	**-10%**	0.91 (0.18)	0.89 (0.19)	
	2	**0**	1.13 (0.21)	1.10* (0.19)	
	8	**+10%**	1.72 (0.25)	1.69 (0.23)	
6km.h^{-1} 20kg FS-LL	6	**-10%**	0.99 (0.27)	0.98 (0.27)	
	3	**0**	1.16 (0.21)	1.17 (0.21)	
	9	**+10%**	1.78 (0.25)	1.83* (0.24)	

* Denotes a significant difference (p<0.05) between the 3rd and 6th minute.
] Denotes a significant difference (p<0.05) between gradients.

The results indicate that tidal volume was not the means of increasing minute ventilation over time as the subjects adjusted to meet the energetic demands being placed on them. Any increases in minute ventilation over time can therefore be attributed to increases in breathing frequency (discussed in the previous section).

LEVEL MARCHING

According to McArdle **et al.** (1996) resting tidal volume is approximately 0.6 $l.br^{-1}$, which can increase to as much as 2.0 $l.br^{-1}$ during intense exercise. In the present study, level gradient walking resulted in a mean tidal volume of 1.1 $l.br^{-1}$, an increase of 47% from resting values, to approximately 50% of tidal volume capacity. A change in speed-load combination had no effect on tidal volume during level walking (see Figure 9), signifying that responses under these conditions were similar.

DOWNHILL MARCHING

The lowest tidal volume of 0.89 (±0.19) $l.br^{-1}$ was achieved under downhill walking with the MS-ML combination. A change in gradient to a negative slope resulted in a significant reduction in tidal volume with the MS-ML and FS-LL combinations. There was a decrease in tidal volume of 16 and 19% for the FS-LL and MS-ML combinations respectively, with an average decrease of 17.7% (from 1.1 $l.br^{-1}$ to 0.94 $l.br^{-1}$). Similar to the level gradient responses, a change in speed-load had no significant effect on tidal volume (see Figure 9) during downhill marching.

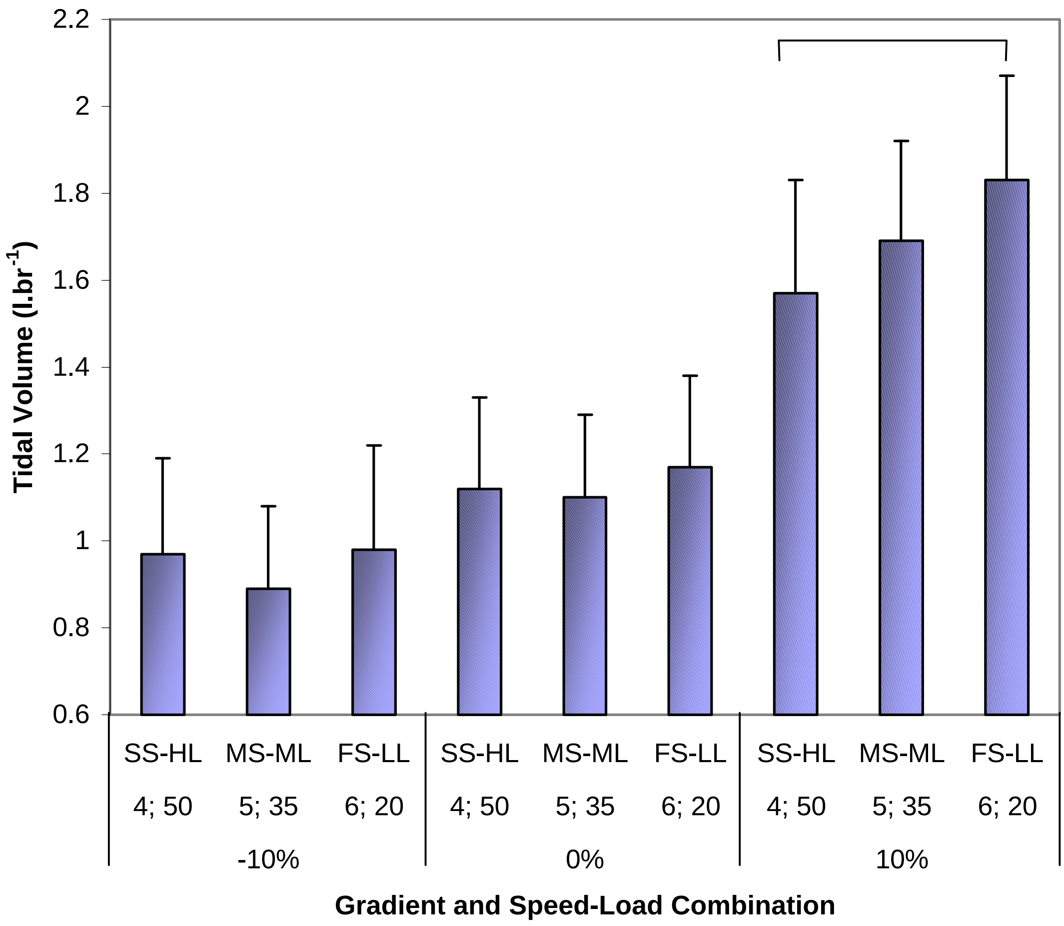


FIGURE 9: **Tidal volume responses under three different gradients.**

Longitudinal bars link conditions with significant differences ($p<0.05$) between speed-load combinations under an uphill gradient.

UPHILL MARCHING

Uphill walking resulted in the greatest changes in tidal volume with all three speed-load combinations. The 10% incline resulted in a 29, 35 and 36% (an average of 33%) increase in tidal volume with the SS-HL, MS-SL and HS-LL combinations respectively, when compared to the equivalent conditions on the level. A change in speed-load combination had a significant effect on tidal volume under uphill marching, with it being significantly higher with the FS-LL combination. The highest tidal volume of 1.8 $l.br^{-1}$ was three times higher than resting volumes, and as high as 92% of maximum tidal volume, indicating that subjects were near maximum under incline walking.

With respect to hypothesis 1 (b), although breathing frequency was higher under the downhill condition than during level walking, significantly lower tidal volumes under the negative gradient resulted in lower minute ventilations than were recorded under the level conditions, regardless of speed-load combination. In both level and downhill marching, breathing frequency and minute ventilation followed similar trends, both variables being highest in the SS-HL combination, with a steady decline to lowest in the FS-LL combination (see Figure 8). During incline marching this trend was maintained for the breathing frequency responses, but not for the minute ventilation responses. It appears that the heavy load carried in these conditions had a substantial effect on breathing patterns.

The high coefficients of variation for breathing frequency responses indicate that there was a wide variety of breathing strategies adopted by the subjects. This may be due to individual differences in backpack positioning, load distribution and tightness of the strapping, and/or postural adaptations to the gradient encountered. Heavy loads require tight strapping to the upper torso, which may impede free and easy movement in the upper body. This could in turn affect ventilation, and negatively impact on the perceived levels of discomfort attributable to backpack strap position and tightness. This would be in agreement with the findings of Myles and Saunders (1979) and Harty **et al.** (1999) who proposed that heavy loads restricted chest movements, affecting breathing frequency and minute ventilation. Gonzalez **et al.** (1999) contended that chest wall restrictions, whether the result of disease or mechanical constraints (Protective outerwear and heavy loads) can cause decrements in pulmonary function and performance capacity. These authors argued that not only are mechanical constraints restrictive, but in fact they significantly increase the oxygen cost of the external intercostal muscles. With a load of 50 kg subjects may have found it difficult to expand the chest and therefore to breath effectively, which may account for the large variability in pulmonary responses.

ENERGY EXPENDITURE RESPONSES

Knowledge of the energy expended in any march is necessary to ensure that soldiers are combat efficient after the march. With optimised walking speed and load, adjusted appropriately to changes in environmental conditions, and in terrain and gradient, soldiers will reach their destination with minimal fatigue and discomfort, and thereby be better equipped to perform vital post-march tasks. Account must be taken of the fact that subjects expend energy, not only in moving themselves, but also in moving any external load being carried. Therefore energy expenditure is here expressed relative to total load moved i.e. body mass plus load carried (kJ. $kg^{-1}.h^{-1}$).

When energy expenditure was expressed relative to total load (body mass, in full uniform, plus the load being carried) the lowest value per kilogram was 13.7 (±1.8) kJ. $kg^{-1}.h^{-1}$, recorded under negative slope marching with a load of 35 kg (i.e. a total load of 106 kg) at a speed of 5 $km.h^{-1}$ (see Table XIII). The highest energy cost, 39.6 (±4.1) kJ. $kg^{-1}.h^{-1}$, occurred walking uphill with a 20 kg load at 6 $km.h^{-1}$.

TABLE XIII: **Energy expenditure responses to changes in gradient with three combinations of speed and load (means, with SD in brackets).**

Speed Load	Condition	Gradient	$kcal.min^{-1}$	$kcal.h^{-1}$	$kJ.min^{-1}$	$KJ.\sum kg^{-1}.h^{-1}$	Watts
$4km.h^{-1}$ 50kg SS-HL	4	**-10%**	7 (1.1)	421.2 (66)	29.4 (4.7)	14.6 (2.4)	490 (78)
	1	**0**	8.2 (1.1)	493.2 (66)	34 (4.5)	17.1 (2.3)	574 (74)
	7	**+10%**	13.3 (1.4)	796.2 (84)	55.6 (6.1)	27.6 (2.8)	927 (101)
$5km.h^{-1}$ 35kg MS-ML	5	**-10%**	5.7 (0.7)	343.8 (42)	24 (2.9)	13.7 (1.8)	400 (48)
	2	**0**	7.7 (0.9)	459.6 (54)	32.1 (3.7)	18.3 (2.3)	535 (61)
	8	**+10%**	13.9 (1.8)	831 (108)	58 (7.4)	32.9 (3.8)	967 (124)
$6km.h^{-1}$ 20kg FS-LL	6	**-10%**	5.7 (0.7)	339.6 (42)	23.7 (3)	15.7 (1.7)	395 (49)
	3	**0**	7.7 (1.1)	463.2 (66)	32.3 (4.4)	21.4 (2.5)	539 (74)
	9	**+10%**	14.3 (1.6)	855.6 (96)	59.7 (6.8)	39.6 (4.1)	995 (113)

Note: These data are derived from VO_2 responses in the 6^{th} minute.

LEVEL MARCHING

There was a mean energy expenditure of 7.9 $kcal.min^{-1}$ or 18.9 $kJ.\sum kg^{-1}.h^{-1}$ for the three level marching conditions, with the cost of the SS-HL combination being nominally higher. McArdle **et al.** (1996) developed a five-level classification scale for rating intensity of physical exertion and according to this scale the energy expenditure responses to level walking could be considered to be "heavy".

Goldman (1965) postulated that males tend to select an energy expenditure of 425 kcal.h^{-1} (494 Watts), and Hughes and Goldman (1970) found a similar expenditure of 430 kcal.h^{-1} (500 Watts) during loaded treadmill walking. These values are lower than the mean expenditure found under the level conditions (472 kcal.h^{-1}; 549 Watts) in the present study (see Figure 10) but almost identical to the self-selected energy expenditure found by Evans **et al.** (1980). The energy expenditure of 500 Watts reported by Hughes and Goldman (1970) could be sustained for an 8 h work shift, and considering that soldiers are seldom expected to march for more than two or three hours without a break, the demands being placed on them when required to march at these pre-selected speed-load combinations on the level should be seen as acceptable.

DOWNHILL MARCHING

The metabolic responses to the negative slope resulted in an energy cost of approximately 5.7 kcal.min^{-1} with both the MS-ML and FS-LL combinations. However, the cost of carrying the heavy load (50 kg) downhill was significantly higher at 7 kcal.min^{-1}, an increase of approximately 19%. According to the classification scale of McArdle **et al.** (1996), these decline responses (including the SS-HL combination) can be considered to be “moderate” in intensity.

In comparison to level marching, the MS-ML and FS-LL combinations (downhill) resulted in significant reductions in energy expenditure of up to nearly 27%. However, the SS-HL combination only resulted in a 15% decrease in energetic demands (see substantial range under the negative gradient illustrated in Figure 10). The smaller decrease associated with the heavy load demonstrates the impact it has on energy expenditure, particularly when the load is required to be moved downhill.

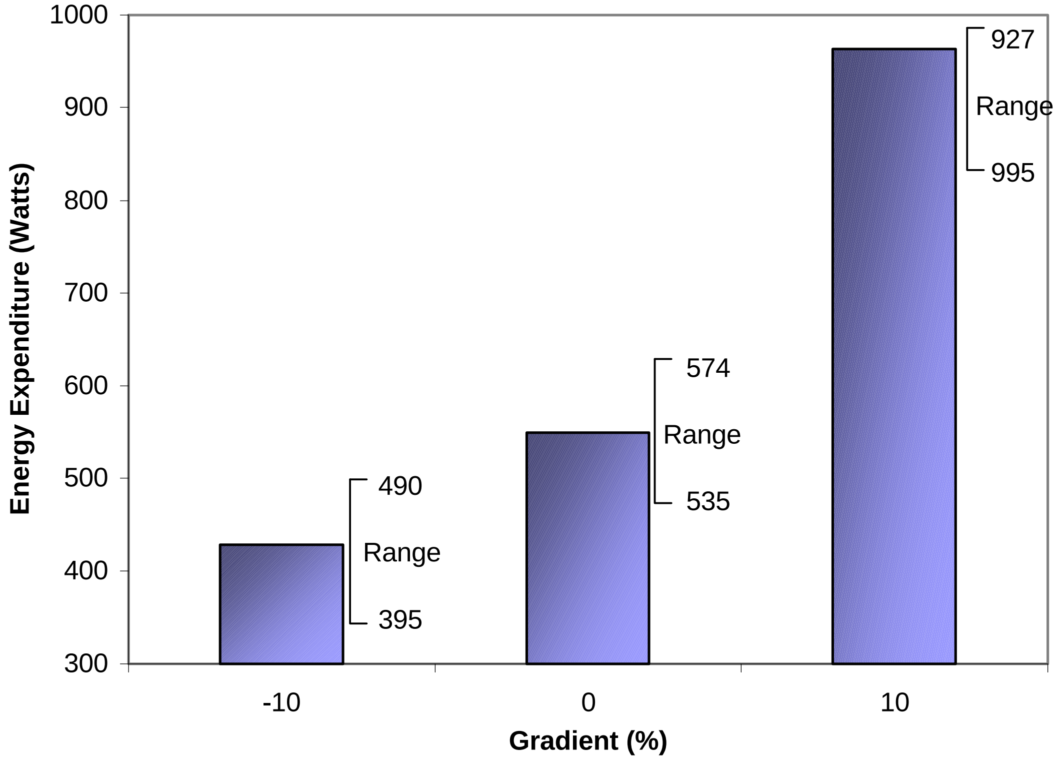


Figure 10: **Energy expenditure responses (means, with ranges as indicated) under three different gradients.**

Without the heavy load, the mean energy expenditure under the downhill marching conditions was 341.7 kcal.min^{-1} or 398 Watts (see Figure 10), approximately 20% lower than the acceptable limits proposed by Goldman (1965) and Hughes and Goldman (1970), easily maintainable for extended marches.

UPHILL MARCHING

Incline marching resulted in significant increases in energy expenditure, regardless of the speed-load combination, when compared to level marching. There was a mean energy expenditure of 13.8 kcal.min^{-1} compared to 7.9 kcal.min^{-1} for level conditions, an increase of approximately 43%. According to the McArdle **et al.** (1996) classification scale these demands could be considered to be “unduly heavy”. The lowest energy expenditure under uphill marching was achieved with the SS-HL combination, and the highest with the FS-LL combination, contrasting to the findings under downhill walking conditions where the FS-LL combination resulted in the lowest demands and the SS-HL combination the greatest demands. However, the difference between the highest and lowest values obtained under positive grade marching was only 7%, which is substantially less than the 19% found for negative grade marching (see range in responses in Figure 10).

Energy expenditure increased more than two-fold (a mean increase of 56%) when comparing the mean for all three speed-load combinations under negative gradient conditions against responses relative to positive gradients. The greatest increase in energy expenditure (60%) was recorded when marching with the FS-LL combination (an increase from 5.7 (±0.7) $kcal.min^{-1}$ to 14.3 (±1.6) $kcal.min^{-1}$). Obviously such increases in energy expenditure will have a substantial deleterious effect on ability to perform post-march tasks effectively, particularly if required to march uphill for an extended period of time.

GAIT PATTERN RESPONSES

Cadence and Step Length

Walking speed is the product of step frequency (cadence) and step length, both factors increasing with an increase in speed. Subjects naturally select a cadence which optimises energy expenditure as well as enhancing stability, particularly when carrying heavy loads. In the present study, cadence was measured during the 3rd and 6th minutes of each test condition. Since walking speed was known and cadence measured, step length could be calculated for the 3rd and 6th minute of each test condition. Related Student t-tests revealed that there were no significant differences between the cadence responses collected during the 3rd and 6th minutes of experimentation. Therefore Table XIV only shows the 6th minute cadence and step length responses.

TABLE XIV: **Cadence (st.min^{-1}) and step length (m) responses to changes in gradient with three combinations of speed and load (means, with SD in brackets).**

Speed Load	Condition	Gradient	Cadence	p<0.05	Step length
4km.h^{-1} 50kg SS-HL	4	**-10%**	114 (8.2)		0.586 (0.004)
	1	**0**	113 (7)		0.592 (0.004)
	7	**+10%**	115 (7.4)		0.582 (0.004)
5km.h^{-1} 35kg MS-ML	5	**-10%**	118 (5.4)		0.707 (0.003)
	2	**0**	117 (7.2)		0.714 (0.004)
	8	**+10%**	120 (7.2)		0.695 (0.004)
6km.h^{-1} 20kg FS-LL	6	**-10%**	124 (4.6)	]	0.806 (0.003)
	3	**0**	124 (6.2)		0.809 (0.004)
	9	**+10%**	128 (7.4)	]	0.786 (0.005)

Note: Responses in the 6th minute are reflected.
] Denotes a significant difference (p<0.05) between gradients.

During level walking there were substantial adjustments to cadence and step length with changes in speed-load combination (see Figure 11). Therefore the effect of a change in gradient was assessed at similar speed-load combinations. There were no significant differences in either cadence or step length between the downhill and the level marching conditions, regardless of the speed-load combination.

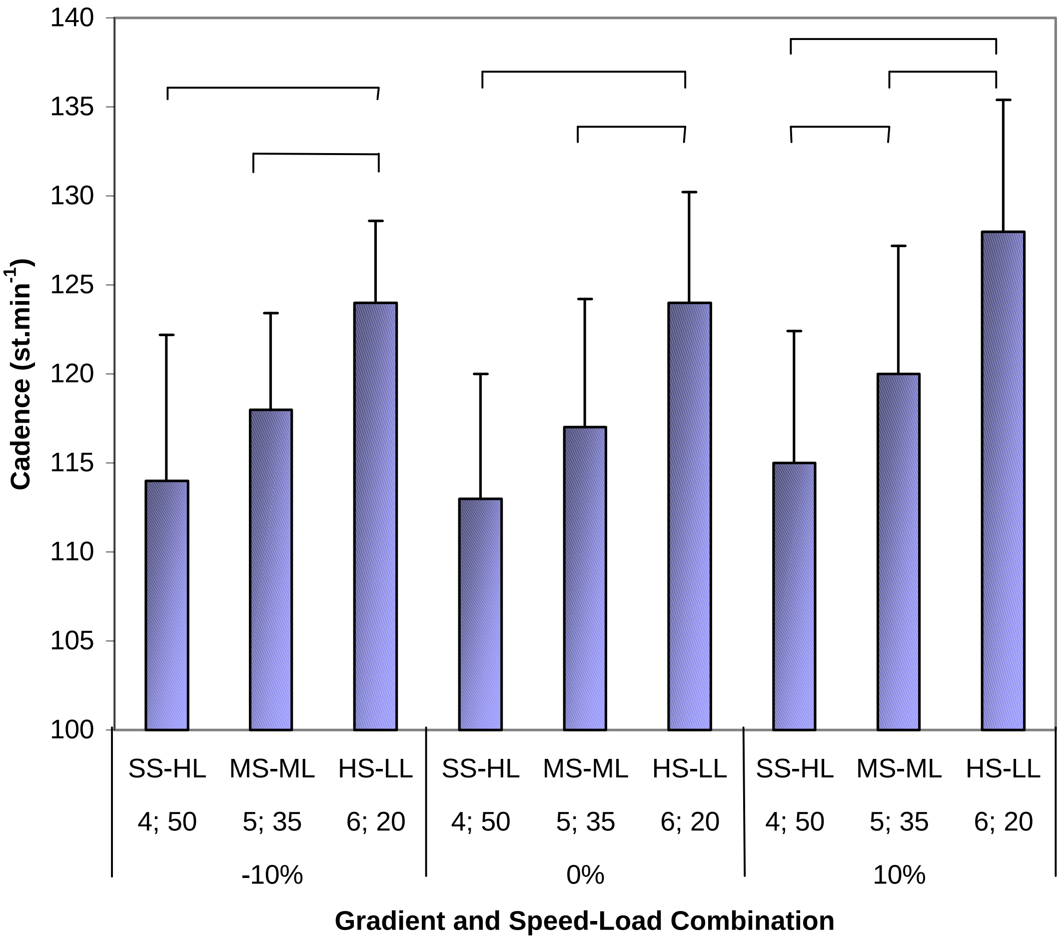


FIGURE 11: **Cadence responses under three different gradients.**

Longitudinal bars link conditions with significant differences ($p<0.05$) between speed-load combinations.

With the MS-ML combination, the positive gradient resulted in a nominally higher cadence (120 ±7.2 st.min^{-1}) and hence a shorter step length (0.69 ±0.04 cm) than the other two gradients, although this difference was not statistically significant.

The responses with the SS-HL combination were very similar to those found with the MS-ML combination, with the incline resulting in a nominally higher cadence and shorter step length.

The highest cadence of 128 (±7.4) $st.min^{-1}$ was recorded walking uphill with the FS-LL combination, which was nominally higher than the level marching condition and significantly higher than the downhill condition (124 ±4.6 $st.min^{-1}$). It follows that the step length was longest under the downhill condition and shortest for the uphill condition.

A change in walking speed resulted in an increase in cadence and step length at all three speeds. Under uphill marching conditions a change in speed-load combination resulted in a significant change in cadence and step length for all three combinations. However, for level and downhill marching, there was no significant difference between the SS-HL and MS-ML combinations. This is congruent with the physiological data, were there was no difference in the heart rates between these two combinations, when walking downhill. The increased cadence walking downhill with the heavy load, once again suggests the difficulty subjects experienced in maintaining balance during this condition resulting in a reduction in step length and an increased cadence and therefore an increase in the metabolic cost.

The natural responses (Wall **et al.**, 1981; Sun **et al.**, 1996) to a positive gradient are to reduce the cadence and step length (as well as walking speed). In the present study only the FS-LL combination resulted in any significant changes in gait patterns. This could be expected, as Wall **et al.** (1981) argued that when subjects are required to walk at an enforced paced, the normal responses to gradient marching may not be elicited.

PSYCHOPHYSICAL RESPONSES

Rating of Perceived Exertion

When optimising performance, whether in military, industrial or sporting contexts, the focus is often exclusively on the physical demands of the task. However, cognisance of the psychological factors is important when trying to establish an understanding of how different individuals perceive and adjust to the same physical tasks. These factors play a major role in motivation and in a person's willingness to work, which in turn will substantially impact on performance and hence productivity. Any two individuals of similar physical ability may perceive the same task differently, resulting in divergent responses. Given the diversity of ethnic groups and cultures within the SANDF, an investigation of individual perceptions of the situation is essential. Holistic investigation of the demands placed on the soldiers is imperative in gaining an understanding of their responses to military tasks in order to enhance performance.

TABLE XV: **Local and Central RPE responses to changes in gradient with three combinations of speed and load (means, with SD in brackets).**

Speed Load	Condition	Gradient	Local RPE	p<0.05	Central RPE	p<0.05
$4 km.h^{-1}$ 50kg SS-HL	4	**-10%**	14 (1.8)		14 (1.9)	
	1	**0**	14 (1.7)		14 (1.6)	
	7	**+10%**	15 (1.7)		15 (1.7)	
$5 km.h^{-1}$ 35kg MS-ML	5	**-10%**	12 (1.5)		11 (1.5)	
	2	**0**	13 (1.6)		12 (1.4)	
	8	**+10%**	13 (1.7)		13 (1.9)	
$6 km.h^{-1}$ 20kg FS-LL	6	**-10%**	10 (1.8)		10 (1.6)	
	3	**0**	11 (2)		10 (1.4)	
	9	**+10%**	13 (1.8)		13 (1.6)	

Note: Responses in the 6th minute are reflected
[Denotes significant difference (p<0.05) between gradients.

LEVEL MARCHING

The significant differences between all three level marching conditions evident in Figure 12, indicate that the subjects perceived a change in speed and load to have a substantial impact on the task demands. The subjects perceived the SS-HL combination for Local RPE to be the most difficult with a rating of 14, and the FS-LL to be the easiest at 11. As in the case of Local RPE responses subjects perceived the SS-HL combination (14 ±1.6) as demanding the greatest cardiovascular effort, and the FS-LL combination (10 ±1.4) the least effort. Both the Local and Central RPE were therefore highest when subjects were required to carry the heavy load of 50 kg. Subjects perceived all three conditions as requiring more muscular effort than cardiovascular effort (see Figure 12).

DOWNHILL MARCHING

A change from the level gradient to downhill marching resulted in very little fluctuation in either Local or Central RPE. There were no significant changes in Local and Central RPE, regardless of the speed-load combination. These results indicate that the subjects did not perceived the cardiovascular demands of negative slope walking to be different to level gradient walking. This could be expected with the SS-HL combination, where there was no significant difference in the heart rate responses between the two conditions but not with the other two speed-load combinations were there was a significant decrease in heart rate when walking down declines.

A change in speed-load combination during downhill walking significantly affected the subjects' perception of the task demands. Subjects rated the SS-HL combination significantly more stressful (both Local and Central RPE), than the other two combinations (see Figure 12). The FS-LL combination was perceived least stressful, with responses being significantly lower than those expressed with the MS-ML and SS-HL combinations. The RPE responses indicate (although the negative gradient was generally less taxing from an energy cost perspective), subjects did not perceive downhill conditions to be less stressful either cardiovascularly or muscularly. Reduced stability caused by the negative gradient (particularly under the heavy load conditions) probably forced subjects to consciously address the problem of balance therefore elevating the subjects perception of the task demands.

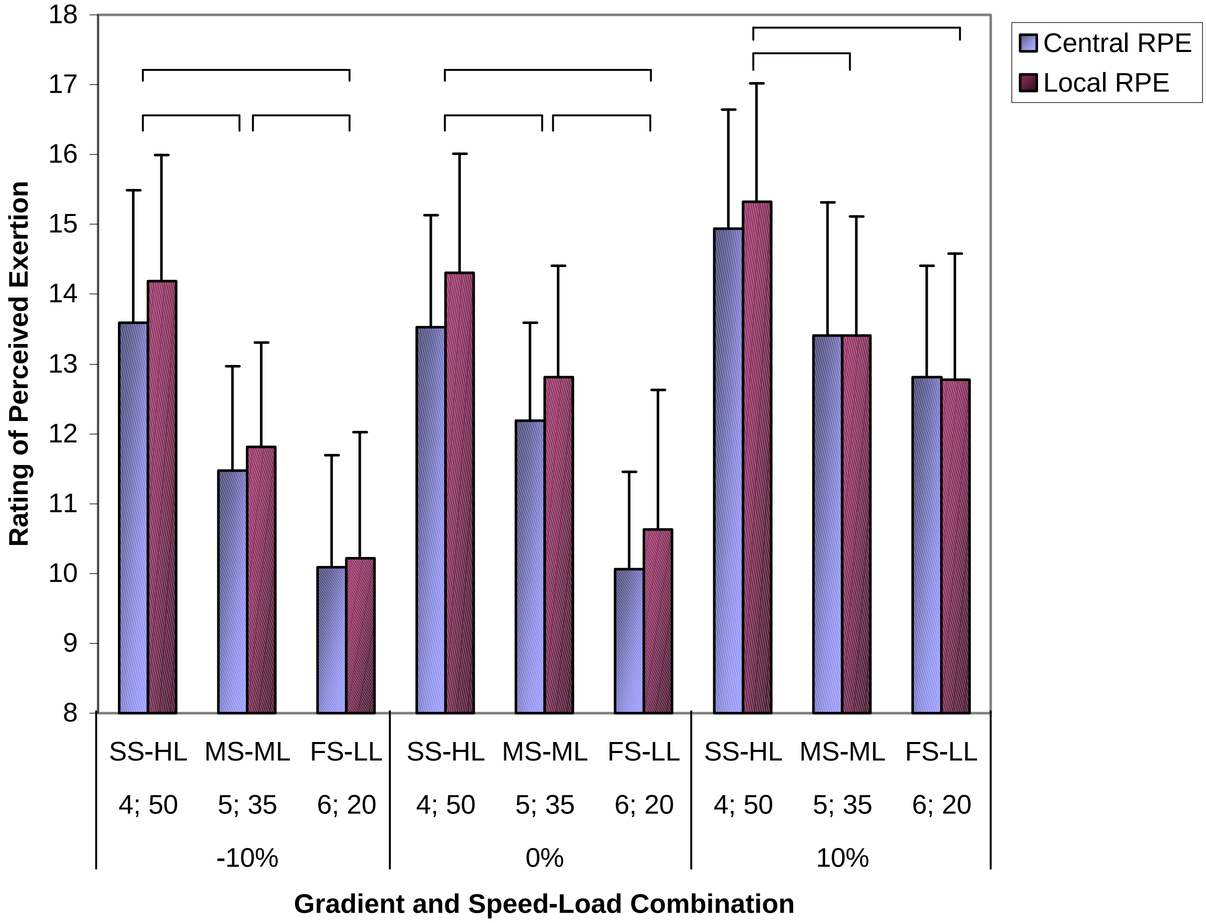


FIGURE 12: **Local and Central RPE responses under three different gradients.**

Longitudinal bars link conditions with significant differences ($p<0.05$) between speed-load combinations for **BOTH** Local and Central RPE.

UPHILL MARCHING

Positive gradient conditions dramatically affected both Local and Central RPE responses compared to those expressed under level marching conditions. Local RPE showed a significant increase with the FS-LL combination from 11 to 13. There were more considerable increases for Central RPE, which elicited significant increases with both the SS-HL and FS-LL combinations. Central RPE showed the greatest increase with the FS-LL combination, corresponding with heart rate responses where the FS-LL combination showed the greatest increase from level to uphill marching.

As with the level and downhill responses, a change in speed-load combination significantly affected the perceptual responses to uphill walking. Figure 12 illustrates how subjects perceived the SS-HL combination to be significantly more taxing than the MS-ML and FS-LL combinations, while there was no significant difference between the two faster speed-lighter load combinations (both Local and Central RPE).

Body Discomfort Rating

An important tool in assessing an individual's perception of task demands is the Body Discomfort Scale (Corlett and Bishop, 1976). This scale gives an indication of discomfort experienced as the result of physically demanding tasks, in this case gradient, walking speed or load carried. Subjects were required to identify specific sites of discomfort and then rate the intensity of discomfort on a scale of 1 to 10. In the present study subjects were required to locate areas of body discomfort and to rate this discomfort on completion of each experimental condition.

The Body Discomfort results indicate that subjects experienced the highest intensity of discomfort with the SS-HL combination (see Table XVI). Of these the uphill condition elicited the highest incidence of discomfort (62 ratings). The subjects also felt more discomfort when marching uphill than under the other two gradient conditions, regardless of speed-load combination. The FS-LL combination (particularly for level and downhill marching) resulted in very little discomfort being noted, (17 and 12 ratings for these two conditions respectively) indicating that they did not impose much discomfort on the subjects.

Table XVI: **Body Discomfort Ratings**

	4 km.h^{-1} 50 kg Combination						5 km.h^{-1} 35 kg Combination						6 km.h^{-1} 20 kg Combination					
Gradient	+10		0		-10		+10		0		-10		+10		0		-10	
Condition	7		1		4		8		2		5		9		3		6	
	N	I	N	I	N	I	N	I	N	I	N	I	N	I	N	I	N	I
Neck	1	7	1	3	2	3	0	0	0	0	0	0	0	0	0	0	0	0
Shoulders	14	5.2	15	4.7	12	4.9	9	4.7	12	4.1	7	4.3	4	4.8	6	3.8	3	4
Upper Back	8	4.5	1	4	4	5	5	4.2	5	4.2	2	3	3	4	1	2	1	3
Lower Back	3	5	5	3.6	9	5.6	5	3.8	2	4.5	7	4	2	4	3	3	1	3
Chest	3	5.7	2	4	4	5.5	2	7	2	3.5	2	5.5	2	7	0	0	0	0
Hips	9	5.4	7	5.7	6	6.1	6	5	5	5.6	6	4.8	4	3.5	3	4.3	5	3.2
Thighs	14	5.2	15	4.7	11	3.6	12	5.3	8	4.4	4	3.3	9	4.4	2	3	1	2
Knees	2	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Calves	8	5	4	5	1	3	8	4.4	1	4	0	0	11	4	2	3	1	3
Feet	0	0	1	3	2	5.5	2	6	0	0	1	4	0	0	0	0	0	0
Total Ratings	62		51		52		49		36		29		35		17		12	

N = Number of ratings for each area; I = mean intensity of discomfort for each area

LEVEL MARCHING

Under level marching conditions the shoulder region consistently elicited the greatest number of discomfort ratings (32% of responses). There were, however, several other areas which produced significant responses (see Figure 13).

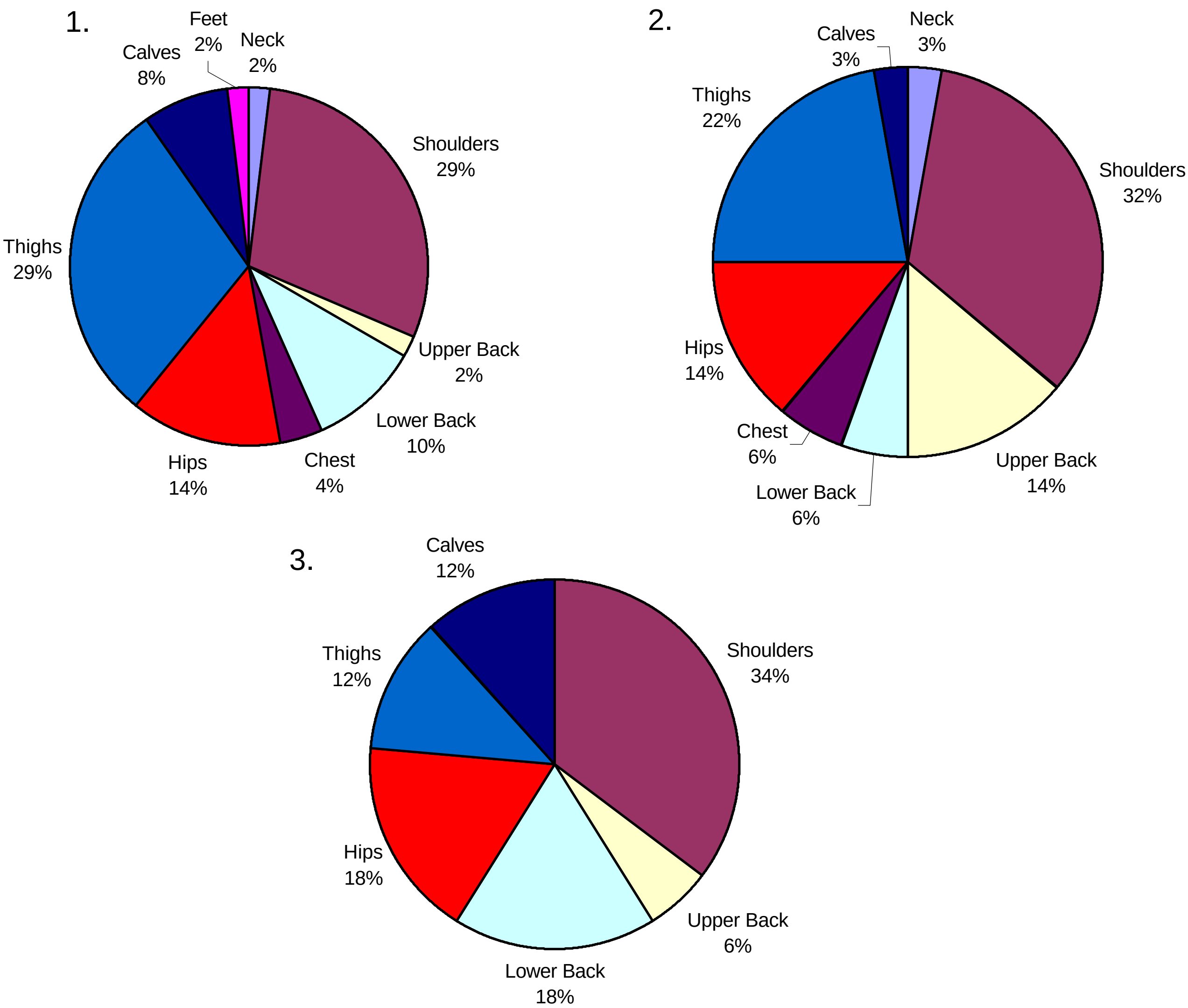


Figure 13: **Body discomfort incidence under level walking conditions.**
(Condition 1: SS-HL; Condition 2: MS-ML; Condition 3: FS-LL).

Note: Each pie chart shows the incidence of discomfort in each region as a percentage of total responses for each condition.

The FS-LL combination identified the hips and the lower back (both 18% of the responses) as well as the thighs and calves (both 12% of the responses) as substantial discomfort sites. In the case of the MS-ML combination the highest incidences (other than the shoulders) were the thighs (22%), hips and upper back (both 14%). With the SS-HL combination the thighs (29%), hips (14%) and lower back (10%) were also major areas of discomfort.

There was a substantial difference between the speed-load combinations under level marching conditions. The FS-LL combination only resulted in 17 responses, indicating that subjects did not perceived this combination to be physically taxing. The MS-ML combination produced 36 responses, while the SS-HL combination resulted in 51 responses. From these responses one can conclude that as the load carried increased, subjects perceived the demands to be greater and responded with a higher incidence rate, although the percentage of discomfort from each area remained relatively stable (for example the shoulders resulted in 29-34% of the responses depending on the condition).

DOWNHILL MARCHING

The three marches on the decline resulted in the lowest number of responses with each of the speed-load combinations, when compared to level and incline conditions. The discomfort in the shoulder region remained high under negative gradient marching, with approximately 24% of the total responses citing this region.

A change in speed-load combination substantially effected decline marching responses. Figure 14 illustrates that there was an increase in the percentage of responses citing the hip region from 12% to 21% to 43% with the SS-HL, MS-ML and FS-LL combinations respectively. Contrastingly there was a reduction in the percentage of responses citing the thigh region with a change in the speed load combination from the SS-HL to the FS-LL combination.

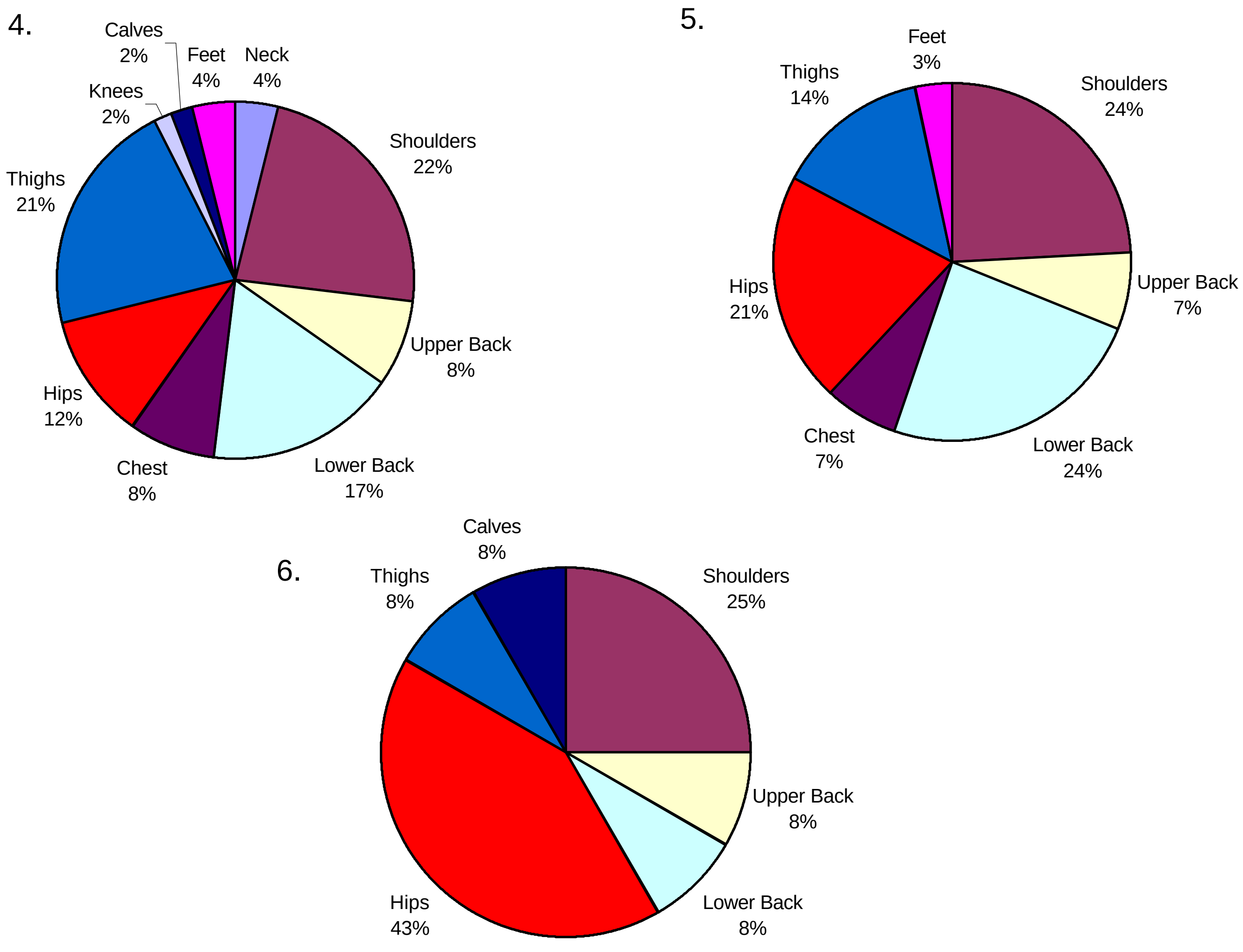


Figure 14**: Body discomfort incidence under downhill walking conditions.**
(Condition 4: SS-HL; Condition 5: ML-MS; Condition 6: FS-LL)

Note: Each pie chart shows the incidence of discomfort in each region as a percentage of total responses for each condition.

UPHILL MARCHING

In comparison to the level marching conditions Table XVI indicates that there was an increase in the number of responses at all three speed-load combinations under positive gradient marching conditions. For uphill marching (see Figure 15) there were three main areas of discomfort experienced in all three combinations.

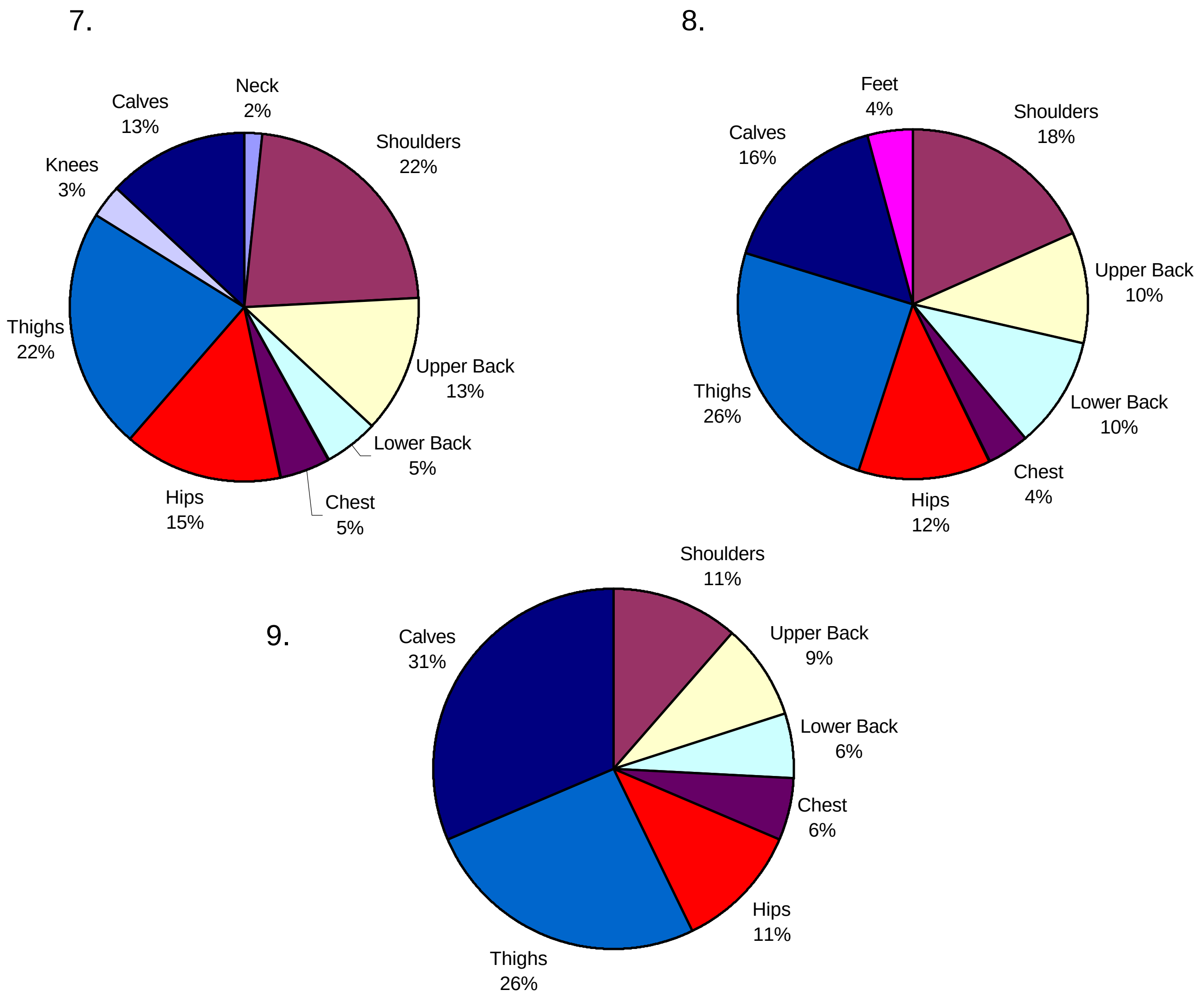


Figure 15: **Body discomfort incidence under uphill walking conditions.** (Condition 7: SS-HL; Condition 8: MS-ML; Condition 9: FS-LL)

Note: Each pie chart shows the incidence of discomfort in each region as a percentage of total responses for each condition.

The shoulder, thigh and calf regions were found to consistently be identified as areas of discomfort. There was a substantial increase in the amount of discomfort experienced in the calves when required to walk uphill, resulting in 20% of the total responses compared to only 7.7% under level marching conditions and only 3.4% under downhill marching conditions. This indicates that incline marching placed a greater demand on the musculature of the lower extremities (see Figures 13 and 15). However, the discomfort ratings in the thigh region remained similar, with approximately 24.7% of the total responses under positive gradient marching from the thigh region compared to 21% under level marching.

A change in speed-load combination under incline marching resulted in several changes – particularly with the shoulder and calve region discomfort responses. As walking speed increased and the load carried decreased a greater amount of the discomfort experienced was in the calve musculature, increasing from 13% of the total responses with the SS-HL combination to 31% with the FS-LL combination. The shoulder discomfort responses follow the opposite trend – as the speed increased and load decreased there was a decrease in the discomfort recorded in the shoulder region (from 22% with the SS-HL combination to 11% with the FS-LL combination).

In conclusion RPE responses in Table XV show how subjects perceived the SS-HL combination, regardless of gradient as causing the greatest amount of strain, both muscular and cardiovascular. Although the subjects did perceive the incline conditions to be more strenuous than the level conditions, these increases did not match the increases caused by the heavy load carriage (50 kg) combination.

Although from an energy expenditure perspective the uphill conditions (regardless of speed and load) were the most strenuous, it is clear that the subjects perceived the heavy load carriage conditions to be the most taxing. This personalized response is highly likely to have a significant impact on the successful completion of the requirements, for as Borg (1970) said, “Man responds to the world as he perceives it and not as it really is”.

INTEGRATED DISCUSSION

The attainment of minimal energy expenditure per unit distance covered is a primary objective of any troop movement. It is therefore essential to investigate the variables which may affect this – factors such as speed-load combinations, distance covered, terrain factors and work-to-rest ratios. The ability to minimise the effects of fatigue (regardless of the cause) during any military situation is imperative in ensuring that critical post-march tasks can be completed with precision.

During any field march soldiers are likely to encounter uphill, level and downhill terrain. Figure 16 shows the mean energy expenditure for three different speed-load combinations across all three gradients, absolute energy expenditure and relative to body mass. When considering the mean for all three gradients at each speed-load combination, the absolute energy expenditure shows that the highest cost was at a speed of 4 $km.h^{-1}$ carrying 50 kg. While the lowest energy expenditure (mean of 2281 $kJ.h^{-1}$) was at a marching speed of 5 $km.h^{-1}$ carrying 35 kg, suggesting (as illustrated in Figure 16) that when foot soldiers encounter undulating terrain for substantial periods of time a moderate load and walking speed (5 km.h^{-1} carrying 35 kg) would be optimal in maintaining energy expenditure at a minimum. Although it should be noted that the mean energy expenditure for these three conditions of 545 kcal.h^{-1} or 635 Watts is still substantially higher than proposed acceptable limits.

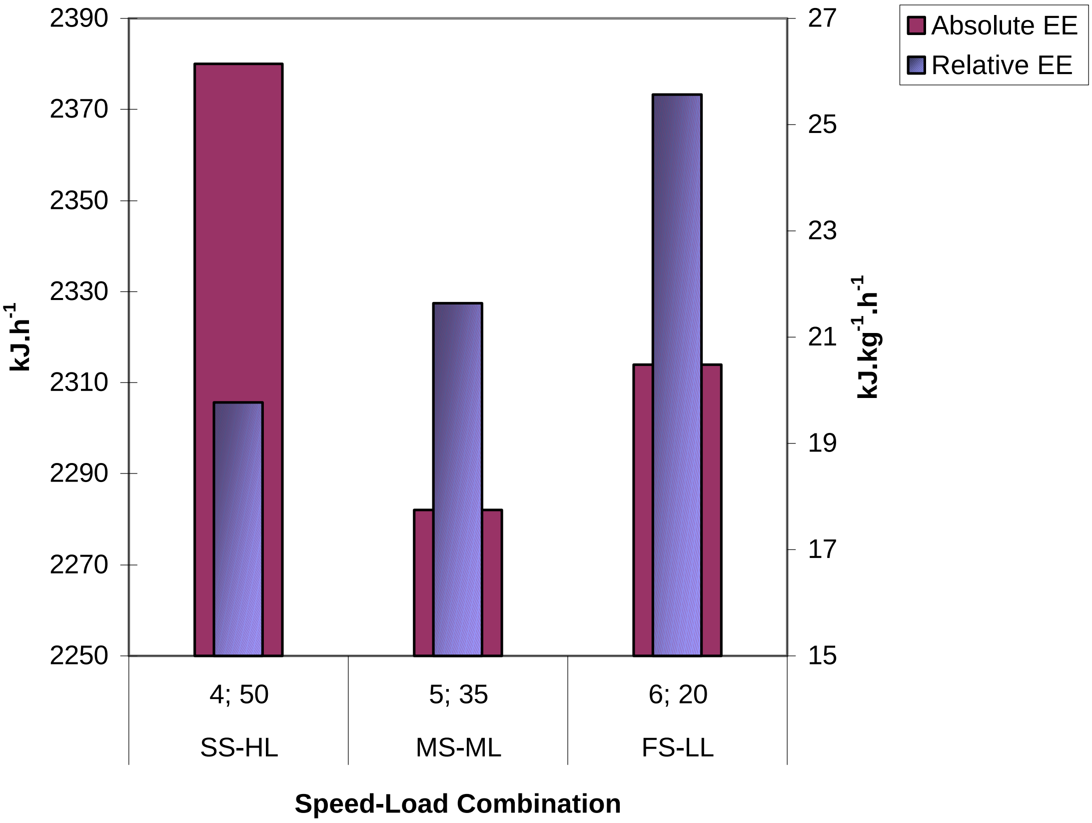


Figure 16: **Energy expenditure with various speed-load combinations, under three gradient conditions.**

However, when considering the energy expenditure per kilogram of mass moved (kJ.Σkg^{-1}.min^{-1}), the SS-HL combination was the most efficient method of transport, with a mean energy expenditure of 19.8 kJ.Σkg^{-1}.h^{-1} for all three gradients. Whereas the FS-LL combination was the least efficient with an average energy expenditure of 25.6 kJ.Σkg^{-1}.h^{-1} for all three gradients, which is a difference of 22.5% between speed-load combinations. This is due mainly to the substantial differences found under the incline conditions where the heavy load resulted in an energy expenditure of 27.6 (± 2.79) kJ.∑kg^{-1}.h^{-1} in comparison to the light load of 39.56 (±4.09) kJ.∑kg^{-1}.h^{-1}, when relative to total load being moved. Therefore although in absolute terms, the energy expenditure resulting from heavy load carriage is significantly higher than from the two lighter loads, when expressed relative to total load being moved, Figure 16 shows this load to result in the lowest relative energy expenditure.

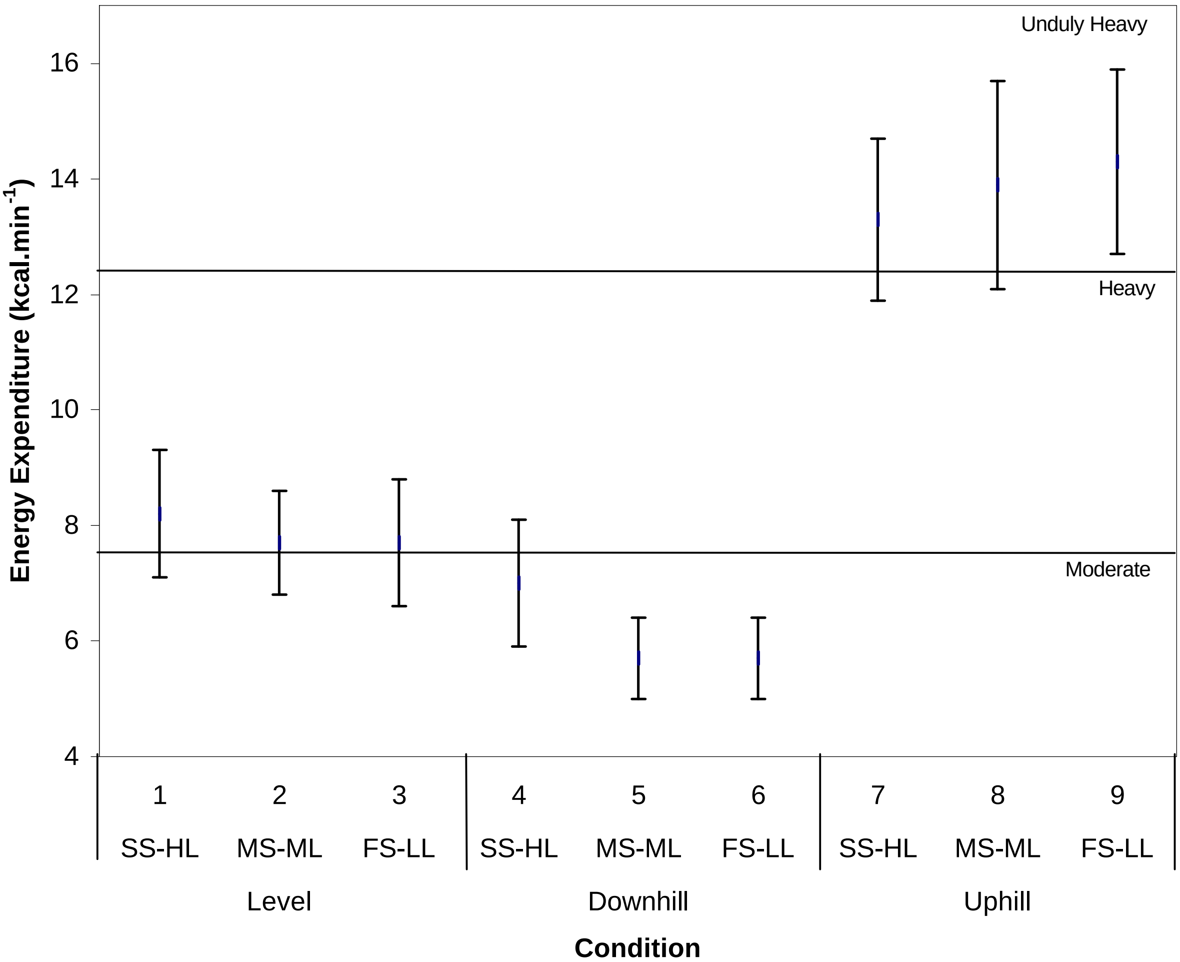


Figure 17: **Energy expenditure responses under nine experimental conditions comparing 3 gradients and 3 speed-load combinations.**

Figure 17 illustrates the energy expenditure elicited during all nine test conditions. It is evident that Conditions 7-9 (uphill conditions) resulted in an energy cost which could be considered to be unduly heavy. Foot soldiers would be unlikely to be able to maintain this intensity for any extended period without undue fatigue setting in.

Although Condition 4 (SS-HL downhill) was found to elicit a metabolic cost lower than Conditions 1-3 (level marching), several other physiological variables showed these conditions to be similar (see Table XVII). Furthermore the energy expenditure under this condition was found to be significantly higher than with the other two downhill conditions. Similarly, while the MS-ML combination under decline marching was metabolically lower than level marching it was only significantly lower than Condition 1 (SS-HL under level gradient) when taking all the physiological responses into account. This indicates that speed-load combinations which may elicit similar responses under level and positive gradient marching, may not do so under negative gradient marching. Additionally downhill marching will not necessarily result in reductions in energy expenditure compared to level marching, and factors such as speed and load will have a substantial impact on these responses. It is also evident that any decreases in energy cost associated with negative slopes are not nearly as substantial as the increases associated with positive slopes.

Table XVII: **Physiological variables (and percentages) NOT significantly different between the nine test conditions**.

Condition	1	2	3	4	5	6	7	8	9
1		VO_2, R, Br, V_T, V_E	VO_2, R, Br, V_T, V_E	HR, R, Br, V_T, V_E	R, Br,	R, Br, V_T	Br	Br	Br
2	83		HR, VO_2, R, Br, V_T, V_E	VO_2, R, Br, V_T, V_E	HR, R, Br, V_E	R, Br, V_T	-	Br	Br
3	83	100		VO_2, R, Br, Ve	HR, R, Br, Ve	R, Bf	-	-	Br
4	83	83	67		R, Br, V_T, V_E	R, Br, V_T	Br	Br	Br
5	33	67	67	67		HR, VO_2, R, Br, V_T, V_E	-	Br	Br
6	50	50	33	50	100		-	-	Br
7	17	0	0	17	0	0		HR, VO_2, R, Br, V_T, V_E	HR, VO_2, R, Br, Ve
8	17	17	0	17	17	0	100		HR, VO_2, R, Br, V_T, V_E
9	17	17	17	17	17	17	83	100	

Variables in top half of matrix indicate variables **not** significantly different between conditions. Numbers in lower half of matrix are percentages (%) of variable responses that are similar (as identified above).
Three examples are presented below:
Between Conditions 1 and 2 there are no significant differences between VO_2, R, Br, V_T and V_E; i.e. 83% of responses are similar.
Between Conditions 4 and 7 there is no significant difference between Br; i.e. only 17% of responses are similar.
Between Conditions 8 and 9 there are no significant differences between Hr, VO_2, R, Br, V_T and V_E; i.e. 100% of responses are similar.

The results illustrated above clearly demonstrate the effects of changes in gradient on three speed-load combinations that have been found to be “ideal” during level marching (Christie, 2001). However, during any march there is an interaction of all three variables. Therefore, it is worthwhile investigating the effects of gradient, load and speed upon the physiological and psychological responses of military personnel. Table XVIII shows the nine experimental conditions and the relationship between them.

There are several key responses to changes in speed-load combination and gradient illustrated in Table XVII. Although the energy cost (see Figure 17) under positive gradient marching was significantly higher than under level and decline marching, there were very few changes in breathing frequency. It is evident in Table XVII that breathing frequency was only significantly different between 17% of the conditions. This can be attributed to restricted breathing caused by shoulder strapping, as has been found previously (Myles and Saunders, 1979; Harty **et al.**, 1999). It is therefore noteworthy that increases in minute ventilation to provide increased oxygen supply were brought about solely by increases in tidal volume (significantly different between 77% of the conditions).

When comparing level marching to downhill marching it is evident that when oxygen consumption responses were similar, heart rate responses under the downhill conditions were significantly higher. Correspondingly, when heart rate responses were similar, oxygen consumption responses under the downhill conditions were significantly lower (see Table XVII). This indicates that at similar levels of oxygen consumption, downhill walking results in higher heart rates than level walking. Pimental **et al.** (1982) found similar differences between uphill and downhill walking, while Petrofsky **et al.** (1981) argued that eccentric work causes a pressor response, increasing mean arterial pressure and therefore heart rate.

Although beyond the scope of the present study, cognisance of the delayed consequences of downhill marching must be taken. Eston **et al.** (1995) argued that prolonged downhill running, and to a lesser extent walking, caused a delayed onset of muscle soreness. The muscle pain experienced may impair muscle function and in turn have a deleterious affect on performance after a long march. These consequences associated with downhill marching needs further investigation.

The three speed-load combinations used in the present study elicited submaximal demands, supporting the findings of Christie (2001). However, changes in gradient had a significant impact on the physiological and psychophysical responses to these apparently ‘ideal’ speed-load combinations. The responses to the uphill conditions indicated that excessive demands were placed on the subjects. These demands are most likely to result in undue fatigue and injury, if maintained for extended periods. The downhill conditions revealed that speed-load combinations that are similar under level marching conditions are not necessarily similar under downhill marching conditions. The responses recorded for the SS-HL downhill condition were similar to those recorded for level marching and significantly higher than the other two downhill conditions. An awareness of the demands of grade walking, allows appropriate adjustments to be made, ensuring completion of route marches with less likelihood of fatigue or injury.

CHAPTER V

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

INTRODUCTION

The attainment of minimal energy expenditure per unit distance covered is a primary objective of any military march. It is therefore essential to investigate the variables which may affect this – factors such as speed-load combinations, distance covered, terrain factors and work to rest ratios. The ability to minimise the effects of fatigue (regardless of the cause) during any military operation is imperative in ensuring that critical post-march tasks can be completed with precision. Speed-load combinations which have been found to be optimal through rigorous research may not always be practical in meeting military demands. Therefore, when attempting to optimise military efficiency it is necessary to minimise metabolic and perceptual demands placed on soldiers, by making appropriate *in situ* compromises/adjustments which guarantee the successful completion of the task in minimal time and with least wasted effort.

The human element is a key component in any military context as the effectiveness of military operations is dependent on the efficiency of the soldier. Therefore, in any Ergonomics investigation the focus is on evaluating the compatibility between the task demands and the capabilities of the operator. Achieving this 'balance' between military requirements and soldier capabilities is extremely complex, due to many compounding factors over and above speed and load combinations. Another key factor to consider is that of marching gradient as route marches are likely to be over undulating terrain. The positive and negative gradients encountered influence the biomechanical, physiological and psychological demands placed on the soldiers. An understanding of these factors and the responses to grade walking will allow more suitable adjustments to be made to minimise the physical and mental demands placed on the soldier, thereby enhancing the likelihood of achieving military goals. The purpose of the present study was therefore to investigate the effect of changes in gradient on selected metabolic, physical and perceptual responses of military personnel, at three pre-selected speed-load combinations.

SUMMARY OF PROCEDURES

The present study was conducted in the Physiology laboratory at Rhodes University. Nine experimental marching conditions formed the basis of the study, with subjects required to march over various gradients with different speed-load combinations. Three different walking levels including positive and negative gradients were tested: -10%, 0% and +10%. Subjects were required to march using three different speed-load combinations of 4 $km.h^{-1}$ carrying 50 kg (SS-HL); 5 $km.h^{-1}$ carrying 35 kg (MS-ML) and 6 $km.h^{-1}$ carrying 20 kg (FS-LL). Each condition required subjects to march on a motorized treadmill for six minutes. The order of presentation of the nine conditions was randomised, and scheduled for the same time of day for the same subjects to minimise the influence of circadian rhythms.

Thirty-two healthy male soldiers (mean age 26.4 years, mean stature 1717 mm, mean mass 67.6 kg, mean BMI 22.7, mean body fat 14.9 %) participated in the study. Subjects were organised into eight groups of five subjects each. Ten subjects (two groups) were tested each week over a four week period, five tested in the mornings and five in the afternoon.

Basic demographic data including age, military experience, stature, limb length and body mass with minimal clothing and in full uniform, plus body composition were collected. Subjects were then habituated to treadmill walking and familiarized with the laboratory equipment used, on three separate occasions. Subjects were also required to participate in a submaximal predictive VO_{2max} test (Bruce protocol) to obtain an estimate of the group's aerobic capacity and to relate experimental outputs to individual predicted maxima.

Each subject was required to complete each condition at the preset gradient and speed carrying the predetermined load. During each condition heart rates, cadence and RPE were manually recorded during the 3rd and 6th minutes. Body Discomfort ratings (site and intensity) were assessed at the end of each condition. The following MetaMax data were measured over the 3rd and 6th minutes of each condition:

oxygen consumption (VO_2);
breathing frequency (Br);
tidal volume (V_T);
minute ventilation (V_E); and
respiratory exchange ratio (R).

Additionally, from the VO_2 responses the following energy expenditure properties were derived:

kcal.min^{-1};
kJ.min^{-1};

kJ. $\sum kg^{-1}.h^{-1}$

Power output (Watts)

From the cadence responses collected during the 3rd and 6th minutes of each condition the corresponding step length responses were calculated.

Basic descriptive statistics relative to the variables assessed were computed, providing general information concerning the sample. Related Student t-tests were computed to assess whether the responses of the 3rd and 6th minutes of each condition differed. Two-way ANOVAs were calculated to determine whether there were any differences between the nine experimental conditions ($p<0.05$).

SUMMARY OF RESULTS

All nine test conditions resulted in different energy expenditure, cadence and perception of exertion responses. Under the three level gradient marching conditions changes in speed-load combination had little impact on physiological responses, with few variables showing significant differences. Heart rate responses were significantly higher with the SS-HL combination compared to the other two speed-load combinations, with a mean heart rate of 121 $bt.min^{-1}$ under the two faster speed – lighter load combinations and a heart rate of 136 $bt.min^{-1}$ under the heavy load combination. There were, however, no significant differences in the oxygen consumption, tidal volume and breathing frequency responses. This indicates that all three (level walking) speed-load conditions resulted in similar levels of exertion, as was found by Christie (2001) who used similar speed-load combinations. Although the mean heart rate of 121 $b.min^{-1}$ for the two optimal conditions is higher than the acceptable limit of 110 $b.min^{-1}$ for sustained effort proposed by Brouha (1967), these limits were designed for an eight-hour work shift. Since soldiers are seldom required to march for extended periods without breaks, the levels found in the present study may be considered to be acceptable.

There was a mean oxygen consumption (under level marching) of 23.5 $ml.kg^{-1}.min^{-1}$, approximately 61% of VO_{2max}. Although it has been proposed by Saha **et al.** (1979) and Evans **et al.** (1980) that workloads higher than 40-50% of VO_{2max} would result in excessive strain, within a military context higher levels of exertion may be seen as reasonable, given that soldiers are seldom required to march for more than two or three hours without a break. Oxygen uptake while walking in the SS-HL condition was higher than for the other two combinations. There was a mean energy expenditure of approximately 32.9 $kJ.min^{-1}$ (or 18.9 $kj.\sum kg^{-1}.h^{-1}$), which, according to McArdle **et al.** (1996), could be classified as being a “heavy” workload.

However, any route march is unlikely to be executed over level terrain and soldiers will be required to march uphill and downhill, and these changes in gradient are likely to have an impact on energy demands. The results of the present study indicate that a 10% positive gradient significantly increases both metabolic and perceptual requirements. When subjects were required to negotiate a positive gradient there was a significant increase in metabolic demands with all three speed-load combinations. The FS-LL (6 $km.h^{-1}$) combination resulted in the greatest increases, to a heart rate of 168 $bt.min^{-1}$ and VO_2 of 42.1 $ml.kg^{-1}.min^{-1}$. Such substantial increases in the metabolic demands have recently been supported by Sagiv **et al.** (2000) who found comparable heart rate responses under similar marching conditions.

Under the three incline marching conditions there was no significant differences between the speed-load combinations for any of the metabolic parameters. There was a mean oxygen consumption of 41 $ml.kg^{-1}.min^{-1}$ during uphill marching, which was an average increase of 42.7% from the equivalent level marching conditions. The mean heart rate of 170 $bt.min^{-1}$ was approximately 88% of age-predicted maximum heart rate, an increase of 26% in comparison to the level marching conditions. It is clear that the subjects were required to work near to their maximum capacity during these three conditions, confirmed by the fact that the oxygen consumption was 106% of the predicted VO_{2max} for the group. It is therefore unlikely that subjects would have been able to maintain the task requirements for any extended period of time.

There was an increase in energy expenditure from 7.9 $kcal.min^{-1}$ during level marching to 13.8 $kcal.min^{-1}$ during positive slope marching. According to the McArdle **et al.** (1996) classification scale, this energy expenditure may be considered to be “unduly heavy”. This once again suggests that positive grade walking may place excessive strain on subjects, something that needs to be addressed when selecting loads and marching speeds for troops. Although the physiological responses suggest that uphill marching is the most strenuous, subjects perceived the three heavy-load conditions, regardless of gradient, to be the most strenuous with both “Local” and “Central” ratings of exertion being highest in these conditions.

The three negative gradient conditions also resulted in significant changes in cardio-respiratory responses when compared to the level marching conditions. The two faster speed-lighter load combinations resulted in significant reduction in heart rate, while the there was no change in heart rate responses with the heavy load combination. Under this condition heart rate responses were approximately 18% higher than with the other two speed-load combinations for decline marching, suggesting that with heavy-load carriage the decrease in metabolic demands due to the eccentric work associated with downhill walking may not be elicited. The negative gradient did, however, result in a significant decrease in oxygen consumption under all three speed-load combinations, although once again it was highest with the heavy-load combination. These three conditions resulted in an oxygen consumption of 44-54 % of the predicted VO_{2max}, which could be considered to be acceptable for an 8-hour work shift.

These results indicate that there is a clear need for an adjustment in walking speed and/or load carried to cater for changes in gradient. Positive gradients will substantially increase the demands placed on the cardio-respiratory system. The decreases associated with downhill marching were found to be substantially less than the increases found for the uphill marching, indicating that the two do not counterbalance each other. Further consideration must be made of the fact that heavy load carriage during downhill marching resulted in very few reductions in the variables measured (only oxygen consumption and tidal volume showed reductions compared to the level condition). Although generally negative (eccentric) work is more cost-effective than positive (concentric) work, with the heavy load (50 kg) combination (and sometimes even the moderate load (35 kg) combination) there was added cost due to added work in maintaining stability and restricted chest movements.

HYPOTHESES

It was expected that subjects' responses after six minutes of load carriage would reflect greater physiological and psychological strain under a positive gradient and less strain under a negative gradient.

Hypothesis 1 (a):

The hypothesis under test was that there would be no change in cardiovascular and metabolic responses (Heart rate, VO_2 and R) over the nine conditions in response to changes in gradient and selected speed-load combinations. On balance this hypothesis is rejected as significant differences were found in heart rate in 78% of the cases, in VO_2 in 75% of the cases and in respiratory exchange ratio in 50% of the cases.

The cardiovascular and metabolic responses were lowest under negative gradient marching, and highest under positive gradient marching. In general, there was a substantially smaller decrease in the responses with the 4 $km.h^{-1}$ carrying 50 kg combination compared to the decreases found with the other two speed-load combinations (level marching vs. downhill marching). There was consistently a significant difference between the SS-HL combination and the MS-ML and FS-LL combinations during downhill and level marching. Incline marching resulted in excessive strain being placed on the subjects, with subjects working near to maximum levels.

Hypothesis 1 (b):

The hypothesis under test was that there would be no change in ventilatory responses (V_E, V_T and B_r) over the nine conditions in response to changes in gradient and speed-load combination. On balance this hypothesis is rejected as significant differences were found in V_E and V_T in 64% of the cases, but is tentatively retained for breathing frequency in which only 17% of the responses showed a significant difference between conditions.

The ventilatory responses were lowest under the negative gradient conditions and highest under positive gradient conditions. The ventilatory responses to the downhill conditions showed smaller decreases (compared to level marching) with the SS-HL combination than with the other two speed-load combinations. As with the cardiovascular responses, the uphill conditions resulted in excessively high demands on the ventilatory system.

There were very few changes in breathing frequency, regardless of changes in gradient or speed-load combination. Heavy loads requiring tight strapping to the upper torso, restrict chest movements and therefore impede free movement of air through the respiratory system. These restrictions may account for the lack of changes in breathing frequency found in the present study.

Hypothesis 2:

The hypothesis under test was that there would be no change in the perceptual responses over the nine conditions in response to a change in gradient and speed-load combination. On balance this hypothesis is rejected as significant differences were found in Local RPE in 67% of the cases and in Central RPE in 72% of the cases.

Although the perceptual responses mirrored the physiological responses for several of the conditions, they did appear to be suppressed under the uphill conditions. It is also argued that the “Central” RPE responses were suppressed under the FS-LL conditions, regardless of the gradient.

In contrast to the physiological responses, subjects perceived a change in speed-load combination to have a significant effect on the task requirements. They perceived the heavy load carriage conditions to be the most taxing (both cardiovascularly and muscularly), regardless of the gradient, while the light load conditions (particularly during downhill and level marching) were perceived to be the least taxing of the nine conditions. The body discomfort responses follow a similar trend with the greatest incidence of discomfort elicited for the three heavy load conditions. As with the Local and Central RPE responses the light load conditions elicited the lowest incidence of discomfort.

Hypothesis 3:

The hypothesis under test was that there would be no change in the gait kinematic responses over the nine test conditions in response to changes in gradient and speed-load combinations. On balance this hypothesis is rejected as significant differences were found in cadence in 50% of the cases and in step length in 75% of the cases.

Cadence was lowest and step length smallest under the 4 $km.h^{-1}$ conditions, and progressively increased as speed increased to the highest and largest under the 6 $km.h^{-1}$ conditions. Although there were significant changes in response to changes in speed-load combination, the kinematic responses to changes in gradient elicited very few significant differences. Therefore any changes in gait kinematics can be attributed to changes in speed-load combination and not to changes in gradient.

CONCLUSIONS

The results indicate that a change in walking gradient, either positive or negative, will significantly affect the physiological and perceptual responses to specific speed-load combinations. When downhill marching is compared to level marching, it is clear that, particularly at faster speeds carrying lighter loads, there was a significant decrease in the physiological demands placed on the subjects. Simultaneously there was a decrease in the psychological demands on the subjects under the lighter load conditions. However, it must be noted that during heavy load carriage (50 kg) even at optimal walking speed (4 $km.h^{-1}$) not all physiological variables showed a significant decrease walking downhill. Cognisance of the fact that the physiological benefits of the eccentric work associated with downhill walking are counteracted by both an increased instability (caused by the negative gradient and heavy load) and the inefficiencies of the ventilatory system during heavy load carriage (due to backpack positioning and strap tightness). Therefore it could be argued that under heavy load carriage the benefits of a negative gradient are revoked and there is unlikely to be a decrease in energy expenditure.

Uphill marching resulted in significant increases in both the physiological and perceptual demands on soldiers. A positive 10% gradient increased oxygen consumption to above predicted VO_{2max} and heart rates to near age-predicted maximum. It is clear that speed-load combinations which may result in optimal responses during level marching, do not elicit similar responses when performed uphill. None of the speed-load combinations used in the present study could be maintained for any extended period without resulting in substantial fatigue and discomfort. It is clear that during uphill marching the considerable increases in the energy requirements associated with uphill marching need to be given careful consideration when planning any route march.

RECOMMENDATIONS

It is evident from this study that terrain traversed has a significant influence on the responses of soldiers and it is strongly recommended that further studies be conducted in this important area of research.

Although every effort was made to minimise the variability in the age of the subjects tested, this factor was ultimately under the control of the South African National Defence Force. The result was that there were two distinct age groups tested in the present study – one group with a mean age of 22 years and the other of 31 years of age. However, since age-related differences were not considered as one of the original hypotheses this variable was not considered in the present project. It is however evident that such marked age differences may significantly impact the physiological and perceptual responses of soldiers, which would in turn influence the ability of the group to function as a unit. It is therefore recommended that future research investigate the demographics of the SANDF and the effects of aging on the metabolic and perceptual responses to gradient marching.

It was originally hoped to assess female as well as male responses to gradient walking. However, due to the limited number of female subjects available they were not included in the study. With increasing female participation in all aspects of military operations, it would be worthwhile to investigate differences between the sexes in order to make more relevant recommendations to optimise the performance of a platoon in which it is highly probable that there will be both male and female soldiers.

It is also recommended that further research be done on the biomechanical and physiological responses to loaded downhill marching with backpacks of varying loads. The results of the present study indicate that the energy cost of downhill walking cannot be simply extrapolated from a linear relationship with uphill marching. It is apparent that increasing loads may differentially tax individuals during negative gradient walking. Furthermore only one negative gradient was investigated during this study. A suggestion for future studies would be to investigate a wider range of negative gradients with a greater variety of loads.

Subjects in the present study were only required to march downhill for six minutes under each condition, which is unlikely to cause delayed onset of muscle soreness. However the impaired function of the musculature caused by muscle soreness after prolonged downhill marching will have an impact on post-march objectives. It is therefore recommended that future studies investigate the delayed effects of loaded downhill marching on post-march capabilities.

Although the cadence and step length data revealed no significant differences (due to the enforced pace set by the treadmill), for qualitative observations of the subjects it was evident that there were substantial changes in the gait patterns adopted by the subjects during loaded downhill marching. Such changes in the 'natural' gait pattern would affect metabolic cost, exacerbated in an extended march. It is therefore suggested that further studies investigate the gait adjustments associated with loaded downhill marching.

Although laboratory testing allows for the rigorous control of as many extraneous variables as possible, the responses found may not be truly representative of what would occur *in situ*. It is therefore recommended that further studies investigate the effects of changes in gradient *in situ*, in order to establish more realistic responses, taking environmental conditions into consideration.

The following practical applications for the military were also suggested:

It is clear from the level marching conditions that in order to maintain a workload of approximately 50% of VO_{2max}, the load carried must be adjusted according to the required speed and vice versa.

Although not metabolically the most demanding, subjects perceived the heavy load (50 kg) conditions to be the most taxing, regardless of the gradient. Subjects therefore perceived changes in load to be more demanding than changes in walking speed.

The results indicate that a load over 35 kg will result in an energy cost that is above 50 % of maximal effort. This is congruent with the literature, which proposes that in order to work at 40-50% of maximum, loads carried should not exceed 50% of body weight. There was a mean body weight of 66 kg in the present study, therefore a 35 kg load was 53% of body mass.

When considering all three gradients the 5 $km.h^{-1}$ carrying 35 kg speed-load combination resulted in the lowest energy requirements. Therefore when required to march for extended periods over undulating terrain, a moderate speed and moderate load would be preferred in keeping the demands at a minimum.

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APPENDIX A: GENERAL INFORMATION

Equipment Check List

Detailed Test Schedule

Letter to Subject

Consent Form

MetaMax Preparation

EQUIPMENT CHECK LIST
ADMINISTRATION

Letter to Subject

Consent Form

General information data sheet

Subject data sheet

Instructions to subject for RPE

Instructions to subject for Body Discomfort

COMPUTER EQUIPMENT

1 Laptop with cables

Portable printer

Storage discs

DATA COLLECTION EQUIPMENT

Toledo scale

LIPOCARE Bioelectrical Impedance Analysis

METAMAX
- Silver bag
- Gas cyclinder
- 3 litre syringe
- Rubber bladder with clamp
- 6 masks with head cap assembly

Heart rate monitors

RPE scale

Body Discomfort scale

DATA COLLECTION SCHEDULE

A weekly plan testing ten subjects per week was followed. Therefore required 10 subjects per week for four weeks (ie: 40 subjects). Once habituation and submax testing had been completed (Monday and Tuesday every week), there were two testing sessions per day (Wednesday through to Friday every week):

Session 1: 8.00 – 11.45 **Session 2: 13.00 – 16.45**

The ten subjects for each week were split up into two groups of 5. There were therefore eight groups of five subjects each: G_1, G_2, G_3, G_4, G_5, G_6, G_7 and G_8.

<u>WEEK 1:</u> Monday 23rd – Friday 27th October

10 subjects for the week: G_1 and G_2. These two groups came together on Monday and on Tuesday morning, after which they were split up and required to come separately at different times. The first group (e.g. G_1) came to session 1: 8.00-11.45 and the second group (e.g. G_2) to session 2: 13.00-16.45 for the Wednesday, Thursday and Friday sessions.

Briefing: Monday 23rd

10.00 – 11.00 G_1 and G_2

Habituation: Monday 23rd

11.00 – 12.00 G_1 and G_2

14.00 – 15.00 G_1 and G_2

Tuesday 24th

10.00 – 11.00 G_1 and G_2

NOTE: There is a need for at least three habituation sessions.

Submax Testing: Tuesday 24th

14.00 – 15.00 G_1

15.00 – 16.00 G_2

Testing Sessions: Wednesday 25th

8.00 – 11.45 G_1 for 3 cond.

13.00 – 16.45 G_2 for 3 cond.

Thursday 26th

8.00 – 11.45 G_1 for 3 cond.

13.00 – 16.45 G_2 for 3 cond.

Friday 27th

8.00 – 11.45 G_1 for 3 cond.

13.00 – 16.45 G_2 for 3 cond.

All 10 subjects must complete all 9 conditions.

<u>WEEK 2:</u> Monday 30th – Friday 3rd November

10 male subjects need for the week. They will be split into two groups of five: G_3 and G_4. These two groups will be required to come together on Monday and on Tuesday morning, after which they will be split up and required to come separately at different times. The first group (e.g. G_1) will come to session 1: 8.00-11.45 and the second group (e.g. G_2) to session 2: 13.00-16.45 for the Wednesday, Thursday and Friday sessions.

Briefing: Monday 30th

10.00 – 11.00 G_3 and G_4

Habituation: Monday 30th

11.00 – 12.00 G_3 and G_4

14.00 – 15.00 G_3 and G_4

Tuesday 31st

10.00 – 11.00 G_3 and G_4

NOTE: There is a need for at least three habituation sessions.

Submax Testing: Tuesday 31st

14.00 – 15.00 G_3

15.00 – 16.00 G_4

Testing Sessions: Wednesday 1st

8.00 – 11.45 G_3 for 3 cond.

13.00 – 16.45 G_4 for 3 cond.

Thursday 2nd

8.00 – 11.45 G_3 for 3 cond.

13.00 – 16.45 G_4 for 3 cond.

Friday 3rd

8.00 – 11.45 G_3 for 3 cond.

13.00 – 16.45 G_4 for 3 cond.

WEEK 3: Monday 6th – Friday 10th November

10 subjects needed for the week. They will be split into two groups of five: G_5 and G_6. These two groups will be required to come together on Monday and Tuesday morning, after which they will be split up and required to come separately at different times. The first group (e.g. G_1) will come to session 1: 8.00-11.45 and the second group (e.g. G_2) to session 2: 13.00-16.45 for the Wednesday, Thursday and Friday sessions.

Briefing: Monday 6th

10.00 – 11.00 G_5 and G_6

Habituation: Monday 6th

11.00 – 12.00 G_5 and G_6

14.00 – 15.00 G_5 and G_6

Tuesday 7th

10.00 – 11.00 G_5 and G_6

NOTE: There is a need for at least three habituation sessions.

Submax Testing: Tuesday 7th

14.00 – 15.00 G_5

15.00 – 16.00 G_6

Testing Sessions: Wednesday 8th

8.00 – 11.45 G_5 for 3 cond.

13.00 – 16.45 G_6 for 3 cond.

Thursday 9th

8.00 – 11.45 G_5 for 3 cond.

13.00 – 16.45 G_6 for 3 cond.

Friday 10th

8.00 – 11.45 G_5 for 3 cond.

13.00 – 16.45 G_6 for 3 cond.

<u>WEEK 4:</u> Monday 13th – Friday 17th November

We will need10 subjects for the week. They will be split into two groups of five: G_7 and G_8. These two groups will be required to come together on Monday and Tuesday morning, after which they will be split up and required to come separately at different times. The first group (e.g. G_1) will come to session 1: 8.00-11.45 and the second group (e.g. G_2) to session 2: 13.00-16.45 for the Wednesday, Thursday and Friday sessions.

Briefing: Monday 13th

10.00 – 11.00 G_7 and G_8

Habituation: Monday 13th

11.00 – 12.00 G_7 and G_8

14.00 – 15.00 G_7 and G_8

Tuesday 14th

10.00 – 11.00 G_7 and G_8

NOTE: There is a need for at least three habituation sessions.

Submax Testing: Tuesday 14th

14.00 – 15.00 G_7

15.00 – 16.00 G_8

Testing Sessions: Wednesday 15th

8.00 – 11.45 G_7 for 3 cond.

13.00 – 16.45 G_8 for 3 cond.

Thursday 16th

8.00 – 11.45 G_7 for 3 cond.

13.00 – 16.45 G_8 for 3 cond.

Friday 17th

8.00 – 11.45 G_7 for 3 cond.

13.00 – 16.45 G_8 for 3 cond.

All 40 subjects would now have finished all nine conditions.

Any subjects that miss a session will be required to come during a fifth week of data collection: 20th – 24th November.

Habituation Schedule

Dates	(10.00- 12.00)	(14.00-15.00)	(10.00-11.00)
	Group	Group	Group
Mon 23rd	G_1; G_2	G_1; G_2	
Tues 24th			G_1; G_2
Mon 30th	G_3; G_4	G_3; G_4	
Tues 31st			G_3; G_4
Mon 6th	G_5; G_6	G_5; G_6	
Tues 7th			G_5; G_6
Mon 13th	G_7; G_8	G_7; G_8	
Tues 14th			G_7; G_8

Data collection schedule

Dates	Session 1 (8.00 – 11.45)	Session 2 (13.00 – 16.45)
	Group	Group
W1 – Wed 25th	G_1	G_2
W1 – Thurs 26th	G_1	G_2
W1 – Fri 27th	G_1	G_2
W2 – Wed 1st	G_3	G_4
W2 – Thurs 2nd	G_3	G_4
W2 – Fri 3rd	G_3	G_4
W3 – Wed 8th	G_5	G_6
W3 – Thurs 9th	G_5	G_6
W3 – Fri 10th	G_5	G_6

W4 – Wed 15th	G_7	G_8
W4 – Thurs 16th	G_7	G_8
W4 – Fri 17th	G_7	G_8

W – week

LETTER TO SUBJECT

Dear ______________

Thank-you for offering to participate as a subject in my Masters research project entitled:

PHYSIOLOGICAL AND PSYCHOPHYSICAL RESPONSES OF MALE SOLDIERS TO CHANGES IN MARCHING GRADIENT, SPEED AND LOAD.

The focus of the present project is to investigate the influence of different combinations of speed, load and gradient on the energy cost of SANDF soldiers.

The main objective is to establish optimal walking speeds to be maintained and loads to be carried during marching, in particular with reference to changes in the gradient of the ground being traversed. The attainment of optimal energy expenditure can then be used to enhance military efficiency.

While there has been extensive research conducted on British and United States troops little work has been published on the South African Troops. This limited information particularly with the recent changes in the demography of the army, identifies an essential need for information relevant to the present SANDF. This research will help establish basic standards and guidelines relative to the manual moving of military material, especially since combat efficiency is affected by numerous factors, with load, speed and gradient being identified as being among the most important.

Foremost you will be medically examined (administered by Army Medical Personnel) to ensure that there are no medical problems associated with your participation in this trial. Prior to data collection all procedures will be explained to you. You will then be required to sign a consent form acknowledging your willingness to participate in the study.

You will be required to come to the Human Kinetics and Ergonomics Department at Rhodes University on seven (7) separate occasions, over the period of a week. The first session will be a briefing session during which time the testing protocol will be explained to you in detail. As all testing will be done in the laboratory on a treadmill, each subject will be required to come in on three occasions to be habituated to treadmill walking. This will familiarize you with the equipment to be used during the data collection. During the third and fourth sessions basic morphological measurements including sex, age, stature, mass and body composition will be collected. Each subject will also undergo a submaximal treadmill test in order to estimate what we call your VO_2 max (a measure of your energy supply). This test requires you to run on the treadmill. Every three minutes speed and gradient will be increased until you reach 85% of your maximum heart rate, which is 220-age, at which time the test will be stopped. This is necessary in order to give us an indication as to what intensity you are working in relation to your ‘maximum’ effort.

The last three sessions involve actual data collection. On each occasion you will be tested three times for a period of six minutes. You will have a face-mask on which will be attached to a machine called the MetaMax. This enables us to analyse the air you breathe in and out to determine how much energy you are expending (how difficult the task is for you physiologically). You will also be fitted with a Polar Heart Rate Monitor, which consists of a belt fitted around your chest, and a watch which gives us your heart rate.

Perceptual data (how you personally feel) will also be collected at various intervals, using psychophysical rating scales called the Rating of Perceived Exertion (RPE) scale and the Body Discomfort scale which will be explained to you in detail.

Following the completion of the data collection, I will gladly discuss your test results with you, should you be interested, as no feedback will be available during the test period. This serves to eliminate competition between subjects and to standardize data collection.

Thank you for showing interest and participation in this research. Please do not hesitate to contact me should you have any further questions.

Yours sincerely

Andrew Todd
(Human Kinetics and Ergonomics Masters Student)

SUBJECT CONSENT FORM

I, ____________________, have been fully informed of the nature of the research entitled: '**Physiological and psychophysical responses of male soldiers to changes in marching speed, load and gradient**', and do hereby give my consent to act as a subject in the above named research.

I am fully aware of the procedures involved as well as the potential risks and benefits attendant to my participation as explained to me verbally and in writing. In agreeing to participate in this research, I waive any legal recourse against the researchers or Rhodes University, from any and all claims resulting from personal injuries sustained. This waiver shall be binding upon my heirs and personal representatives. I realize that it is necessary for me to promptly report to the researcher any signs or symptoms indicating any abnormality or distress.

I am aware that I may withdraw my consent and withdraw from participation in the research at any time. I am aware that my anonymity will be protected at all times, and agree that the information collected may be used and published for statistical or scientific purposes.

I have read the foregoing information sheet and I understand it. Any questions that may have occurred to me have been answered to my satisfaction.

SUBJECT (OR LEGAL REPRESENTATIVE)

_________________   ________________   _________

(Print Name)   (Signature)   (Date)

PERSON ADMINISTERING INFORMED CONSENT

_________________   _________________   ________

(Print Name)   (Signature)   (Date)

PROJECT SUPERVISOR

____________________ ____________________ ___________

(Print Name) (Signature) (Date)

METAMAX PREPARATION

Gas and volume calibration

Connect MetaMax to power source

Place HM transmitter belt and watch on

Connect leads to MetaMax – Ambient Temp

HR

Event marker

Connect gas analysis tube to volume transducer which connects to mask

Connect gas analysis and volume transducer to MetaMax

Place mask on and check no air leakage

APPENDIX B: DATA COLLECTION

RPE Scale

Instructions to Subject for RPE

Body Discomfort Scale

Instructions to Subject for Body Discomfort

Subject Data Sheet

Bruce Protocol Data Sheet

General Data Sheet

UNIVERSAL RPE SCALE

NUMERICAL	*VERBAL*
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	

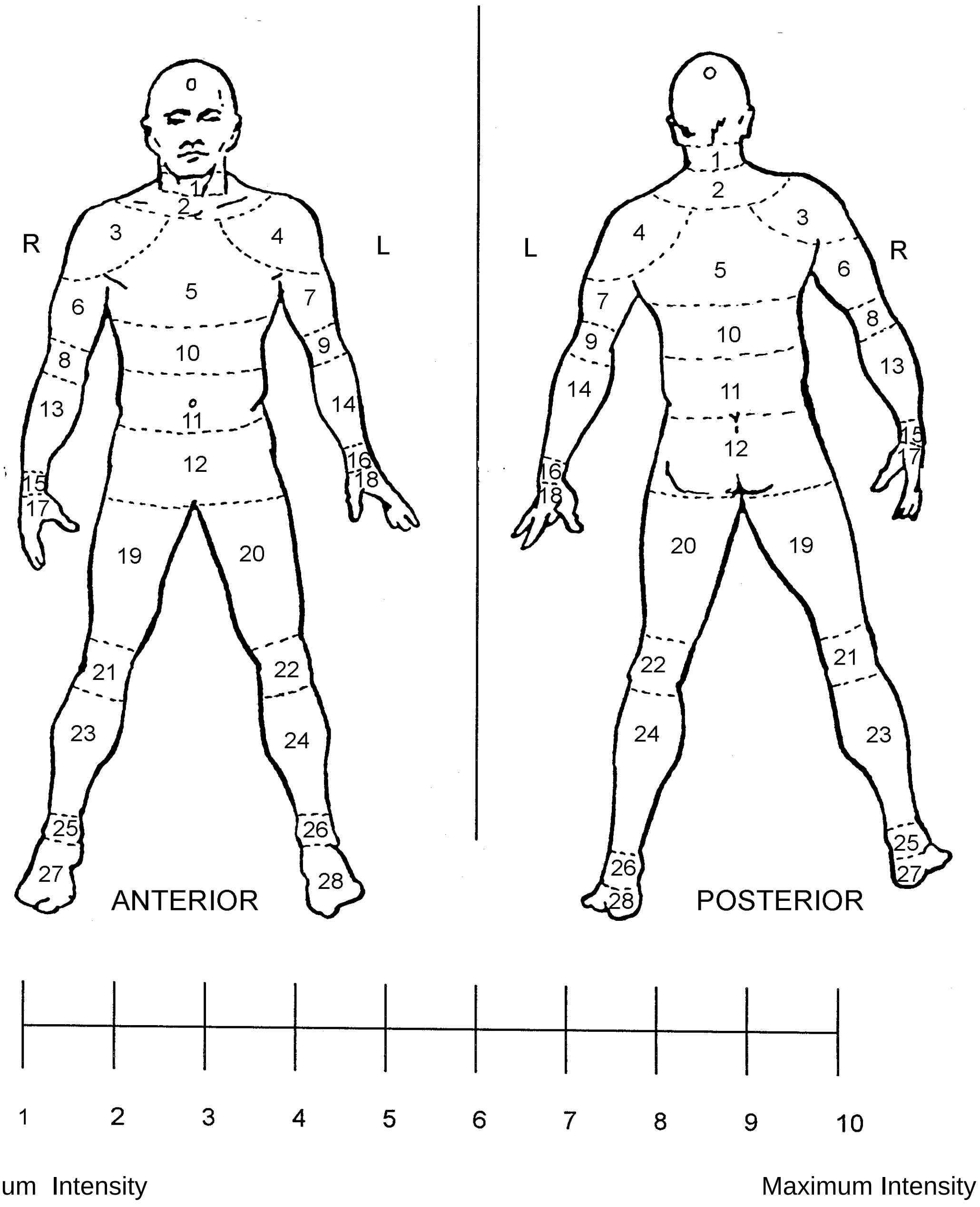
INSTRUCTIONS TO SUBJECT FOR RPE

You will be required to complete 9 different work bouts. You will march with a backpack at different speeds and grades, for six minutes each time while we measure various physiological functions. We also want you to estimate how hard you feel the work is, that is, we want you to rate the degree of perceived exertion you feel. You will be asked to point to a number on the scale presented which corresponds to your rating of perceived exertion. The first will be a “local: muscular rating pertaining to feelings or sensations of strain in the lower limbs. The second rating involves sensations or feelings from the “central” cardiorespiratory system.

Try to estimate as honestly and as objectively as possible. Do not underestimate the degree of exertion you feel, but do not overestimate it either. Try to estimate it as accurately as possible. You will be requested to give ratings of perceived exertion twice during each of the six conditions, at minutes 3 and 5. When asked to rate your work, you should do so by giving the numerical value which indicates your evaluation of your “local” and “central” perceived exertion respectively at that moment. A rating of six (6) corresponds with feelings of exertion while standing quietly, whereas a rating of twenty (20) reflects a maximal exertion.

Corlett and Bishop’s (1976) Body Discomfort Scale.

BODY DISCOMFORT MAP AND RATING SCALE



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

INSTRUCTIONS TO SUBJECT FOR BODY DISCOMFORT

We want you to try and determine the exact location of discomfort or pain experienced during marching. You will be required to point to the site(s) of body discomfort on the body map which has been divided into segments and numbered from 0-27. You will also be asked to rate the intensity of discomfort at each identified site on a ten (10) point scale where one (1) refers to “very comfortable work” and ten (10) refers to an experience of “extreme discomfort”.

Try to estimate as honestly and as objectively as possible. Do not underestimate the degree of discomfort / pain you feel, but do not overestimate it either. Try to estimate it as accurately as possible. You will be requested to identify site(s) of discomfort at the end of each condition. When you are asked to rate your discomfort, you should do so by giving the numerical value which corresponds to the area of your discomfort, and then rate the intensity of discomfort. A rating of one (1) corresponds with “very comfortable work” whereas a rating of ten (10) corresponds with “extreme discomfort”.

SUBJECT DATA SHEET

GENERAL INFORMATION

Name:______________________ Code:______

Age:_____________ (day/ month/ year) Military exp.:______yrs

Injuries:__________ Medication:_______

Group:_____ Face mask size:___

Medical Clearance:______

ANTHROPOMETRIC DATA

Stature:__________mm Leg length:_______mm

Mass:

Minimal Clothing:________kg Uniform:_________kg

Body fat:_________kg Body fat:_________%

LBM:____________kg LBM:____________%

BMI:____________$(kg.m^2)^{-1}$ BMR:____________$kJ.day^{-1}$

Reference Heart rate:__________$bt.min^{-1}$

SUBMAXIMAL TREADMILL TEST – BRUCE PROTOCOL

Name:__________________ Code:______

Age:________yrs Gender:____

Predicted Max HR:_______bt.min^{-1} Body Weight:______kg

85% Max HR:___________bt.min^{-1}

Stage	Minute	Speed (km.h^{-1})	Grade (%)	Central RPE	Local RPE	Heart rate	Comments
1	3	2.7	10				
2	6	4	12				
3	9	5.4	14				
4	12	6.7	16				
5	15	8	18				
6	18	8.8	20				

Changeover to running:_________km.h^{-1}

Distance Covered:_______m

Total Calories:___________kcal

Comments:____

____

____

DATA COLLECTION SHEET

Name:____________ Code:______

Session:____

MetaMax Code:__________

Condition:_________ Speed:_____ Load:_______ Grade:_____

Variable	**Start**	**Min 2-3**	**Min 5-6**	Post
Heart rate*				
Central RPE*				
Local RPE*				
Cadence				

* last 15s

Body Discomfort:

Site	**Rating**

Comments:____

____

- -

Session:____

MetaMax Code:__________

Condition:_________ Speed:_____ Load:_______ Grade:_____

Variable	**Start**	**Min 2-3**	**Min 5-6**	Post
Heart rate*				
Central RPE*				
Local RPE*				
Cadence				

* last 15s

Body Discomfort:

Site	Rating

Comments:____

____

DATA COLLECTION SHEET 2

Session:____

MetaMax Code:__________

Condition:_________ Speed:_____ Load:_______ Grade:______

Variable	**Start**	**Min 2-3**	**Min 5-6**	Post
Heart rate*				
Central RPE*				
Local RPE*				
Cadence				

* last 15s

Body Discomfort:

Site	Rating

Comments:____

____

- -

Session:____

MetaMax Code:__________

Condition:_________ Speed:_____ Load:_______ Grade:______

Variable	**Start**	**Min 2-3**	**Min 5-6**	Post
Heart rate*				
Central RPE*				
Local RPE*				
Cadence				

* last 15s

Body Discomfort:

Site	Rating

Comments:____

____

DATA COLLECTION SHEET 3

Session:____

MetaMax Code:__________

Condition:_________ Speed:_____ Load:_______ Grade:______

Variable	Start	Min 2-3	Min 5-6	Post
Heart rate*				
Central RPE*				
Local RPE*				
Cadence				

* last 15s

Body Discomfort:

Site	Rating

Comments:____

____

- -

Session:____
MetaMax Code:__________
Condition:_________ Speed:_____ Load:_______ Grade:______

Variable	Start	Min 2-3	Min 5-6	Post
Heart rate*				
Central RPE*				
Local RPE*				
Cadence				

* last 15s

Body Discomfort:

Site	Rating

Comments:____

DATA COLLECTION SHEET 4

Session:____

MetaMax Code:__________

Condition:_________ Speed:_____ Load:_______ Grade:______

Variable	Start	Min 2-3	Min 5-6	Post
Heart rate*				
Central RPE*				
Local RPE*				
Cadence				

* last 15s

Body Discomfort:

Site	Rating

Comments:____

Session:____

MetaMax Code:__________

Condition:_________ Speed:_____ Load:_______ Grade:______

Variable	Start	Min 2-3	Min 5-6	Post
Heart rate*				
Central RPE*				
Local RPE*				
Cadence				

* last 15s

Body Discomfort:

Site	Rating

Comments:____

DATA COLLECTION SHEET 5

Session:____

MetaMax Code:_________

Condition:________ Speed:_____ Load:______ Grade:_____

Variable	**Start**	**Min 2-3**	**Min 5-6**	Post
Heart rate*				
Central RPE*				
Local RPE*				
Cadence				

* last 15s

Body Discomfort:

Site	Rating

Comments:____

APPENDIX C: RESULTS

Physiological Formulae and Variables

Polar Heart Rate Monitor Print-out

MetaMax Report

Statistics

PHYSIOLOGICAL FORMULAE AND VARIABLES

Age Predicted Maximum Heart Rate (HR_{max}) in $bt.min^{-1}$:

$$HR_{max} = 220 - \text{age (year)}$$

Heart Rate in $bt.min^{-1}$:

The number of times per minute that the heart beats

Breathing Frequency (Br) in $br.min^{-1}$:

Amount of breaths per minute

Tidal Volume (V_T) in $l.br^{-1}$:

The amount of air moved in and out of the lungs with each normal breath and is approximately 0.5 L at rest in a young adult male.

Minute Ventilation (V_E) in $L.min^{-1}$:

The amount of air breathed in every minute, thus is a function of breathing rate and tidal volume.

$$V_E = \text{Breathing frequency} \times \text{Tidal volume}$$

Oxygen Consumption (VO_2) in $ml.kg^{-1}.min^{-1}$:

The amount of oxygen consumed by the body each minute.

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

Respiratory Exchange Ratio (R):

$R = VCO_2 \div VO_2$

Standard Deviation (SD):

68% of score in a normal distribution fall within 1SD of the mean.

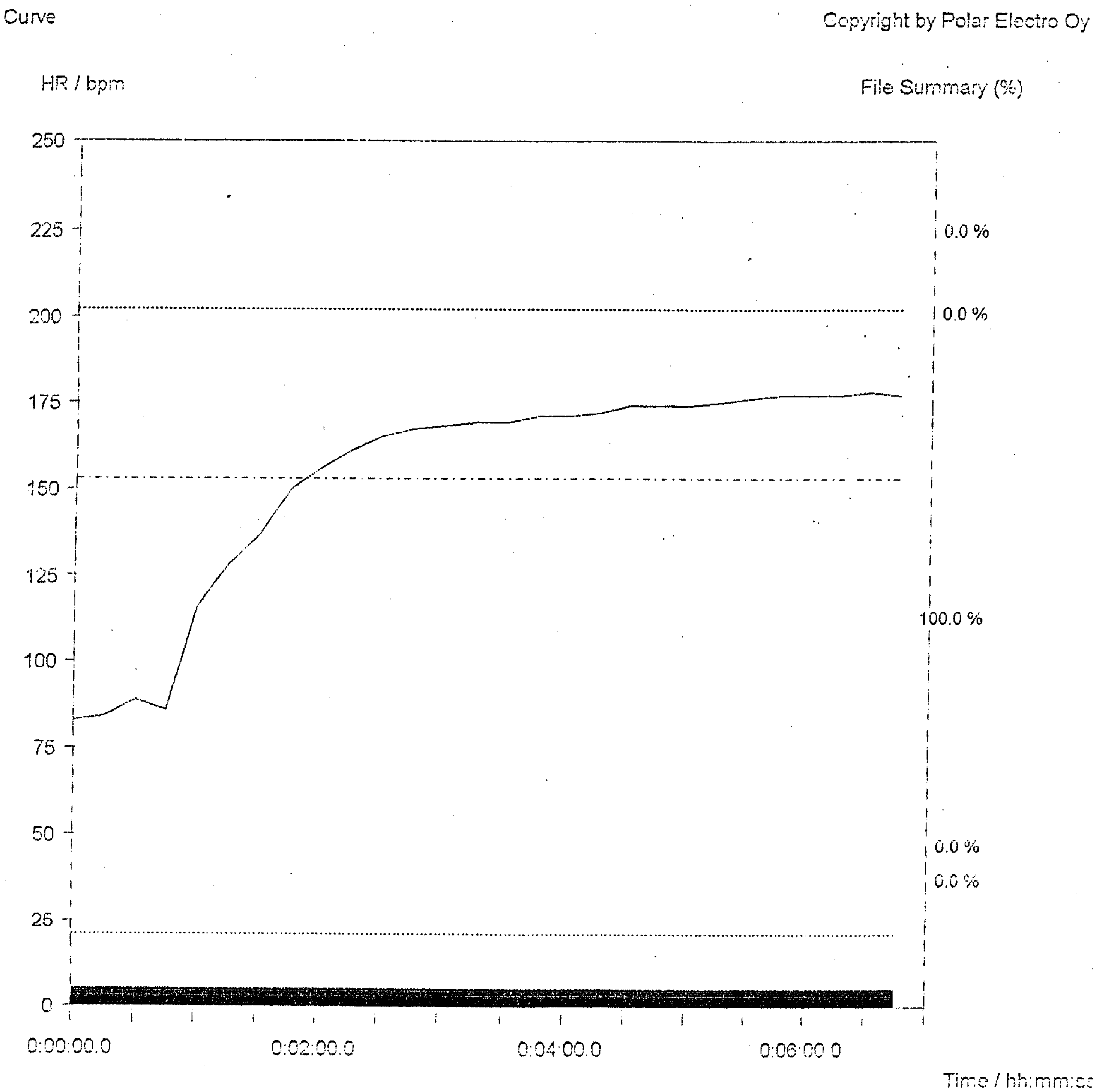
Energy Expenditure (EE):

VO_2 (L.min^{-1}) $\times$ 20.1 = EE (kJ.min^{-1})

kJ.min^{-1} $\div$ 4.186 = EE (kcal.min^{-1})

kcal.min^{-1} $\div$ 0.01433 = power output (W)

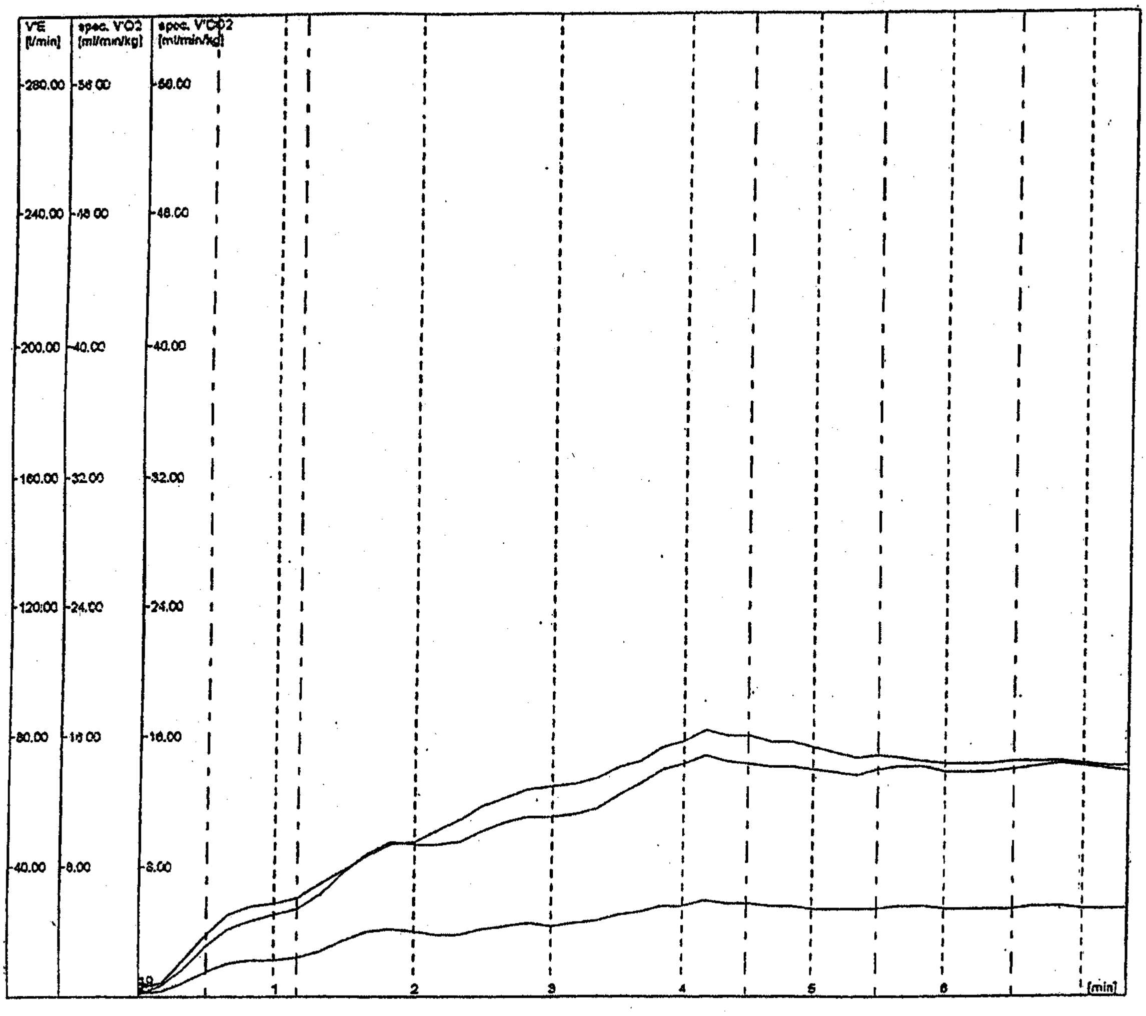
POLAR HEART RATE MONITOR PRINT-OUT

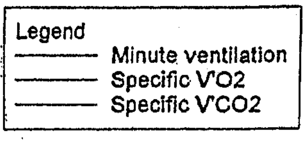


METAMAX REPORT

Example print-out from the on-line metabolic system, the Metamax.

CORTEX GmbH





STATISTICS - DESCRIPTIVE STATISTICS

02/23/01 02:53:09 PM Page

Variable:	VE23 Select (gra	VE56 Select (gra	VT Select (grad
Sample size	32	32	32
Average	38.3881	41.4731	1.13781
Median	38.245	40.365	1.13
Mode	42.81	39.87	1.04
Geometric mean	37.0879	40.6967	1.11885
Variance	71.3512	62.5682	0.0442112
Standard deviation	8.44696	7.91	0.210265
Standard error	1.49323	1.3983	0.0371699
Minimum	10.06	20.84	0.77
Maximum	52.29	59.5	1.54
Range	42.23	38.66	0.77
Lower quartile	34.54	36.99	0.975
Upper quartile	43.35	45.8	1.315
Interquartile range	8.81	8.81	0.34
Skewness	-1.26683	8.2449E-3	0.159234
Standardized skewness	-2.92562	0.0190408	0.367734
Kurtosis	3.11043	0.690628	-0.886526
Standardized kurtosis	3.59162	0.797468	-1.02367
Coeff. of variation	22.0041	19.0726	18.4797
Sum	1228.42	1327.14	36.41

Variable:	VT56 Select (gra
Sample size	32
Average	1.11656
Median	1.105
Mode	1.24
Geometric mean	1.09769
Variance	0.0435975
Standard deviation	0.2088
Standard error	0.036911
Minimum	0.82
Maximum	1.54
Range	0.72
Lower quartile	0.965
Upper quartile	1.29
Interquartile range	0.325
Skewness	0.215164
Standardized skewness	0.4969
Kurtosis	-1.06474
Standardized kurtosis	-1.22945
Coeff. of variation	18.7003
Sum	35.73

STATISTICS - ANOVA

ANOVA TABLE showing the interaction of the nine experimental conditions using a Multifactor ANOVA ($p<0.05$)

Variable		SS	df	MS	F-ratio	Sig. Level
Heart Rate	Between	169499.48	8	21187.435	106.922	.0000
	Within	55087.81	278	198.15759		
VO_2	Between	27398.838	8	3424.8548	222.708	.0000
	Within	4275.1532	278	15.378249		
R	Between	0.8508543	8	0.1063568	31.843	.0000
	Within	0.9285444	278	0.0033401		
Br	Between	5413.7594	8	676.71992	5.756	.0000
	Within	32681.682	278	117.56002		
V_E	Between	81413.893	8	10176.737	110.957	.0000
	Within	25497.67	278	91.718236		
V_T	Between	30.97063	8	3.8713288	76.85	.0000
	Within	14.004216	278	0.0503749		
Cadence	Between	6485.8905	8	810.73631	17.307	.0000
	Within	13022.96	278	46.845179		
Local RPE	Between	739.50684	8	92.438355	31.02	.0000
	Within	828.43044	278	2.9799656		
Central RPE	Between	697.32317	8	87.165397	32.5	.0000
	Within	745.58972	278	2.6819774		