PHYSIOLOGICAL AND PERCEPTUAL RESPONSES OF SANDF PERSONNEL TO VARYING COMBINATIONS OF MARCHING SPEED AND BACKPACK LOAD

BY

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ABSTRACT

The objective of the present study was to establish effective combinations of marching speed and backpack load in order to meet specific military requirements.

Thirty infantrymen from the South African National Defence Force (SANDF) comprised the sample and experimental procedures were conducted in a laboratory setting using a Cybex Trotter treadmill. Sixteen conditions were set up which included combinations of four speeds (3.5, 4.5, 5.5, and 6.5 $km.h^{-1}$) and four backpack loads (20, 35, 50, and 65kg). Each subject was required to complete 8 of the sixteen conditions, each consisting of a six-minute treadmill march. Physiological data (heart rate, ventilation and metabolic responses), kinematic gait responses (step-rate and stride length) and perceptions of exertion ("Central" and "Local" RPE) were collected during the third and sixth minutes of the treadmill march and areas of body discomfort were identified post-march.

Responses revealed five distinct categories of exertional strain. Three marches constituted "nominal" (below 40% $VO_{2\ max}$) and three "excessive" strain (above 75% $VO_{2\ max}$). These represent combinations of extreme military demands and are highly unlikely to be utilised by the military. Three "tolerable" levels of required effort were recommended and these 10 combinations were further divided into three sub-categories. The "moderate" stress marches were identified as "ideal" for prolonged marches and had statistically similar responses of working heart rates (range of 118 $bt.min^{-1}$ to 127 $bt.min^{-1}$), energy expenditure (26 $kJ.min^{-1}$ and 27 $kJ.min^{-1}$) and ratings of perceived exertion ("Central" ratings of 10 and 11). Thus, marching at 5.5 $km.h^{-1}$ with 20kg, 4.5 $km.h^{-1}$ with 35kg or 3.5 $km.h^{-1}$ with 50kg all require a similar energy cost. Four "heavy" category marches were identified for possible use when the duration of the march is reduced. During these marches responses were statistically similar with heart rates ranging from 127 $bt.min^{-1}$ to 137 $bt.min^{-1}$, energy expenditure from

32 $kJ.min^{-1}$ to 37 $kJ.min^{-1}$ and “Central” ratings of perceived exertion were 12 and 13. When short, high intensity marches are necessary, then combinations from the “very heavy” category may be utilised but with caution. During these marches, soldiers were taxed between 65% and 75% of $VO_{2\ max}$.

The results of this study clearly demonstrate that the interplay between speed and load needs to be adjusted when determining “ideal” combinations for specific military demands. Essentially, if speed is of the essence then load must be reduced, and if heavy loads need to be transported then speed must be reduced.

DEDICATION

I dedicate this thesis to my parents Malcolm and Carole Christie for their unconditional love, support and constant faith in my ability.

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CHAPTER I

INTRODUCTION

BACKGROUND TO THE STUDY

It is well documented that the combined demands of marching speed and backpack weight will affect the energy cost of marching (Hughes and Goldman, 1970; Patton **et al.**, 1991; Scott and Christie, 2000). However, as minimal energy expenditure per unit of distance moved is a primary objective of any military march, extensive research is ongoing (Knapik **et al.**, 1996; Quesada **et al.**, 2000). Furthermore, due to the many compounding factors that need to be considered, the establishment of effective combinations of speed and load for diverse operational conditions remains an enigma. Rigorous investigation is therefore needed to determine optimal speed and load combinations; for there are occasions when speed is the primary objective and others when considerable loads need to be transported.

The overall objective within any army situation is to ensure that the effects of fatigue are minimal and that on completion of a march critical military tasks can be executed with precision. Several authors have suggested that in order to attain this, the combined demands of marching speed and load weight should not exceed 30-45% of maximal oxygen consumption (Astrand, 1967; Saha **et al.**, 1979; Haisman, 1988). However, the relative combinations of speed and load, which ensure this level is maintained, are not well established. In addition there is disparity in the literature regarding the optimal walking speed. Hughes and Goldman (1970) and more recently McArdle **et al.** (1996)

suggest a linear relationship between speed and energy cost from 3 $km.h^{-1}$ to 5 $km.h^{-1}$. In contrast, Soule **et al.** (1978) showed a curvilinear relationship between these two variables and identified 4 $km.h^{-1}$ as the speed at which energy cost is minimal. It is generally accepted however, that depending on the weight of the load to be carried the optimal speed should be shifted. Hence the 4 $km.h^{-1}$ proposed by Soule **et al.** (1978) might be considered too slow when lighter loads are being transported, resulting in sub-optimal efficiency of a soldier. Furthermore, several investigations have suggested that speed imparts a greater influence on energy cost than load (Hughes and Goldman, 1970; Soule **et al.**, 1978; Charteris **et al.**, 1989). This indication of the greater impact of speed on energy expenditure was further emphasised by the identification of an "energetic free ride" with head-loads up to 20% of body weight (Maloiy **et al.**, 1986; Charteris **et al.**, 1989). When the primary aim is to reduce the energetic cost of a march it appears that marching speed needs to be carefully selected and then the mass of the load manipulated depending on the requirements of the march.

Studies have shown that load weight should not exceed 30% (Legg, 1985; Haisman, 1988; Knapik, 1989) to 40% of body mass (Carthcart **et al.**, 1923) in order to lessen the effects of fatigue. A problem in military operations, and of particular concern to researchers, is that soldiers are often required to carry the same absolute load regardless of differences in stature and mass. In the South African situation this is particularly evident with soldiers of either sex being required to carry similar loads which at times can amount to 60 or more kilograms. Carrying these increasingly heavier loads will disproportionately increase energy cost, ultimately resulting in premature fatigue and a decrease in combat efficiency. When excessive walking speeds are then imposed the result is greater mechanical, physiological and psychophysical strain, which further increases energy cost and hence hastens the onset of fatigue.

Recent research by Quesada **et al.** (2000) has found that a speed of 6 $km.h^{-1}$ can be maintained if load does not exceed 30% of body mass. Other studies have reported that speeds of 6 $km.h^{-1}$ and higher are unacceptable and will result in a disproportionate increase in energy cost (Hughes and Goldman, 1970; Soule **et al.**, 1978; Charteris **et al.**, 1989). This apparent contrast in findings may be due to several factors, one of which is that the load carried by the soldiers in the Quesada **et al.** (2000) study was not excessive thereby enabling a higher walking speed to be employed. Another factor to consider is that not all military tasks require prolonged marching and in such situations the intensity of the demand could be increased. An important consideration therefore is that if the mission requires a high walking speed, duration and load need to be reduced. This notion, proposed by Knapik in 1989, suggested that the optimal range of 30-45% of $VO_{2\ max}$ could be shifted if load and distance are reduced. Knapik (1989) suggests that an intensity of 60% of $VO_{2\ max}$ can be tolerated if high speeds are required, but over shorter distances and with lighter loads. Furthermore slower walking speeds can be selected if longer duration marches are needed or when heavier loads are being transported. Myles and Saunders (1979) reported that when individuals select their own pace they automatically adjust intensity from 37% $VO_{2\ max}$ on the first day to 32% on subsequent days when distance is the primary objective.

Due to problems associated with collecting data on extended marches, the formulation of prediction equations has enabled researchers to predict long-term energy cost from short-term studies. Redfearn **et al.** (1956) produced an equation which best described marching with loads on level ground and since then numerous other researchers have added to this equation (Givoni and Goldman, 1971; Pandolf **et al.**, 1977). Some studies suggest that these prediction equations underestimate long term energy cost and do not take into consideration that energy cost appears to increase over time (Epstein **et al.**, 1988; Patton **et al.**, 1991).

The South African situation is unique in that political transformation during the early 1990's has resulted in a considerable shift in the morphological and cultural make-up of the personnel in the South African National Defence Force (SANDF). Although extensive research has been conducted on the US military (Soule **et al.**, 1978; Knapik, 1989; Quesada **et al.**, 2000), little is known about South African soldiers. While identification of optimal speeds and loads is a universal problem, these combinations need to be relevant to the South African soldier. It is important therefore to take cognisance of the fact that although a platoon marches as a unit, within it there may be diversity of ethnic groups and individual differences in physical, as well as psychological variables. This variability must be acknowledged when selecting speeds and loads in order to reduce differential stress on individuals. The principle of relativizing backpack weight according to the physical make-up of the soldiers was thus established (Cathcart **et al.**, 1923; Scott and Ramabhai, 2000). Although relativizing speeds and loads is considered to be 'ideal', it is often impractical particularly as certain essential items of military equipment need to be transported by a platoon which is required to operate as a single unit.

While physical and physiological factors have been identified as key issues, there appears to be limited literature on psychophysical responses to military marches. Increasing recognition of the importance of the human element has identified that individual perceptions of a task play a substantial role on the ability to adapt to a situation (Borg, 1970; Scott, 1986). The Rating of Perceived Exertion (RPE) Scale (Borg, 1971) and the Body Discomfort Scale (Corlett and Bishop, 1976) are both effective psychophysical measures which were utilised in the present study to establish a measure of perceptual responses to the imposed physical demands. These were then integrated with the physiological responses in order to attain a holistic understanding of soldiers' responses under military conditions.

It is thus apparent that the cost of marching is dependent on a number of factors including those which cannot be altered such as sex, cultural differences and morphological differences, and those which can be manipulated, including the individuals training status, the speed of the march, the load to be carried and the distance to be covered. Recognising the many influences which impact on a soldier's performance, this investigation utilised the "Centre-M: Human Kinetic" model proposed by Charteris **et al.** (1976). Four broad domains serve as the cornerstones of this model, including the physical, biological and psychophysical perspectives of human movement.

The final domain, of a conceptual nature, emphasises the need for a holistic, interdisciplinary approach, and this served as the basic paradigm for the present project.

STATEMENT OF THE PROBLEM

The determination of the physiological and perceptual costs of different speed and load combinations is essential to ensure fatigue is reduced and combat efficiency optimised. However, few guidelines exist for ideal combinations of marching speed and backpack weight, which require adjustment according to military requirements. In addition, limited research has focused on the current SANDF whose personnel differ considerably from that of the US military where much of the research has been conducted. Therefore, the main focus of this investigation was to address the problem of speed and load combinations for backpack-loaded marching to ensure optimal military performance within the South African setting. Assessments of morphology, energy cost and perceptual responses ensured a holistic integrated approach.

RESEARCH HYPOTHESIS

It is expected that the cardiovascular, respiratory and metabolic responses under investigation will be affected by changes in combinations of speed and load.

It is further expected that perceptual responses of ratings of perceived exertion and body discomfort will be altered by conditions of incremented speed and load.

A further expectation is that the kinematic variables investigated, viz. stride length and cadence will be affected by changes in speed and load combinations.

STATISTICAL HYPOTHESIS

1. The null hypothesis proposed is that physiological responses remain unchanged with increments in speed and load.

(a) Ho: $\mu\ C_{(A)} = \mu\ C_{(B)} = \mu\ C_{(C)} = \ldots\ldots\ldots\ldots\mu\ C_{(P)}$

Ha: $\mu\ C_{(A)} \neq \mu\ C_{(B)} \neq \mu\ C_{(C)} \neq \ldots\ldots\ldots\ldots\mu\ C_{(P)}$

(b) Ho: $\mu\ R_{(A)} = \mu\ R_{(B)} = \mu\ R_{(C)} = \ldots\ldots\ldots\ldots\mu\ R_{(P)}$

Ha: $\mu\ R_{(A)} \neq \mu\ R_{(B)} \neq \mu\ R_{(C)} \neq \ldots\ldots\ldots\ldots\mu\ R_{(P)}$

(c) Ho: $\mu\ M_{(A)} = \mu\ M_{(B)} = \mu\ M_{(C)} = \ldots\ldots\ldots\ldots\ \mu\ M_{(P)}$

Ha: $\mu\ M_{(A)} \neq \mu\ M_{(B)} \neq \mu\ M_{(C)} \neq \ldots\ldots\ldots\ldots\mu\ M_{(P)}$

2. The second null hypothesis proposed is that the perceptual responses remain unaffected by changes in combinations of speed and load.

Ho: $\mu\ RPE_{(A)} = \mu\ RPE_{(B)} = \mu\ RPE_{(C)} = \ldots\ldots\ldots\ldots\mu\ RPE_{(P)}$

Ha: $\mu\ RPE_{(A)} \neq \mu\ RPE_{(B)} \neq \mu\ RPE_{(C)} \neq \ldots\ldots\ldots\ldots\mu\ RPE_{(P)}$

3. The last null hypothesis states that kinematic responses remain the same with increases in speed and load.

Ho: $\mu\ K_{(A)} = \mu\ K_{(B)} = \mu\ K_{(C)} = \ldots\ldots\ldots\ldots\mu\ K_{(P)}$

Ha: $\mu\ K_{(A)} \neq \mu\ K_{(B)} \neq \mu\ K_{(C)} \neq \ldots\ldots\ldots\ldots\mu\ K_{(P)}$

Where:

- C = Cardiac responses (HR).
- R = Respiratory responses including F_B; V_T; V_E.
- M = Metabolic responses including VO_2; VCO_2; R; kcal; kJ.
- RPE = Ratings of Perceived Exertion (“Central” and “Local”).
- K = Kinematic responses including cadence and stride length.
- (A); (B); (C)…………(P) are the 16 pre-set combinations of speed and load specified on p 54 (Chapter III).

DELIMITATIONS

This study was delimited to 30 male SANDF infantry foot soldiers with an average of 7 years military experience ranging in age from 24 to 35 years. The prime focus of the project was the investigation of the energy cost of marching at different speeds while carrying varying loads. After discussions with army personnel four speeds, between 3.5 $km.h^{-1}$ and 6.5 $km.h^{-1}$, and four loads, between 20kg and 65kg were selected; this resulted in 16 combinations of speed and load.

Dependent variables examined included selected cardiovascular, respiratory, metabolic, kinematic and perceptual data, all relevant to the assessment of the energy cost of backback-loaded military marching. All data were collected during level-gradient, speed-controlled treadmill walking under laboratory conditions.

LIMITATIONS

Due to limited troop numbers at the local infantry base, subjects were not randomly selected. They were, however, taken from different companies within the military base in order to obtain a broad spectrum of potential subjects.

Although subjects were requested to maintain habitual dietary intakes and exercise habits for the duration of the experimental trial, there was no control over these external influences. However, for the duration of testing subjects were not permitted to eat or drink anything other than water.

CHAPTER II

REVIEW OF RELATED LITERATURE

INTRODUCTION

The physically taxing nature of marching raises several issues typically associated with any physically demanding locomotor activity, the key factors being the metabolic cost of the speed of the activity and the load carried, plus the relationship between the two. That soldiers are required to be "combat-ready" on completion of a march emphasises the importance of identifying optimal combinations of speed and load.

Reports suggest that with an increase in backpack load there is an associated increase in heart rate, oxygen uptake and pulmonary ventilation (Borghols **et al.**, 1978; Bobet and Norman, 1984). However, in respect of the relationship between speed and load, results have shown that increases in speed impart the greatest influence on energy cost (Soule **et al.**, 1978; Charteris **et al.**, 1989). This may be associated with the findings of Maloiy and associates who, in 1986, first proposed the "free ride" hypothesis which proposed that increments in load up to about 20% of body mass are carried with no rise in energy cost above unloaded walking. In addition, a recent investigation by Quesada **et al.** (2000) showed that even perceptual responses remain unchanged for loads up of to 15% of body mass. Although the study by Maloiy **et al.** (1986) was conducted on head-loaders, other authors have also reported no significant increases in metabolic cost with loads up to 30kg (Bobbert, 1960; Goldman and Iampietro, 1962; Soule **et al.**, 1978). However, Soule **et al.** (1978) do argue that with increasingly heavy loads, energy cost will increase regardless of speed.

When situations require fast walking speeds and heavy backpack loads there is a disproportionate increase in energy cost (Hughes and Goldman, 1970). Soule **et al.** (1978) showed that when a high speed (6.4 $km.h^{-1}$) and load (70kg) were combined, subjects were working at 90% of their maximal oxygen consumption. Numerous studies have identified the optimal range, in terms of energy cost, to be 30-45% of $VO_{2\ max}$ particularly under conditions of prolonged load carriage (Bink, 1962; Astrand, 1967; Saha **et al.**, 1979; Haisman, 1988). This range ensures that soldiers will not fatigue prematurely and therefore be combat-ready on completion of marching.

Although the military do adapt marching speed and load mass under various conditions, few of these adjustments have been thoroughly researched. Despite considerable literature on marching speed, load placement and load weight, little account has been taken of the actual requirements of the military task and hence of the relationship between these two key components. A further problem is the limited data-base on South African armed forces; hence the importance of the present investigation.

SPEED OF WALKING

ENERGY COST OF WALKING

The efficiency of human locomotion varies as a function of walking speed. As speed of walking increases more myofibrils are recruited which demands increased amounts of energy and a greater oxygen supply reflected as increased oxygen consumption. Oxygen consumption rises rapidly during the first few minutes of submaximal exertion and plateaus around the third or fourth minute (McArdle **et al.**, 1996). This plateau in the oxygen consumption curve is referred to as "steady-state" and some propose that once this steady-state is achieved an individual can go on indefinitely (Sagiv **et al.**, 1994). Contrary findings suggest energy cost will continue to increase over time (Epstein **et al.**, 1988; Patton **et al.**, 1991).

Most people reach steady-state below 50-60% $VO_{2\ max}$ after which oxygen consumption continues to rise (Casaburi **et al.**, 1987; Epstein **et al.**, 1988; McArdle **et al.**, 1996). In terms of marching therefore, attainment of steady-state is essential when soldiers are required to undergo long duration marches. Numerous studies have erred on the side of caution, suggesting that VO_2 not exceed 30-45% of maximal oxygen consumption in order to lessen the effects of fatigue during prolonged load carriage (Astrand, 1967; Myles and Saunders, 1979; Saha **et al.**, 1979;). At times, however, prolonged marches may not be necessary and therefore this optimal intensity could be shifted to a higher level. Knapik (1989) suggested that this level be shifted to 60% of $VO_{2\ max}$ if short duration, high intensity marching is required. However, the findings of Soule **et al.** (1978) suggest that if speed is maintained at 6.4 $km.h^{-1}$, with no load being carried, soldiers are already working at 40% of $VO_{2\ max}$. In this same study loads up to 50kg were tolerated when walking speed was 3.2 $km.h^{-1}$. Therefore, although many argue that speed has a greater influence on energy cost, it is clear that both speed and load need to be manipulated in order to ensure that the soldier is not being excessively strained. In addition, the optimal speed of 4 $km.h^{-1}$, suggested by many authors (Cathcart **et al.**, 1920; Soule **et al.**, 1978; Bunc and Dlouha, 1997), may need to be adjusted depending upon the loads transported.

Slow Walking Speeds

Although the relationship between walking speed and oxygen consumption has been studied extensively, the results are equivocal. McArdle **et al.** (1996) report that the relationship is approximately linear between speeds of 3 $km.h^{-1}$ and 5 $km.h^{-1}$. In contrast, as early as 1979, Pimental and Pandolf demonstrated that as speed increases up to 2.8 $km.h^{-1}$ there is an increase in energy expenditure, but that thereafter energy expenditure decreases to an optimal at 4 $km.h^{-1}$; a theory which is supported by many authors including Cathcart **et al.** (1920), Soule **et al.** (1978) and Bunc and Dlouha (1997). In addition higher speeds, above this optimum, result in further increases in energy cost (Hughes and Goldman, 1970; Soule **et al.**, 1978; Charteris **et al.**, 1989). This is in accordance with Goslin (1985) who reported an exponential relationship between VO_2 and walking speed relative to stature ($st.s^{-1}$), but showed an essentially linear relationship with running.

Duff-Raffaele **et al.** (1996) provided a rationale for the increase in energy cost at slower speeds. They suggest that the total energy cost can be accounted for by changes in the potential and kinetic energies, and internal muscular work. They demonstrated that the metabolic energy cost of changing the potential energy of the centre of mass (CM) during walking is significantly less relative to the total energy consumption at slower speeds. Internal muscular work must therefore play a key role in the total energy cost at slow speeds.

Optimal Walking Speed

The optimal walking speed can be defined as the speed at which energy cost is at its minimum. This does not take into consideration the addition of an external load or the duration of the task. Soule **et al.** (1978), working specifically with the military, have shown that the optimal speed is approximately 4 $km.h^{-1}$. These authors reported that slower speeds result in a higher energy cost, a finding supported by a more recent study by Bunc and Dlouha (1997).

As soldiers rarely march without loads, a compromise needs to be obtained between speed and load if the goal is to minimise unnecessary strain. The optimal intensity, in terms of oxygen uptake, has therefore been identified in the range of 30-45% $VO_{2\ max}$ (Astrand, 1967; Myles and Saunders, 1979; Saha **et al.**, 1979). The manipulation of walking speed and backpack weight, in order to achieve this optimal intensity, could therefore yield several ideal speeds, but will be dependent on the load required to be carried. Thus, although 4 $km.h^{-1}$ may be the ideal speed on level ground with no load imposed, some authors have argued that the optimal speed can vary between 4 $km.h^{-1}$ to 5 $km.h^{-1}$ providing the load is not excessive (Epstein **et al.**, 1988; Patton **et al.**, 1991). Although reports have also claimed that for prolonged load carriage while walking at 5 $km.h^{-1}$ to 6 $km.h^{-1}$, oxygen uptake is in the range of 30-45% of maximum, the loads transported were lighter in order to accommodate the increase in speed (Goslin and

Rorke, 1986; Haisman, 1988; Patton **et al.**, 1991; Quesada **et al.**, 2000). Taking cognisance of previous work in the area, the speeds selected for the present investigation ranged from 3.5 $km.h^{-1}$ to 6.5 $km.h^{-1}$ to include slow and fast acceptable speeds while at the same time to ensure that the broad “optimal range” was accommodated.

Faster Walking Speeds

Soule **et al.** (1978) demonstrated that increasing speed from 3.2 $km.h^{-1}$ to 6.4 $km.h^{-1}$ results in a significant increase in energy cost, doubling between the slowest and fastest speeds. These authors further reported that the cost of carrying 35kg at a speed of 6.4 $km.h^{-1}$ corresponded to a level of 73% $VO_{2\ max}$ which is contrary to a recent investigation by Quesada **et al.** (2000). These latter authors found that when soldiers marched at a similar speed (6 $km.h^{-1}$) and with a lighter load (24kg), subjects were only working at 41% of $VO_{2\ max}$.

Interestingly these different responses are from studies conducted on US troops of very similar morphologies, where the only difference between the Soule **et al.** (1978) and Quesada **et al.** (2000) soldiers was their maximal oxygen consumption values. The soldiers in the Quesada **et al.** (2000) study were in a better cardiovascular condition than those in the Soule **et al.** (1978) study (58 $ml.kg^{-1}.min^{-1}$ and 47 $ml.kg^{-1}.min^{-1}$ respectively) and this must be one explanation for the substantial differences in responses to similar workloads. Nevertheless it does seem unlikely that a single factor could result in a difference of 32% in VO_2 with only an additional 11kg in load, and therefore numerous other factors must have played a role. A likely explanation could be that the higher load (50% body mass) carried by the soldiers in the Soule **et al.** (1978) study surpassed the "energetic free ride" proposed by Maloiy **et al.** (1986). In contrast, the soldiers in the Quesada **et al.** (2000) study were carrying only 30% of their body weight which is within the 'no cost' range suggested by Charteris **et al.** (1989).

WALK TO RUN INTERFACE

Research has indicated that the crossover point from walking to running is dependent on factors such as stature and leg length. As step frequency increases, the double support phase disappears causing the transition from walking to running (Zatsiorky **et al.**, 1994). In their study this transition was found to occur at 6.91 $km.h^{-1}$, although earlier Givoni and Goldman (1971) report that this crossover point does not occur at any one particular speed, but is dependent on stature. Taller individuals will be able to continue walking at a higher speed than shorter individuals, mainly due to differences in morphology, in particular leg length.

The maximum speed (6.4 $km.h^{-1}$) employed by Soule **et al.** (1978) was close to the speed at which running becomes more economical than walking. It therefore could have been more economical for their subjects to start running, which might explain the high metabolic cost of that speed/load combination. The highest speed selected in the present study was 6.5 $km.h^{-1}$, a speed similar to the highest speed used in the Soule **et al.** (1978) study.

Work conducted since 1950 supports the concept of an almost linear relationship between running speed and oxygen uptake. This linear relationship appears to hold during submaximal running where energy demands are met aerobically. However there is a point at which an individual can no longer continue and where oxygen consumption is likely to be maximal.

MAXIMAL OXYGEN CONSUMPTION ($VO_{2\ max}$)

Maximal oxygen consumption ($VO_{2\ max}$) is a measure of the highest rate at which oxygen can be consumed by an individual during exertion at sea level, and is a reflection of the maximum rate of whole body oxygen-dependent adenosine triphosphate (ATP) formation. Measurement of $VO_{2\ max}$ is common in work physiology studies and is frequently used to indicate an individual's cardio-respiratory training status. There is a considerable amount of literature on this topic and a great deal of interest has been shown in attempting to identify the physiological factors that limit maximal oxygen consumption (Noakes, 1988; Basset and Howley, 2000; Bergh **et al.**, 2000).

In the 1920's Hill and colleagues concluded that for running, oxygen requirements increase continuously as speed increases, attaining the highest values at the highest speeds. Once this maximum had occurred, no further increases in oxygen uptake would occur no matter how much the speed was increased, indicating a limitation of the cardiorespiratory system. The concept of the 'plateau' in oxygen consumption during short-term maximal exercise was therefore established, a view accepted by many authors (Costill **et al.**, 1973; Saltin and Strange, 1992; Basset and Howley, 2000).

Noakes (1988) however, argued that the ‘levelling off’ criterion is dubious because only about 50% of subjects show this characteristic. Noakes (1988) proposed that local muscle factors limit $VO_{2\ max}$ by halting maximal exercise before the oxygen delivery systems are taxed to their maximal capacity. Numerous applied physiologists have challenged this notion and in 2000 Bergh and associates reported that even though they support Noakes’ critical examination of the conventional data, his argument is not convincing. Others have argued that no single factor can be found to be directly limiting as all links in oxygen transport are closely matched (di Pramperor, 1985). This debate continues to receive much attention.

With specific reference to the military, Soule **et al.** (1978) reported an impaired performance when soldiers carried loads ranging between 60kg and 70kg while marching at a speed of 6.4 $km.h^{-1}$. With these speed and load combinations, soldiers were working at greater than 90% of $VO_{2\ max}$. These authors did not indicate whether their subjects exhibited more cardiorespiratory discomfort or local muscular fatigue. In the present study, assessment of local muscle fatigue was deemed necessary. Although it is seldom that soldiers march at excessive speeds with heavy loads, there may be times in combat situations when such high work intensities would be required.

MUSCLE DYNAMICS IN WALKING

In walking and running the progression of the body involves changes in kinetic energy with each step due to acceleration and deceleration, plus changes in potential energy due to vertical displacement. In walking an alternating exchange of kinetic and potential energy takes place with each step so that the muscles have only to restore the small part of the energy that is not recovered. The most economical speed of walking is that at which this recovery is maximal. The remainder of the energy required for locomotion is attributed to the cost of positive and negative work done by the muscle (Sabiene, 1990)

With each walking stride the muscles of the landing leg store ‘impact energy’ (negative work) as they contract eccentrically to absorb the shock. Most of the stored energy is then used during the concentric muscle contraction (positive work) that propels the body forward during the next stride. During locomotion the ankle and hip do more positive work than negative work, while the knee absorbs energy and does negative work (Saunders **et al.**, 1953). It is generally accepted that the performance of negative work is more economical than the performance of positive work (Pierrynowski **et al.**, 1981; Williams and Cavanagh, 1983).

The metabolic cost of generating muscular force over time will determine the metabolic cost of locomotion. Taylor and Heglund (1982) demonstrated that the rate of metabolic energy consumption increases linearly with increasing speed of locomotion, compared to the rate of muscular mechanical work which increased curvilinearly. Recently however, this linear relationship between speed and energy cost has been shown to be curvilinear with the lowest energy cost occurring at approximately 4 $km.h^{-1}$ (Bunc and Dlouha, 1997).

Fibre Type Composition

Taylor and Heglund (1982) presented a theory suggesting that the intrinsic velocity of shortening of motor units may determine the metabolic cost of generating muscular force during locomotion. They suggested that fast motor units are recruited at faster speeds. Motor units can be classified based on either their physiological, biochemical or histological properties. A generally accepted classification is one that categorises motor units between extreme categories of large, fast and fatigable or small, slow and fatigue resistant (McArdle **et al.**, 1996). The slow-oxidative (Type I) fibres have slow contractile properties due to the slow release of calcium (Ca^{++}) and the low myosin ATPase (adenosine tryphosphatase) activity; they have a large mitochondrial content and are fatigue resistant. They are therefore best suited for sustaining constant tension output that is needed for postural control at rest and during sustained locomotion, including prolonged military marches at a low intensity. Fast-oxidative glycolytic (Type IIa) fibres have fast contractile properties, which are correlated with Ca^{++} uptake properties of the sarcoplasmic reticulum. They have a high oxidative and a high glycolytic activity. The fast-glycolytic (Type IIb) has similar contractile properties to Type IIa, but have fewer mitochondria, less myoglobin and are readily fatigable.

Each skeletal muscle contains varying amounts of these different motor units depending on the size and location of the muscle. The ratio of motor unit types is to a large extent genetically determined, but can be influenced to a small extent by training. As speed of walking increases and the speed of muscular contraction increases, fast motor units are recruited and more energy is expended. As fast motor units are readily fatigable, soldiers will fatigue much sooner at high walking speeds, experiencing more local muscular fatigue, than if slower speeds were maintained. Those soldiers who have a higher percentage of fast twitch muscle fibres would be at an advantage when high intensity marching is undertaken, while those with a higher percentage of slow twitch fibres would be better suited to submaximal activities of a prolonged nature. Genetic predisposition therefore plays a significant role in determining individual responses to different military tasks. A factor which is not dependent on genetics, and which is determined by the intensity of the activity, is the fuels being metabolised.

SUBSTRATE UTILIZATION

Carbohydrates are stored in the body as muscle and liver glycogen. As soon as exercise begins these fuel stores, and others, are broken down to be used as energy. At lower exercise intensities more fats are used as an energy source, and as the intensity of exercise increases so more carbohydrates are used (Brooks and Mercier, 1994). This has been reflected in numerous exercise physiology studies by an exponential increase in blood lactate concentration and a higher respiratory exchange ratio (RER) at higher exercise intensities. Brooks and Mercier (1994) used the term “crossover concept” to indicate the switch from fats to carbohydrates as exercise intensity increased.

As the depletion of muscle glycogen has been associated with the onset of fatigue (Hermansen **et al.**, 1967) higher walking speeds required for prolonged periods will result in premature fatigue. The most severe glycogen depletion occurs during prolonged activities at an intensity of 70-85% of $VO_{2\ max}$ (Bosch **et al.**, 1993). Although this range is above exercise intensities usually employed for prolonged marches, unlike marathons or ultra marathons, marches may continue for up to eight hours a day for several days, weeks or sometimes even months. The result being that it becomes increasingly more difficult to replace used carbohydrate stores.

Carbohydrate intake while individuals are participating in prolonged marches also needs to be optimised in order to prevent hypoglycaemia (Bosch **et al.**, 1993), a condition associated with a low blood glucose concentration, causing dizziness and disorientation. Further research is therefore needed in order to consider substrate utilisation and nutritional factors, particularly when undergoing prolonged marches, as soldiers could be limited by their available fuel sources. It is thus argued that the subjects in the Sagiv **et al.** (1994) study would not have been able to continue indefinitely as muscle glycogen levels would have eventually been depleted, particularly if carbohydrate stores were not replenished. In addition, those soldiers who are in good cardiovascular condition would according to Brooks and Mercier (1994) have a greater ability to utilise fats as an energy source and would therefore be at an advantage if prolonged marches were undertaken.

LOAD FACTORS

ENERGY COST AND THE OPTIMAL LOAD TO BE CARRIED

Charteris **et al.** (1989) argued that the energy cost of locomotion is not only a function of speed walked, but also of load carried. This combination of speed and load is of critical importance in a military environment in which soldiers are required to maintain a particular walking speed while carrying loads. A linear increase in oxygen uptake, heart rate and pulmonary ventilation with increasing load was reported by Astrand and Rodahl (1977) and later confirmed by other authors (Borghols **et al.**, 1978; Bobet and Norman, 1984). This linear relationship between load and energy cost is different to the curvilinear relationship identified between speed and energy cost by Soule **et al.** (1978) and Bunc and Dlouha (1997). Therefore clarification of the relationship between energy cost and speed/load combinations is essential in order to determine the most efficient combinations and thereby ensure that the soldier is not excessively strained.

It has further been demonstrated that energy expenditure per kilogram of load carried is equal to the energy expenditure of an additional kilogram of body weight up to loads of 30kg (Goldman and Iampietro, 1962; Hughes and Goldman, 1970; Soule **et al.**, 1978). Additional weight, whether in the form of additional body weight or as an external load, results in an increase in energy cost (McArdle **et al.**, 1996). Individuals of varying body weights will therefore be working at different percentages of maximal oxygen consumption when performing the same task; an effect that is similar if an external load is added. Pierrynowski **et al.** (1981) therefore suggested that the carrier be given credit for carrying body mass, and indeed several studies have focused on relative backpack weights (Cathcart **et al.**, 1923; Quesada **et al.**, 2000; Scott and Ramabhai, 2000).

Relative Loads

The idea of relativizing backpack weight is long standing and takes into account varying morphologies. In 1923 Cathcart **et al.** had already suggested that load should not exceed 40% of body mass. This is particularly important in a diverse population such as the military where soldiers differ considerably in morphology. Since then numerous authors have suggested that load carried be made relative to individual body mass in order to ensure that soldiers are not excessively strained or more importantly, differentially taxed (Cathcart **et al.**, 1923; Kinoshita, 1985; Haisman, 1988; Scott and Ramabhai, 2000).

It has also been demonstrated that there is a “no cost” effect for loads of 20% to 30% of body mass (Maloiy **et al.,**1986; Charteris **et al.**,1989). The conclusions of these authors were based on the analysis of African woman head-loaders, and while Maloiy and associates noted no differences in kinematics, Charteris **et al.** (1989) consistently found differences in the gait patterns of the head-loaders. Although in the present study detailed kinematics were not examined, changes in cadence were monitored under each condition in order to determine the effects of speed and load on step frequency. Quesada **et al.** (2000), working specifically with military subjects, also found that marching loads up to 30% of body mass did not significantly increase metabolic cost.

In 2000 Scott and Ramabhai suggested that load be made relative to lean body mass and not total body mass, as several others had suggested (Cathcart **et al.**, 1923; Haisman, 1988). Female soldiers in their study showed minimal change in heart rate when comparing responses to carrying absolute and relative loads. The reason offered was that female subjects had more than double the percentage fat of their male counterparts, suggesting that relative loads be calculated based on lean body mass. However, very few military operations relativize load weight and therefore research is still ongoing for the determination of the optimal absolute load weight (Soule **et al.**, 1978; Bhambhani **et al.**, 1997).

Absolute Loads

The US Army doctrine recommends maximum "combat loads" of 22kg and maximum "approach loads" of 33kg (Knapik, 1989). These loads are based on studies which investigated the energy cost of different loads and identified which loads are carried most economically per unit of distance (Cathcart **et al.**, 1923; Hughes and Goldman, 1970). Since these early studies the ability of soldiers to carry heavy loads has been the subject of considerable research (Haisman, 1988; Knapik, 1989). Haisman (1988) suggests that there may be some consensus for the traditional rule of thumb of one-third-body weight, or 24kg on an assumed body weight of 72kg, being equivalent to one third of $VO_{2\ max}$ for a normal working day. Although Soule **et al.** (1978) support the findings which suggest speed impacts energy cost more that load, they reported that increasing load from 35kg to 70kg whilst walking at 4.8 $km.h^{-1}$ still resulted in approximately a 15% increase in energy expenditure, indicating that increasingly heavy loads will negatively impact on energy cost. At this speed and load their subjects were working at higher than 60% $VO_{2\ max}$. Due to the many factors which need to be considered, there has been no conclusive evidence for the identification of the optimal absolute load weight. Factors which need to be considered include the morphology of the soldier, load placement plus task requirements.

LOAD PLACEMENT

An important factor in determining the energy cost of marching is the load placement (Soule and Goldman, 1969; Pandolf **et al.**, 1977). An external load can cause a shift of the centre of mass which may alter efficiency and thereby increase energy cost. It is however well known that loads should be kept as close to the body's centre of mass as possible in order to ensure greater stability and efficiency.

Datta and Ramanathan (1971) compared the energy cost of seven different ways of carrying a 30kg load. They concluded that the most physiologically efficient method was the double-pack. In accordance, Kinoshita (1985) and more recently Lloyd and Cooke (2000) also found that the double-pack was more effective especially when carrying heavier loads. In contrast, no difference has been found between packs by Legg and Mahanty (1985), and the double-pack has also been shown to impair heat loss by means of reduced evaporation of sweat from the chest (Johnson **et al.**, 1995). Knapik **et al.** (1996) also reported that the backpack provides greater versatility and does not restrict movement particularly when awkward activities need to be performed. Winsman and Goldman (1976) found that weight, rather than its distribution, is the most important factor in load carriage. They claimed that as long as the weight is centred on the mid-section of the body, gait is still modified by any additional load. Traditionally in the military, load placement has been confined to the backpack and was therefore the method selected for the present investigation.

SPEED AND LOAD COMBINATION

ENERGY COST

Numerous studies have investigated the metabolic cost associated with carrying a variety of loads at a wide range of speeds over different types of terrain (Goldman and Iampietro, 1962; Soule and Goldman, 1972; Soule **et al.**, 1978).

In terms of energy expenditure, the classic study of Soule **et al.** (1978) found that the cost for carrying a given load is approximately doubled when increasing speed from 3.2 $km.h^{-1}$ to 6.4 $km.h^{-1}$. In 1991 Patton and associates reported that at a speed of 4.9 $km.h^{-1}$ there was a significant increase in the energy cost when load was increased from 31.5kg to 49.4kg. Furthermore, both these studies showed a significant increase in energy cost when speed was increased above 5.5 $km.h^{-1}$.

Haisman (1988) found that when load was increased the subjects, who were allowed to self-pace, automatically decreased walking speed. However, when load was decreased they walked at a faster pace and the energy expenditure was the same as when the load was heavier. Haisman (1988) demonstrated that the energy cost when walking at 8 $km.h^{-1}$ with no load was more than when carrying 60kg walking at 3.7 $km.h^{-1}$, and yet individuals perceived the latter combination to be more difficult. Myles and Saunders (1979) also showed that subjects compensate for heavier loads by decreasing walking speed. In their study walking at 6.7 $km.h^{-1}$, with a load equivalent to 10% of body weight, cost no more than walking at 5.9 $km.h^{-1}$ carrying 40% of body weight.

Earlier, Hughes and Goldman (1970) reported that a load of 40-50% of body mass could be tolerated if speed was maintained at 5 $km.h^{-1}$, and Epstein **et al.** (1988) found that at a speed of 4.5 $km.h^{-1}$ the energy cost of carrying 25kg (36% of body mass) was constant over time, but that once load was increased to over 50% of body mass there was a significant increase in energy cost. However, recently Quesada **et al.** (2000) showed that at a higher walking speed (6 $km.h^{-1}$) loads up to 30% body mass could be tolerated with energy cost still remaining at approximately 40% of $VO_{2\ max}$. Although speed was shifted to a higher level in their study, the mean load carried was only 24kg. What is evident from all these studies is that speed and load need to be adjusted to optimise energy cost in order that soldiers can carry out military requirements.

In the present project the speeds chosen ranged from 3.5 $km.h^{-1}$ to 6.5 $km.h^{-1}$ and the loads between 20kg and 65kg. Although the latter speed and load may be considered excessive, there are times when soldiers, under extreme situations, may be required to march at high speeds with loads weighing as much as their own body weight. Johnson **et al.** (1995) emphasise that irrespective of speed and load, a platoon must be able to complete these marches with minimum fatigue and discomfort in order to be "combat- ready". However, Soule **et al.** (1978) had demonstrated that individuals will be excessively strained under extreme conditions. These authors reported that when walking at 6.4 $km.h^{-1}$ with a 70kg load subjects were close to maximal oxygen consumption, resulting in sub-optimal efficiency, an undesirable situation for any army.

MORPHOLOGICAL CONSIDERATIONS

Simple anthropometrical measurements such as stature and mass can help provide a rough estimation of body composition and the general morphology of the human body, for example in the form of ponderosity indices such as the Body Mass Index (BMI) and linearity indices such as the Reciprocal Ponderal Index (RPI). This information is important for determining the most efficient speeds of walking relative to stature, and the most efficient load weights relative to morphology. In addition, particularly with regard to the South African situation, these measurements help to establish a morphological profile of the South African soldier.

Anthropometrical Indices

Basic anthropometrical measurements provide information about absolute size and when used as the basis for specific formulae, can provide valuable information about the morphological make-up of an individual. The study of body size, structure and composition may be useful in characterising the profile of military soldiers or athletes participating in different activities in order to determine the best profile for optimal health and performance (Yannakoulia **et al.**, 2000).

Stature and body mass measurements can be used to obtain an individual's body mass index (BMI), which is an overall indicator of total body composition. This basic index is easy to calculate and thus useful to use when testing large population groups such as the military. Obesity-related health risks begin in the BMI range of 25-30kg.$(m^2)^{-1}$ (ACSM, 1986).

Body Composition

Body Composition refers to the relative percentages of fat and fat free body tissue. One method used to determine body composition is bioelectrical impedance analysis (BIA), the method used in this investigation. BIA has been used extensively in assessing the total body water (TBW) and fat-free mass (FFM) of various groups of people. It is safe, rapid, portable and easy to measure which makes it particularly useful for large samples such as the military.

In biological systems electrical conductance is related to water and electrolyte distribution in the biological conductor. Therefore, because water and conducting electrolytes are found only in FFM including the protein matrix of adipose tissue, conductivity of this mass is greater than that across a fat-mass. Thus the low frequency current associated with bioelectrical impedance measurement represents the conductivity of the FFM and correlates highly with total body water measures. This technique is based on the principle that impedance to the current is related to conductor length and to conductor volume. Resistance is the variable that is measured using a tetrapolar lead system. This may be described as the resistance to the flow of electrical current and is proportional to the drop in voltage of an applied current through a resistive substance. Conductive tissues (FFM) offer low resistance.

There are certain assumptions upon which this technique is based. These include that hydrated lean tissue has a uniform density, adipose tissue contains an insignificant amount of water and that the total volume of the conductive material is related to impedance (Kotler **et al.**, 1996). However, with standardised testing procedures and experimental rigor, the most accurate measurements can be obtained and numerous authors have attested to its reliability (Komiya and Masuda, 1990; Liang and Norris, 1993).

The present study was conducted primarily on Black Xhosa men who, in a recent investigation by Wagner and Heyward (2000), were shown to have a greater bone mineral density and body protein content than whites, thereby resulting in a greater fat-free body density. Additionally these authors also reported that there are ethnic differences in the distribution of subcutaneous fat and the length of the limbs relative to the trunk. These recent findings reiterate the importance of the present study on South African soldiers.

Stature and leg length

Stature plays an important role when walking speed is altered particularly as the relationship between leg length and stride frequency is one of the main determinants of walking speed. Individuals use different frequencies dependent on leg length, which in turn plays a substantial role in determining the energy expenditure associated with a particular walking speed. Shorter individuals will need to increase stride frequency and/or stride length to maintain the same speed as taller individuals, resulting in a greater energy cost. In the present study, stride frequency was recorded during each speed/load combination.

GAIT PATTERNS

In order to increase walking speed an individual must adjust either their stride frequency or stride length. Increases in one or both will result in a faster walking speed. As stride length is altered it has an important effect on all active muscles involved. Each muscle is forced to work on a slightly different region of the force-velocity curve which in turn influences movement efficiency and ultimately energy cost.

Cavanagh and Williams (1982) demonstrated that increases, rather than decreases in stride length, were associated with greater increases in energy cost, a finding more recently confirmed by other investigators (Holt **et al.**, 1991; Bunc and Dlouha, 1997). Holt **et al.** (1991) observed that the combination of low frequency/long stride length produced significantly higher metabolic costs than the equivalent high frequency with a short stride length. In 1952 Hogberg showed that increases in running speed from 10-20 $km.h^{-1}$ resulted in an increase in stride length by 85%, and stride frequency by only 9%. In contrast however, in the same study competitive walkers did not increase speed in the same way. Here increases in speed were accomplished by increasing stride frequency more than stride length.

Morphological considerations and in particular stature and leg length will influence stride length. Shorter individuals will need to take a longer stride length or increase their stride frequency in order to maintain the same speed as their taller counterparts. In a military setting soldiers are frequently required to march as a unit and hence speed is strictly controlled restraining these individuals to certain movement patterns. Charteris **et al.**

(1982) demonstrated this when they showed that at the same absolute locomotor speeds, shorter people expend more energy per kilogram of body mass than the taller individuals. In an earlier study however, Wyndham **et al.** (1971) found that stature was a poor indicator of locomotor energy cost.

Grieve and Gear (1966) first introduced the concept of setting the speed of locomotion relative to stature. This was termed relative speed (RS) and refers to that fraction of body stature (m) covered overground during locomotion per second and is expressed as statures per second ($st.s^{-1}$). Qualitative definitions of various relative walking speeds were provided by Charteris (1982) and Charteris **et al.** (1982) and are presented as follows:

TABLE I: Relative speed classifications (Charteris, 1982; Charteris **et al.**, 1982).

Relative Speed ($st.s^{-1}$)	**Classification**
0.3	very slow
0.4-0.6	slow
0.7	slow medium
0.8-1.0	medium
1.1	medium fast
1.2-1.4	fast
1.5	very fast

In terms of load carriage, Kinoshita (1985) suggested that loads be kept lower than 20% of body mass in order to prevent an altered walking gait. Subsequently, Charteris **et al.** (1989) reported that with head-loading kinematics are altered when carrying 20% and more of body mass.

Self Pacing

Athletes appear to choose the stride length at which they are most economical (Cavanagh and Williams, 1982) and when individuals are required to adjust their stride length and frequency through forced pacing they become less economical and hence expend more energy than if allowed to self-pace. Hughes and Goldman (1970) found that men select a pace equivalent to 40-50% of $VO_{2\ max}$ when required to self-pace, which is collaborated by the findings of Evans **et al.** (1980) a decade later. However, all these results are reported from studies conducted in activities of a relatively short duration (1-1.5 hours), whereas foot soldiers are often required to march for much longer periods. Myles and Saunders (1979) found that if subjects were required to self-pace walk for up to eight hours they automatically adjust their VO_2 to a lower level, and this level corresponded to approximately 40% of maximal oxygen consumption.

PHYSIOLOGICAL DETERMINANTS

METABOLIC COST OF WORK

The determination of the metabolic cost of walking using indirect calorimetry is a standard physiological procedure, which dates back to the early studies of Cathcart **et al.** (1923). In most studies concerning backpacking, the main goal has been to determine the energy cost of walking taking into account different walking speeds and external loads (Goldman and Iampietro, 1962; Datta and Ramanathan, 1971); together with determining the metabolism expressed as a percentage of maximal oxygen uptake (Evans **et al.**, 1980). Physiological measurements which reveal this information help to determine the most ‘physiologically efficient’ individuals when varying loads and speeds are imposed.

PREDICTION EQUATIONS

The energy cost of walking with loads is also dependent on factors other than speed and load. These include body weight and physical condition of the individual plus gradient and terrain of the ground covered together with the duration of the activity. Equations which predict long-term energy cost from short-term studies have therefore been derived to provide valuable information about the energy cost of military activities which are generally of substantial duration.

As early as 1956, Redfearn and associates produced an equation which best described the data for marching with loads on level ground and since then numerous other researchers have put forward other suggestions. Pandolf **et al.** (1977) modified Givoni and Goldman’s equation (1971) which is relevant for males and females.

$$M = X\,(W + L)\,[2.3 + 0.32\,(V-2.5) + g\,(0.2 + 0.07\,(V-2.5))]$$

Where: M = metabolic rate, kcal.h^{-1}
W = body weight, kg
L = external load, kg
X = terrain factor, defined as one for treadmill walking
V = walking speed, km.h^{-1}
G = gradient, %

However, this prediction method was found to have limitations. Pimental **et al.** (1982) concluded that it underestimated energy cost for level walking. In addition, other researchers postulated that applying a prediction model which estimates energy expenditure from short-term load carriage efforts to prolonged load carriage exercise will result in significant underestimation of the actual energy cost (Patton **et al.**, 1991). In contrast, Duggan and Haisman (1992) found that the Pandolf equation gave valid group predictions of metabolic rate. The main problem is the inability to accurately represent all possible impinging variables.

Sagiv **et al.** (1994) reported no significant differences in metabolic cost between minutes 5 and 240 with the same load and speed. However, when load was increased from 38kg to 50kg differences in energy expenditure were seen within the first five minutes. These results are in contrast to those of Patton **et al.** (1991) who in an earlier study showed that the energy cost of prolonged (>2 hours) load carriage at a constant speed increased over time. Subjects in the Patton **et al.** (1991) study were not as well trained as the subjects in the Sagiv **et al.** (1994) study ($VO_{2\ max}$ values of 59 $ml.kg^{-1}.min^{-1}$ compared to 65 $ml.kg^{-1}.min^{-1}$) and therefore the subjects in the latter study were possibly less susceptible to fatigue. In addition a large inter-subject variability in oxygen consumption at the same speeds makes the precision of these equations questionable.

VENTILATION DURING EXERCISE

There are two conflicting views on the primary stimulus for the increased ventilation associated with the onset of movement. One theory argues that increased ventilation results from a chemically mediated stimulus acting through effluent venous blood and reflex receptor sites. The other supports the theory that signals from stretched, metabolically active muscles relay information via neural pathways to the brain stem neurons which results in increased ventilation (Dempsey **et al.**, 1980). It does however appear that both neurogenic influences arising in exercising muscles and the metabolic signals of CO_2, O_2 and pH changes must interact in some way.

During exercise there is an immediate increase in ventilation proportional to the workload, after which there is a progressive increase until steady-state is achieved (McArdle **et al.**, 1996). The duration of this steady-state is dependent on whether the work rate is above or below the ventilatory turnpoint. There is a linear relation between minute ventilation (V_E) and metabolic carbon dioxide production (VCO_2) as well as oxygen consumption (VO_2). This linear relationship is broken at approximately 60-75% of maximal oxygen consumption. This is termed the 'ventilatory turnpoint' where V_E increases in a non-linear manner when compared to VO_2, thereafter there is a progressive increase in ventilation until maximum is reached (Perronet **et al.**, 1987). The linear relationship between V_E and VCO_2 exists past this turnpoint, which reflects a greater increase in metabolic CO_2 production than O_2 consumption.

Increasing either breathing frequency (F_B) or Tidal Volume (V_T), or a combination of both can accomplish increases in V_E. It has been identified that with endurance training V_T is increased more than F_B during exercise (Fringer and Stull, 1974). This training phenomenon has been shown to minimise wasted dead-space ventilation (V_D) and would therefore be an advantage during exercise as most of the air taken in participates in alveolar ventilation (V_A).

CIRCULATORY CONTROL UNDER STRESS

Immediately prior to and during exercise there is initiation of the feed-forward and feedback control of circulation. Feed-forward control begins when an individual anticipates the starting of exercise and neural commands from the motor cortex descend to the subthalamic locomotor region (STLR). Once this region is anaesthetised there is an increase in heart rate, arterial pressure, left ventricular systolic pressure and the maximum rate of left ventricular pressure. Acknowledging this response, “Anticipatory” heart rates were recorded in the present study from all subjects prior to each experimental condition. In addition there is an increase in blood flow to the heart, diaphragm and limb skeletal muscles and a decrease in blood flow to the kidneys.

During this anticipatory phase, heart rate and cardiac output (CO) increase and total peripheral resistance and venous compliance fall. Within seconds of the onset of exercise, heart rate and CO can increase 2-3 times (initiation phase). Total peripheral resistance begins to fall within seconds of the onset of exercise due to vasodilation in the active muscles. There is also decreased blood flow to the skin and splanchnic circulation. When exercise is prolonged further reductions in splanchnic blood flow occur. The drop in blood flow to the splanchnic circulation is also a function of the intensity of the exercise expressed as a percentage of the maximum oxygen consumption. The more intense the exercise, the more blood is shunted from the splanchnic circulation and redirected to the active skeletal muscles and skin. This would be the case during most military conditions but particularly during prolonged load carriage or when marching in hot environmental conditions. Skin blood flow will increase due to vasodilatory effects and rising skin and core temperature. As the experimental conditions in this study lasted for only six minutes, skin and core temperatures were not measured.

A stable circulatory response is usually achieved within minutes of the onset of exercise (Adjustment Phase). This steady-state reflects a balance between oxygen supply and oxygen demand, but Patton **et al.** (1991) argued that when prolonged exercise is undertaken a true steady-state may not be reached. In contrast Sagiv **et al.** (1994) reported that during a 4-hour march individuals remain in steady-state. However, numerous findings have shown that there is a continual increase in heart rate and a progressive fall in stroke volume, mean arterial pressure and pulmonary arterial pressure, termed "physiological drift", with prolonged exercise particularly in the heat (Patton **et al.**, 1991; McArdle **et al.**, 1996).

PSYCHOPHYSICAL DETERMINANTS

Few military studies have reported on the perceptual responses of soldiers to the demands of marching speed and load carriage.

RATINGS OF PERCEIVED EXERTION

The Rating of Perceived Exertion (RPE) scale was developed to establish a measure of an individual's response to a physical workload (Borg, 1970). Over the last three decades the RPE scale has been a key measure in numerous studies concerning physiological and psychological responses to various types of work and exercise under a wide range of conditions. The majority of these studies have focused on how the RPE scale relates to physiological responses, particularly heart rate. The validity of the RPE scale has been comprehensively tested (Gamberale, 1985; Watt and Grove, 1993; Garcin **et al.**, 1998) and providing the concept is clearly understood by the subject, it is accepted as a reliable means of establishing how a person ‘feels’ when being physically taxed. It consists of a 15-point scale ranging from a rating of 6 (minimal exertion) to a rating of 20 (maximal exertion); see appendix B.

The early studies of Borg (1970 and 1973) and Pandolf (1978) demonstrated a linear relationship between an overall RPE and heart rate during progressive load cycling and treadmill walking. In 1971 Ekblom and Goldbarg suggested that local influences in the muscles and joints, and central influences involving the cardiorespiratory system both contribute to the perception of exertion. Making use of these differentiated ratings specifically when carrying loads Pandolf **et al.** (1975) and Pimental and Pandolf (1979) found that when walking with external loads the intensities of both local and central signals were similar to the overall sensation. Later Pandolf (1982) suggested that local factors play a greater role than was originally thought.

In terms of walking speed and load carriage, Robertson **et al.** (1982) demonstrated a differentiation threshold (DT). This DT identified the walking speed at which the intensities of the local and central signals were first perceived to be different from the overall sensation of exertion. Summarised in Table II are the walking speeds (Differentiated threshold) and backpack weights, expressed as a percentage of body weight, at which this DT occurs. Speeds faster than this differentiated threshold resulted in signals from the legs being the dominant factor in shaping the overall sensation.

TABLE II: Speed and Load combinations at which local factors of perceived exertion become more dominant (Adapted from Robertson **et al.,** 1982)

LOAD (% Body Weight)	**DIFFERENTIATION ($km.h^{-1}$)**	**THRESHOLD (DT) ($m.s^{-1}$)**
0	6.4	1.78
7.5	6.4	1.78
15	4.8	1.30

These authors concluded that at speeds greater than the DT local signals provide the dominant sensory cues in terms of the perception of exertion. Goslin and Rorke (1986) have since reported that central systemic factors do not predominate in determining perceptions of exertion during light to moderate load carriage.

BODY DISCOMFORT SCALE

Corlett and Bishop introduced the Body Discomfort Scale in 1976 in an attempt to provide a quantitative measure of the effects of working posture on the discomfort experienced by the individual. On this scale the body is divided into 27 segments so the subject can identify site(s) of discomfort experienced and rate the intensity (See Appendix B).

Recently Ramabhai (1999) reported that with prolonged load carriage, body discomfort shifted from the posterior shoulder region in the first hour of marching to the lower limbs by the third hour of marching. Furthermore, Legg **et al.** (1997) argued that local fatigue (back and shoulders) is more important than energy cost in limiting load carriage. This scale thus assists in the understanding of an individual's perception of the external demands placed on them.

OTHER FACTORS

TREADMILL VS OVERGROUND WALKING

Treadmills offer many advantages in the analysis of human locomotion, the most important being that environmental factors can be controlled, steady-state speeds can be selected and cadence can be easily recorded. However, concern has been voiced about differences in ambulation on a treadmill compared with overground walking (White **et al.**, 1998). In addition, if there are differences this is likely to affect energy cost and extrapolation of results from laboratory to *in situ* situations may not be reliable. However, Van Ingen Schenau (1980) theorised that treadmill and overground locomotion were the same if the speed of the treadmill was kept constant, and Basset **et al.** (1985) reported that there appears to be no difference in O_2 uptake between treadmill and overground running at comparable speeds.

Several authors have argued that there is a need for treadmill habituation (Wall and Charteris, 1980; Gordon **et al.**, 1983). Wall and Charteris (1980) identify two phases in treadmill habituation. The first is an initial accommodation to the new modality, which is experienced by faltering, balance-regaining, or "tripping" which lasts for about 10 seconds of exposure to the treadmill. The second is refinement of habituation involving the gradual establishment of a stable and essentially normal gait pattern, but they caution that the kinematic variability associated with the process of habituation is still prevalent after ten to fifteen minutes of treadmill walking (Charteris and Taves, 1978; Wall and Charteris, 1980). This emphasises the importance of habituation particularly if subjects are unaccustomed to treadmill walking, as was the case in the present study.

HUMAN VARIABILITY

While athletes are often attracted to sporting disciplines which best suit their specific talents, soldiers are required to display proficiency in short, intense activities as well as longer, lower intensity activities regardless of their own innate make-up. This raises the issue of human variability and the acceptance that no two soldiers will respond identically to the same task or be equally proficient in all military tasks. Hence the need to emphasise the importance of not only identifying a range of optimal speed and load combinations, but also the need to take into consideration the uniqueness of individuals within a platoon.

An important consideration is individual differences in oxygen uptake. The oxygen demand describes the relationship between walking speed and energy expenditure and is referred to as ‘economy of motion’. At any given walking speed the less oxygen that is required the more ‘economical’ that individual will be. The range of VO_2 for a given velocity of gait expressed as a percentage of the sample mean is typically 20-30% (Daniels, 1985). The causes of these differences have not been adequately addressed;

they could be due to biomechanical, physiological or psychological differences, but what is more probable is a combination of all these factors.

As early as 1930 Dill and co-authors reported the difference in absolute oxygen consumption of a standard running speed to vary as much as 50% between individuals. Their data revealed that differences in excess of 30% still exist if VO_2 is expressed relative to body weight. Recently Martin **et al.** (1993) found that walkers showed less variability in economy than runners. The ranges of VO_2 however were still large, and expressed as a percentage of the sample means were 20.5% and 26.5% for walkers and runners respectively.

TRAINING STATUS

Adaptations induced by exercise can either be acute such as elevated heart rate, body temperature and breathing rate, or chronic which are associated with more permanent adaptations. These chronic adaptations are essential in obtaining and maintaining effective military performance, as the role of adaptation is to allow the person to be able to perform the task better.

Taylor **et al.** (1980) showed that the energy cost of a given activity could be decreased with training. They demonstrated that walking with a backpack over a period of weeks caused a decrease in the energy cost of carrying the load. Kraemer **et al.** (1987) reported that a 12-week physical training programme combining aerobic and resistance training improved the speed at which men completed a 32-km distance carrying 46kg.

The same authors also found that training these systems independently did not result in the same benefits.

Studies done at the University of Cape Town Sports Science Department have shown that running performance may increase prior to an increase in $VO_{2\ max}$ (Lambert and Noakes, 1989). It was apparent in their experiment that $VO_{2\ max}$ increased after training only if there was no change in running economy. Endurance training also induces a considerable proliferation of the capillary network in the muscles that are repeatedly recruited during training. Although unlikely to be causal, this increase in capillarization has been shown to mirror the increase in $VO_{2\ max}$.

The mitochondrial content of muscle exposed to endurance training also increases several fold (Kirkwood **et al.**, 1986). This increase in total mitochondrial enzyme activity is associated with a rise in the capacity to produce ATP by oxidative pathways. Although $VO_{2\ max}$ and muscle oxidative capacity have been reported to be linked (Ivy **et al.**, 1980), other studies have drawn different conclusions. Davies **et al.** (1982) reported that oxygen consumption is not tightly coupled to muscle oxidative capacity.

Increased oxidative capacity in skeletal muscle appears to be important for fuel regulation. This explains why, during submaximal exercise, glycogen is spared in the muscles and liver, and why fat oxidation is increased and the respiratory quotient (RQ) lower in trained individuals. There also appears to be a shift in substrate utilisation with endurance training, which has resulted in recent investigations into the impact of high fat feeding on ultra-endurance performance (Goedecke **et al.**, 1999). Endurance trained individuals have a lower respiratory quotient (RQ) and are better able to utilise fat as an energy source. This, in turn, has a glycogen sparing effect that helps delay the onset of fatigue which is beneficial particularly in long-term performance such as military marches of a prolonged duration. Measurements of RQ were taken throughout each experimental condition in this study.

AGE

There is a progressive decline in the functional capacity of the cardiovascular system with ageing. This deterioration is reflected in a decrease in maximal oxygen consumption (Marti and Howard, 1990) reportedly in the range of 9% decline per decade after the age of 25 years; the mean age of the subjects in the present investigation being 29 years. Fleg and Lakatta (1988) and Noakes (1992) argue that this is the result of a progressive decrease in muscle mass with age, and therefore supports the theory that muscle contractility limits maximal oxygen consumption (Noakes, 1988). These former studies suggest that due to the decrease in muscle mass, older individuals will not be able to work at the same intensity, which will reflect as a lower VO_2 value. Marti and Howard (1990) also reported that with ageing there tends to be a decrease in volume and intensity of training, possibly as a result of this decrease in muscle mass. In terms of the military this implies that the older soldiers will have difficulty maintaining the same intensity of marching as their younger counterparts.

In addition to a decrease in muscle mass, there is an increase in body fat stores with age (Marti and Howard, 1990). Rogers **et al.** (1990) argued however that $VO_{2\ max}$ still falls with those individuals whose body weight and body fat levels remain unchanged. Recent research has also identified that despite the inevitable decline in $VO_{2\ max}$ with ageing, exercise training imparts favourable adaptations in functional capacity in individuals well into their seventh and eighth decades of life (Lemura **et al.**, 2000).

SEX-BASED FACTORS

Due to differences in anthropometry and in particular body composition between males and females, Vogel **et al.** (1986) postulate that females respond differently to workloads than males. In terms of body composition, the main difference is that the average male is heavier and taller than the average female. The female hormone oestrogen is responsible for this difference causing young girls to stop growing approximately two years before boys (Wells and Plowman, 1983). In all probability a male and female of the same body weight will have different amounts of body fat and lean body mass. Females tend to have more body fat and less lean body mass than their male counterparts. The result is that females will have lower $VO_{2\ max}$ values to transport the same absolute body weight. Scott and Ramabhai (2000) therefore suggest that load weight be relative to lean body mass.

Cureton and Sparling (1980) added weight belts to a group of male runners to artificially increase their mass until it equalled that of the female runners. They showed that the initial distance run in 12 minutes was 20% greater than the females, and reduced to

14% after mass had been equalised, indicating that the added weights had reduced the male-female difference. According to Noakes (1992) this difference is due to inherent differences in muscle power and running economy rather than the females' extra body fat. Thus, when weight and $VO_{2\ max}$ values had been equalised, men still ran faster because they reached the same $VO_{2\ max}$ values at higher running speeds. Noakes (1992) postulated that this is the case because men have superior muscle contractility. However, the conclusions drawn by Cureton and Sparling (1980) cannot be refuted as varying amounts of body fat explained as much as 30% of the difference in running performance. Thus, whether or not these differences are related to percentage body fat or superior muscle contractility, it is generally acknowledged that sex-related differences do exist.

In terms of load carriage, Snook and Ciriello (1974) showed that females handled significantly less weight than males. Vogel **et al.** (1986) argue that in general females have less lean body mass (LBM), more absolute and relative body fat, lower $VO_{2\ max}$ values, and a lower muscle strength than males. This lower muscle strength is due mainly to differences in muscle mass rather than differences in muscle composition. It has been reported that there are no significant differences in the percent slow-and-fast twitch muscle fibres in the muscles of similar athletic men and women (Wells and Plowman, 1983; Costill **et al.**, 1987). However, men have larger fibres, which could explain this difference in strength because when strength is expressed relative to LBM, the difference becomes less.

In addition, females seem to adopt self-paced absolute energy expenditures for physical work much below those of males (Evans **et al.**, 1980). In this latter study, the average energy expenditure of males on all terrains with an external load was significantly and consistently higher than the females. The females were extremely consistent in maintaining the same self-paced ‘hard’ energy expenditure regardless of load. However, when their data were expressed as a percentage of $VO_{2\ max}$ there were no differences between the males and females. In the Evans **et al.** (1980) study, the mean percent $VO_{2\ max}$ for males was 46% and 44% for females even though they were walking at different paces.

SUMMARY

Military Ergonomics is concerned with the physical capabilities and well-being of the soldier while at the same time ensuring that military objectives are achieved. Thus a compromise needs to be obtained between unduly stressing a soldier and ensuring that military objectives are carried out effectively. The only way that these two objectives can be achieved effectively is by adopting holistic, integrated approaches which ensure that objectives are met without undue physical or mental stress being placed on personnel in the process.

In the context of the present study this means the optimisation of speed-load interactions to minimise the strain taken by soldiers who must be combat-ready at the end of forced marches under ambient conditions which cannot be controlled.

CHAPTER III

METHOD

INTRODUCTION

As the energy cost of marching is influenced by both the speed selected and the load required to be carried these two variables should not be investigated separately as guidelines for efficient combinations of speed and load need to be established. This is particularly important if a military objective requires either a fast walking pace, when load should be reduced, or the transportation of heavy backpack loads, when the speed should be slower. If these adjustments are not made there is, according to Hughes and Goldman (1970), a disproportionate increase in energy expenditure resulting in fatigue and ultimately compromised combat efficiency. Although some military studies have attempted to provide guidelines for optimal speed and load combinations (Soule **et al.**, 1978; Patton **et al.**, 1991; Quesada **et al.**, 2000) none are specifically applicable to the South African National Defence Force (SANDF).

With the focus on the metabolic cost of marching speed while carrying varying loads, cognisance must be taken of the uniqueness of the soldiers involved. The sample for the present project was taken from the SANDF and compromised individuals from diverse ethnic groups resulting in substantial morphological differences within the group as a whole. Recent evidence has suggested that differences in body composition between Blacks and Whites are such that responses to the same workload may be considerably different (Wagner and Heyward, 2000). This is particularly pertinent, as the relative percentages of fat mass and LBM have been shown to play an important role in the energy cost of an activity (Buskirk and Taylor, 1957; Cureton and Sparling, 1980; Scott and Ramabhai, 2000). It is thus difficult to standardise marching speed and mass carried when there is such a great diversity of not only ethnic groups, but also the increasing number of females recruited to the South African army. Despite this mosaic of backgrounds, troops are all required to participate in group activities and perform as a single unit.

Furthermore, although physiological measures enable one to determine the metabolic cost of various combinations of speed and load, individual perceptions are known to have a significant influence on the level of motivation and ability to complete the task. As the objective of any army platoon is minimal energy expenditure per meter of distance moved, this can only be achieved through the identification of optimal speed and load combinations which are physiologically, perceptually and practically acceptable and which are relevant to the demographics of the particular army platoon. In the present study therefore, measurements of morphological, kinematic, physiological and perceptual responses ensured a holistic investigation.

PILOT RESEARCH

Several pilot studies were conducted in the Ergonomics Laboratory at Rhodes University prior to the final experimental investigation. These studies provided insight into the most beneficial testing protocol and helped to establish a practical order of testing.

Appropriate combinations of speed and load were determined and the suitability of the physiological equipment and perceptual rating scales was established. Furthermore, the identification of the period to reach steady-state was confirmed.

EXPERIMENTAL DESIGN

Numerous authors have identified 4 $km.h^{-1}$ as the optimal speed at which energy cost is at its minimum (Cathcart **et al.**, 1920; Soule **et al.**, 1978; Bunc and Dlouha, 1997). At the other end of the range there is a point at which there is a crossing over of the efficiency of walking to running. Zatsiorky **et al.** (1994) found the transition from walking to running occurred at a velocity of 6.91 $km.h^{-1}$, whereas others propose that this point does not occur at one particular speed, but rather varies according to the individual and external load (Givoni and Goldman, 1971). In the present study the four speeds selected for investigation were 3.5, 4.5, 5.5 and 6.5 $km.h^{-1}$ which covers the optimal range of 4 to 5 $km.h^{-1}$, and in addition included a slower speed at the one end of the range to the speed which is close to that associated with the transition to running at the other end of the range.

Maloiy **et al.** (1986) gave evidence to support an “energetic free ride” of loads up to 20% of body mass. In the present study, this would equate to 14kg, given the mean body mass of the group. Charteris **et al.** (1989) extended this ‘free ride’ to 30% of body mass, which would equate to 20kg for the present subjects, and was the lowest backpack weight used in this investigation. Several recent studies have investigated loads of 30 to 50kg and noted significant increases in energy cost (Patton **et al.**, 1991; Sagiv **et al.**, 1994). In the South African situation however, soldiers are occasionally required to carry loads over 60kg and thus the 4 loads included in the present study, were 20, 35, 50 and 65kg. The four speeds and four loads selected are outlined in Table III. Thus 16 different combinations of speed and load were utilised as the basis for experimental investigation.

TABLE III: Four-by-four matrix used to establish 16 combinations of marching speed and backpack load.

Speed ($km.h^{-1}$)	Load (kg)			
3.5	20	35	50	65
4.5	20	35	50	65
5.5	20	35	50	65
6.5	20	35	50	65

As it would be excessive to require each subject to complete all 16 conditions, two roughly equivalent strain grids (See Table IV) comprising different combinations of speed and load were set up and subjects were assigned to either the A or B grid.

Fifteen subjects were randomly assigned to each grid; subjects in Grid A completed Conditions B, D, E, G, J, L, M and O while subjects in Grid B completed Conditions A, C, F, H, I, K, N and P. To facilitate rigorous experimentation, only five subjects were tested in a session. The sample was divided into six test groups of five subjects each and each group completed two conditions in each of the four test sessions. Unrelated t-tests revealed that the groups in each grid were equally matched in age, body composition and predicted submaximal $VO_{2\,max}$.

TABLE IV: Two grids representing the different speed-load combinations

GRID A					GRID B				
Speed ($km.h^{-1}$)	**Load (kg)**				**Speed ($km.h^{-1}$)**	**Load (kg)**			
	20	**35**	**50**	**65**		**20**	**35**	**50**	**65**
3.5		B		D	**3.5**	A		C	
4.5	E		G		**4.5**		F		H
5.5		J		L	**5.5**	I		K	
6.5	M		O		**6.5**		N		P

During the experimental investigation each subject reported to the laboratory on four separate occasions and was tested under two conditions during each session. As the objective was to investigate the metabolic cost of a wide variety of speed and load combinations independent of duration, a six-minute treadmill march was used as the basis for data collection. During the march each subject was attached to a portable ergospirometer during which time data were collected during the third and the sixth minutes. This was also to allow for the development of steady-state during the submaximal conditions which has previously been shown to occur by the third or fourth minute (McArdle **et al.**, 1996). A steady-state response is associated with fairly constant metabolic and ventilatory responses.

MEASUREMENTS AND EQUIPMENT PROTOCOL

ANTHROPOMETRIC MEASUREMENTS

Any investigation into combinations of speed of marching and load carriage must acknowledge the important role of the basic physical make-up of the individual on the energy expended to execute a task. In order to gain a greater understanding of the demographically changed SANDF it was deemed essential to include basic anthropometric measurements.

Body Mass – Toledo Scale

A calibrated electronic scale (Toledo) was used to measure body mass to the nearest 0.1 kg. Subjects were weighed twice; first with minimal clothing and then with full military uniform excluding battle jacket and helmet.

Stature and Lower Extremity Length

As walking speed is related to stature and in particular limb length, these measurements were obtained using a Harpenden stadiometer and anthropometer. Subjects were requested to stand barefoot with the calcaneus placed against the back of the stadiometer, with an upright posture, head erect and looking straight ahead. Stature was taken from the vertex in the mid-sagittal plane to the floor.

Abducting the hip and locating the greater trochanter obtained the lower extremity length measure. Once this landmark had been identified limb length was measured from greater trochanter to floor on the lateral side of the leg.

Body Composition – Bioelectrical Impedance Analysis (BIA)

Buskirk and Taylor (1957) stated that lean body mass (LBM) is highly correlated with $VO_{2\ max}$ and is a positive factor in load carriage ability. Those individuals with a higher LBM and lower fat mass would therefore be able to work more economically than those with a higher percentage of body fat. There are various techniques available to assess body composition, bioelectrical impedance analysis (BIA) being the technique utilised in this study.

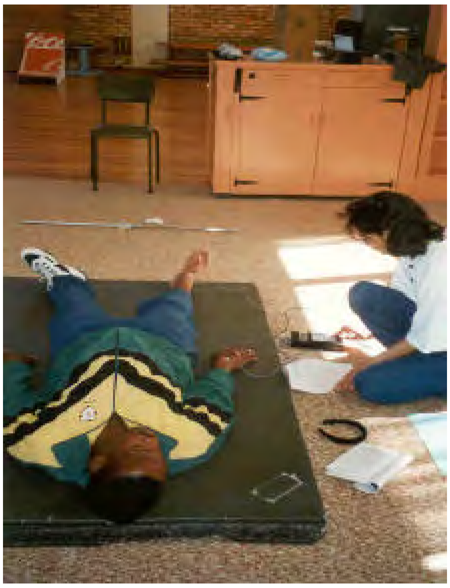


Figure 1: Bioelectrical Impedance Analysis on one of the subjects.

BIA is a technique that has been in existence for many decades, but has only over the last few decades found its way into human application for determination of body composition. It is based on the principle that when a constant, low-level alternating current is applied to a biological structure, this current produces impedance to the spread of current that is dependent on the frequency of the signal (van Loan, 1990).

Subjects were required to lie supine on a non-conductive surface and were requested to remove all jewellery and hand and foot garments. The BIA consists of four electrode placements, two on each hand and foot. Electrodes were placed on the right side of the body with the sensor and current electrodes 55 mm apart (See Figure 1). An AC sine-wave signal generator with a current of 800 A and a frequency at 50 kHz supplies the excitation current (Wagner and Heyward, 1999).

The following estimates were then obtained and manually recorded: Fat mass (kg), Fat mass (%), Lean Body Mass (kg), Lean Body Mass (%) and Body Mass Index (BMI).

PHYSIOLOGICAL PARAMETERS

Polar Heart Rate Monitor

It is generally accepted that heart rate bears a close relationship with energy expenditure (McArdle **et al**., 1996; Wareham **et al.**, 1997). In the present study however, heart rate monitoring was included for the purpose of assessing cardiac strain.

The Polar Accurex Plus and Polar Sports Tester were the heart rate monitors utilised in the present study. An electrode strap was fitted around the subject's chest at the level of the inferior border of the pectoralis major in line with the apex of the left ventricle, situated slightly to the left of the mid-centre of the chest. It contains a transmitter in the front which measures the electrical activity of the heart, which is displayed on the face of the watch. The watch was held by the experimenter in order to prevent interference from the treadmill and from the movement of the subject's arm while marching.

The heart watch serves as a display unit and allows the various functions to be programmed and then stores the data. Although it is difficult to obtain true resting heart rates, "Reference" heart rates were collected during the preliminary testing procedures when subjects had the opportunity to sit quietly. Furthermore, anticipation of an event or task to be completed can result in an increase in heart rate (McArdle **et al.**, 1996) and thus immediately prior to each experimental trial "Anticipatory" heart rates were obtained. The heart monitor was programmed to record every 15 s during the six-minute march and heart rate was manually recorded during the last 15 s of minutes 3 and 6 and on completion of the trial. Data stored were downloaded onto a computer and the relevant printouts obtained (See Appendix C).

Metabolic and Cardiorespiratory Variables

Determination of the energy expended during marching is necessary in order to establish whether the intensity of the activity will result in premature fatigue. These measurements enabled activities investigated to be classified into three broad categories: “Nominal”, “Tolerable” and “Excessive”, following a similar classification to McArdle **et al.** (1996).

The ‘Metamax’ Portable Ergospirometry System

The Metamax base unit contains the complete electronics for measuring and processing physiological responses over a given period. The main parts of the processing unit consist of several microprocessors, with sensors and mechanical components that are controlled by these microprocessors. The volume socket connects the volume transducer to the base unit and fits into the face-mask. The gas tube is linked to a Nafion tube connecting it to the volume transducer on the base unit and onto the face-mask.

(a) (b)

Figure 2: Subject (a) fitted with the face-mask, and (b) resting data collected.

A Hans Rudolph face-mask with head cap assembly was used with a Triple-V volume transducer for the defined exchange of expiratory gas with the base unit (See Figure 2). The face-mask is a single piece mould of translucent silicone rubber, in three sizes: small, medium and large to ensure a tight fit in order to control all the expiratory exchange. The face-mask is held in place with a polyester net head cap that incorporates velcro straps with clips. Expired air, collected during the treadmill march, was passed through the in-built analyser of the Metamax base unit. The expired gases are processed and ventilation, VO_2 and expired CO_2 (VCO_2) are calculated. The software processes a further 24 variables for output via A-D conversion in a Windows environment. These variables and their calculations are shown in Appendix C.

Prior to each experimental trial subjects were fitted with the face-mask shown in Figure 2 and their helmets were placed over the polyester net head cap. Resting data were collected for one minute prior to each condition.

Calibration

Under standardised laboratory conditions any variation in metabolic and ventilatory measurements should reflect biological rather than technical variability. Before each session the Metamax was calibrated: first using a Hans Rudolph 3L syringe, followed by gas volume. The volume transducer on the Metamax base unit was connected to the syringe and the calibration process was initiated from the main unit with six volume measurements conducted and the average compared to the nominal value.

The gas analysers were calibrated using (1) ambient air and (2) a 16.10% O_2; 4.9% CO_2; 79% N_2 mixture. The gas analysis tube was connected to the gas socket at the base unit and pointed towards ambient air. This forms the basis of measurement 1. Measurements are terminated when 3 values are within scope of the allowed deviation. Measurement 2 was performed with the gas mixture of O_2, CO_2 and N_2 which was fed into the base unit from a “bladder” used to collect the gas.

A breath-by-breath gas analyser such as the Metamax, when correctly calibrated, has a capability of less than 0.25% of full scale, and calibration gas concentrations are within 0.03%. The measurement accuracy for ventilation is approximately 4%.

TREADMILL HABITUATION

All subjects were familiarised with equipment and laboratory test conditions during the preparatory briefing sessions. As the experiment involved load carriage on a motorised treadmill, subjects were habituated to walking on the Cybex Trotter 900T in the Ergonomics laboratory at Rhodes University. Subjects were taught how to mount and leave the treadmill safely and during the three habituation sessions walked at diverse speeds, with and without loads and on various gradients.

These comprehensive habituation sessions ensured that the soldiers, who were not previously accustomed to treadmill walking, were completely comfortable on the treadmill prior to the submaximal test and the experiment proper.

MAXIMAL OXYGEN CONSUMPTION ($VO_{2\ max}$)

The accepted criterion for cardiorespiratory endurance is directly measured maximal oxygen uptake ($VO_{2\ max}$) from a maximal-effort test. However, submaximal tests are often used to provide an estimation of maximal oxygen consumption. These predictive tests are particularly useful when working with large, diverse populations such as the military who are unfamiliar with laboratory testing, and/or under conditions in which it is not logistically feasible to conduct direct $VO_{2\ max}$ tests on all subjects.

The submaximal treadmill test utilised in this project was the Modified Bruce Protocol (American College of Sports Medicine, 1986). This protocol increments walking speed and gradient every 3 minutes. As this test uses an end-point based on a predetermined heart rate (HR) all subjects were fitted with a telemetry heart rate monitor (Polar) prior to testing. The predetermined HR was 85% of predicted maximal HR reserve (i.e. [(maximal HR-resting HR (0.85)] + resting HR). Outlined in Table V are the three-minute speed and gradient increments according to the Bruce protocol.

On completion of each stage, HR and perceptual ratings were recorded until subjects either reached their predetermined HR or requested to stop. The following prediction equation was utilised based on exercise duration:

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

TABLE V: Submaximal Bruce Protocol used for the estimation of maximal oxygen consumption.

Stage	Speed ($m.s^{-1}$)	Speed ($km.h^{-1}$)	Grade (%)
1	0.75	2.7	10
2	1.11	4.0	12
3	1.49	5.4	14
4	1.86	6.7	16
5	2.22	8.0	18
6	2.44	8.8	20

PSYCHOPHYSICAL PARAMETERS

Perceptual scales such as the Rating of Perceived Exertion (RPE) Scale and the Body Discomfort Scale reflect each subject's personalised response to the physical demands of a task. These scales assist in the understanding of subjects' perceptions of the external demands placed on them during a march. While these ratings are personalised responses, the numeric ratings recorded are a quantifiable measure from valid rating scales. They also assist in obtaining an overall assessment of the physical demands experienced by the individual, and in locating sites of physical strain.

Acknowledging the importance of the 'human element' in a study of this nature, it is important to obtain a tangible assessment of what the individual soldier actually 'feels' while executing the required military task. Bearing this in mind, a widely used psychophysical scale, RPE (Borg, 1970) and an established Body Discomfort (BD)

Scale (Corlett and Bishop, 1976) were included to enrich an understanding of the soldiers' responses to physically demanding situations.

Rating of Perceived Exertion (RPE) Scale

Borg (1970) was the first to propose the inclusion of the RPE Scale to compliment physiological responses during movement activities, and since then the validity of this scale has been comprehensively tested (Gamberale, 1985; Watt and Grove, 1993; Garcin **et al.**, 1998). It consists of a 15-point scale ranging from a rating of 6 (minimal exertion) to a rating of 20 (maximal exertion).

The conceptual basis and use of the RPE was carefully explained to all subjects prior to testing, as an astute understanding of the use of the scale is essential in order to acquire valid ratings. Two measurements were taken namely "Local" RPE, which was based on feelings of strain in the muscles and/or joints of the lower limbs, and "Central" RPE referring to cardiovascular strain. RPE was collected on conclusion of the third and sixth minutes and manually recorded on data sheets (Appendix B).

Body Discomfort (BD) Scale

The Body Discomfort scale uses the perception of muscular pain as a measure of body discomfort. A "body map", divided into 27 segments is presented. Ratings of intensity of responses are on a 10-point Lickert scale in which 1 refers to "Minimal Discomfort" and 10 to "Extreme Discomfort" (See Appendix B). The Body Discomfort scale was administered at the end of each session while the subject straddled the treadmill before dismounting. Two body regions could be selected. The subjects were asked to point to the site(s) of discomfort and to rate the intensity of such discomfort.

SUBJECTS

Forty infantry soldiers (30 males and 10 females) comprised the initial sample. Failure to perform the most strenuous condition (6.5 $km.h^{-1}$ carrying 65kg) and a high drop out rate in several other conditions resulted in the female data being excluded from analysis. The final sample therefore comprised of males (n=30). Subjects were recruited from the local military base and attended a briefing session where the testing procedures were explained.

Army Medical Personnel cleared all subjects for participation after a full medical examination. Each subject was informed as to the nature of the study and received verbal and written information about the test procedures (Appendix A). All subjects gave voluntary, written, informed consent (See Appendix A) to a research protocol approved by the Ethics Committee of Rhodes University.

SUBJECT CHARACTERISTICS

The average age of the soldiers in this investigation was 29 years, ranging from 24 to 35 years (See Table VI). Although the average military experience was 7 years there was a substantial range of experience as some had been in the military for only 3 years while others had over 10 years experience, the highest being 14 years service.

It is evident from Table VI that there was a wide range of morphologies in the group. This is seen in high coefficients of variation in body mass and body composition. The lightest soldier was 53kg and the heaviest 97kg. Despite these differing morphologies all soldiers recruited to the military are required to carry the same backpack loads and march at the same speeds. Predictably then a large range of responses for a given workload will be evident.

TABLE VI: Demographic Data; n=30.

Variable	Mean	S.D.	C.V.
Age (Years)	29.20	3.02	10.35
Military Experience (Years)	6.93	2.56	36.90
Stature (mm)	1711.40	61.64	3.60
Leg Length (mm)	909.20	38.10	4.19
Body Mass (kg)	68.15	8.69	12.75
Body Fat (%)	17.38	3.87	22.27
LBM (%)	82.80	3.95	4.77
BMI (kg.$(m^2)^{-1}$)	23.81	2.71	11.39
$VO_{2\ max}$ (ml.kg^{-1}.min^{-1})	40.16	7.64	19.03

(S.D-standard deviation; C.V.-coefficient of variation (%); LBM – Lean Body Mass; BMI – Body Mass Index; $VO_{2\ max}$ – maximal oxygen consumption)

Mean BMI of 23.81 kg.$(m^2)^{-1}$ is barely within the ACSM (1986) recommended range of 20-24.9 kg.$(m^2)^{-1}$ for adult men, and although percent body fat (17.38%) is comparable to that reported on soldiers internationally (Christie and Todd, 2001), wide ranges in percent body fat (C.V.=22.27%) and cardiovascular status (C.V.=19.03%) characterised the sample. $VO_{2\ max}$ values measured in otherwise healthy young men are usually between 45 and 55 $ml.kg^{-1}.min^{-1}$ (Kruss **et al.**, 1989), which is 60% lower than that of elite athletes. The results of the present project were considerably lower (40.16 $ml.kg^{-1}.min^{-1}$) than expected, with values 10% lower than those obtained three decades ago by Wyndham and co-workers on several hundred miners in South Africa (Wyndham **et al.**, 1971). These rather low $VO_{2\ max}$ figures could be associated with dietary, health and occupational and socio-economic shifts in South Africa since the 1970's. Furthermore, the mean age of the group (29 years) would indicate a substantial drop in $VO_{2\ max}$ due to the age of the subjects with Noakes (1992) proposing that there is a gradual decline of approximately 9% per decade after the age of 25. It should be noted that subjects in each grid were matched in age, body composition and cardiovascular status.

MILITARY GEAR

All subjects wore standardised military uniform including boots and helmets, but excluding rifles; they also wore battle jackets and backpacks supplied by Ergotech, a military research subsidiary.

The mass of the battle jacket was 11.12 kg for all conditions while the four backpacks, packed by the local infantry base, were adjusted to ensure that the total added load carried was 20kg, 35kg, 50kg and 65kg under the respective conditions. Outlined in Table VII is the breakdown of the loads carried.

TABLE VII: Breakdown of each load making up the four total loads to be carried.

	Battle Jacket (kg)	Helmet (kg)	Backpack (kg)	Total load (kg)
Light Load	11.12	1.26	7.62	20
Light Moderate	11.12	1.26	22.61	35
Moderate Heavy	11.12	1.26	37.62	50
Heavy Load	11.12	1.26	52.62	65

EXPERIMENTAL PROCEDURE

Prior to the experimental phase subjects reported to the laboratory on five separate occasions for habituation. During these sessions subjects were familiarised with laboratory equipment and testing protocols, the main emphasis being on habituation to treadmill walking. While some subjects were being habituated on the treadmill, basic anthropometric measurements were being taken on others. In the final preparation session submaximal $VO_{2\ max}$ assessments were conducted.

On arrival at the laboratory, for each of the four experimental sessions, subjects were fitted with a Polar Heart Rate Monitor, the battle jacket, helmet and relevant backpack. The face-mask was fitted and attached to the portable Metamax. Subjects were then required to sit quietly beside the treadmill for the collection of resting data for one minute before straddling the treadmill. Once the speed had been selected and as the treadmill was building up momentum, "Anticipatory" heart rate was recorded and the subject stepped onto the treadmill and started the six-minute march which is illustrated in Figure 3.

Figure 3: Subject marching on the treadmill during the six-minute march.

Throughout the six-minute test period, cardiorespiratory and metabolic data were collected. Another feature of the Metamax unit is an event marker. Depression of this marker results in a mark being recorded in order to distinguish specific events when data are analysed. An event marker was placed at minutes two and three and minutes five and six in order to analyse the data collected during the third and sixth minutes. This information was then used to ascertain in which of the 16 conditions steady-state had been reached. The data captured by the Metamax included: breathing frequency (F_B), tidal volume (V_T), minute ventilation (V_E), oxygen consumption (VO_2), metabolic CO_2

production (VCO_2) and respiratory quotient (RQ). Energy expenditure ($kcal.min^{-1}$ and $kJ.min^{-1}$) and power output (W) were derived from VO_2. The data were downloaded onto a PC and printouts obtained (See Appendix C).

During the third and sixth minutes cadence was monitored with a cadence meter and during the final 15 s of minutes three and six heart rate was recorded and "Central" and "Local" RPE data were collected immediately thereafter. On completion of the six-minute trial, subjects straddled the treadmill and were asked to identify sites and intensities of discomfort on the Body Discomfort Scale.

STATISTICAL ANALYSIS

All data were downloaded to a STATSGRAPHICS (Version 6.0) statistical software package and basic descriptive statistics were run on all variables (See examples, Appendix C). The level of significance was set at $p<0.05$, providing a level of confidence of 95%. Therefore there were 5 chances in 100 that a Type I error could have been committed (rejecting a true hypothesis). The chances of committing a Type II error (failing to reject a false hypothesis) are dependent on subject numbers. The 30 subjects included in the present project should limit this probability.

Related t-tests were calculated to determine whether there were any differences between minutes three and six in order to establish whether a steady-state had been achieved. All analysis of variance were conducted on data collected during the last (sixth) minute of each condition. Two-way ANOVAs were calculated to determine differences with each increment of speed and load respectively, and between each condition. One-way ANOVAs were calculated to determine differences between different loads when walking at a particular speed and between different speeds when carrying a particular load. One-way ANOVAs were used to determine any differences in physiological and perceptual responses between the five broad categories of exertional effort proposed. Finally, the relationship between Working Heart Rate and RPE, and between VO_2 and V_E was investigated by computing correlations.

CHAPTER IV

RESULTS AND DISCUSSION

INTRODUCTION

The purpose of this investigation was to identify optimal combinations of marching speed and backpack weight applicable for specific military requirements and which are appropriate for the South African soldier. Sixteen conditions, comprising four different speeds (3.5, 4.5, 5.5 and 6.5 $km.h^{-1}$) and four different loads (20, 35, 50 and 65kg), were investigated. These combinations cover the operational spectrum relative to whether a short duration, high intensity march is needed or whether a more prolonged march at a lower intensity is required. The overall objective was to take cognisance of specific military requirements plus the physical capabilities of the soldier in order to ensure post-march combat-readiness.

The variables under consideration were analysed individually, then assimilated in an integrated discussion in order to establish a more holistic profile of responses. Presentation of data is mostly in the form of a four-by-four matrix with speed on the abscissa and load on the ordinate (See Figure 4). In this matrix each of the conditions is represented in one of the sixteen blocks.

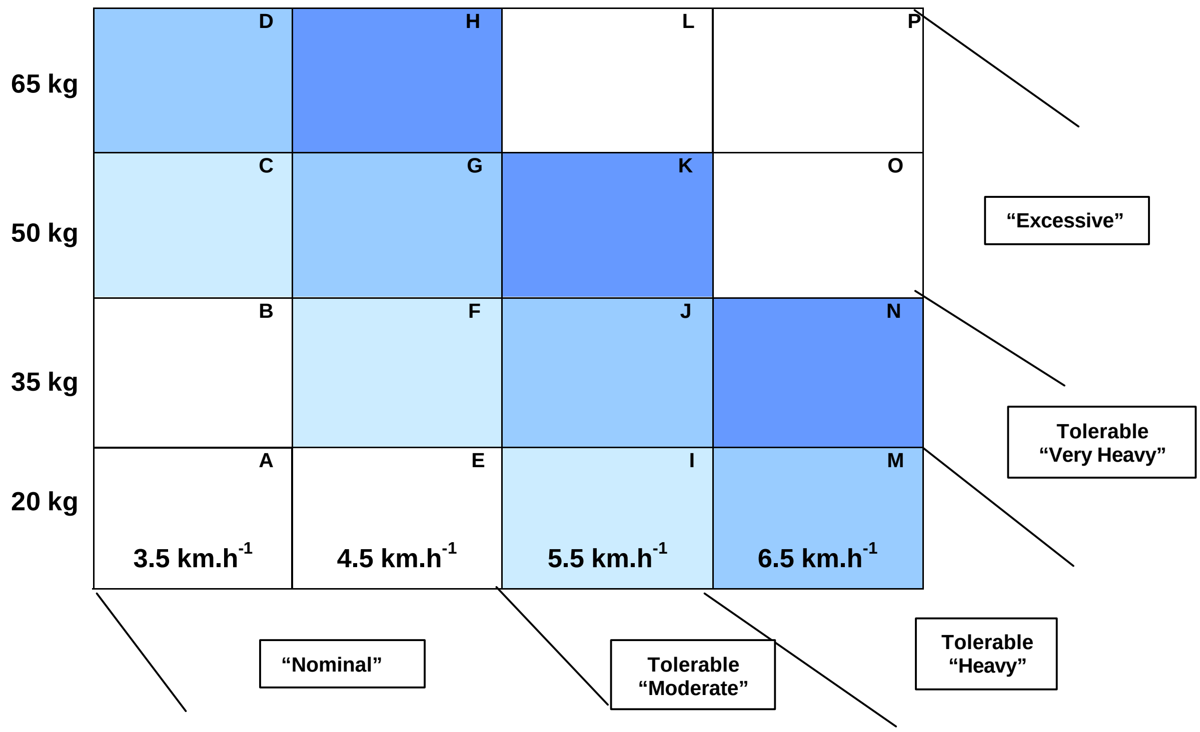


Figure 4: Breakdown of conditions into three broad categories of exertional effort with the "tolerable" category further broken down into three levels of intensity.
(In all subsequent figures using this matrix system the attributes "nominal", "tolerable" and "excessive" are indicated within the grid to facilitate location of roughly equivalent stress levels as diagonals between lower left and upper right sectors).

Preliminary review of the overall results revealed three of the 16 conditions (A, B and E) constituted "nominal", and three (L, O and P) "excessive" strain; these are reflected at the bottom left and top right of Figure 4 respectively. The remaining 10 representing tolerable, but at "moderate", "heavy" and "very heavy" combinations of speed and load, are shown as shaded diagonals comprising combinations which imposed similar levels of stress on the soldiers. The criteria for classification were based on statistically similar physiological responses for varying combinations of speed and load. These categorisations will be discussed fully in the subsequent text.

PHYSIOLOGICAL RESPONSES

CARDIAC RESPONSES

Baseline Heart Rates

Baseline 'Reference' heart rates were recorded during the initial habituation sessions while subjects were seated and rested. The mean reference heart rate for the group was 70 $bt.min^{-1}$, considered a 'normal' adult resting heart rate (McArdle **et al.**, 1996). Cardiac frequency was also recorded prior to, and during, each of the 16 experimental conditions.

"Anticipatory" Heart Rates

Increased cardiac frequency associated with anticipation is largely due to the feed-forward control of the circulatory system (Rowell, 1986). Furthermore, there is an increased release of epinephrine and norepinephrine, hormones known to be released in increasing amounts during periods of anxiety and in response to physical activity (McArdle **et al.**, 1996). These authors demonstrated that heart rates averaged as high as 148 $bt.min^{-1}$ at the starting commands prior to a 55 m sprint. This represented 74% of the total heart rate adjustment to the run.

Anticipatory heart rate responses were recorded immediately prior to each experimental condition while subjects were straddling the treadmill and the treadmill was building up momentum (See Figure 5). It should be noted that the subjects in the present study, whose mean body mass was 68.2kg, were transporting on average 29%, 51%, 73% and 95% of the mean body weight of the group when carrying the 20, 35, 50 and 65kg loads under investigation in the present study. Heart rates were significantly elevated prior to each of the 16 conditions with the lowest anticipatory heart rates, averaging 89 bt.min^{-1}, recorded prior to the three “nominal” stress conditions. Anticipatory heart rates, ranging between 90 bt.min^{-1} and 105 bt.min^{-1}, were recorded prior to the remaining conditions, with no consistent findings observed. It does however appear that most soldiers had preconceptions that higher loads would be more stressful. The only anomaly was Condition H (4.5 km.h^{-1} with 65kg) in which anticipatory heart rate was as high as 117 bt.min^{-1}.

Load (kg) \ Speed (km.h^{-1})	3.5	4.5	5.5	6.5
65	D: 101 (15.41) 15.32% Tolerable (Heavy)	H: 117 (9.26) 8.29% Tolerable (Very Heavy)	L: 98 (14.34) 14.64% Excessive	P: 105 (16.01) 15.28% Excessive
50	C: 102 (16.30) 15.95% Tolerable (Moderate)	G: 95 (8.47) 8.89% Tolerable (Heavy)	K: 96 (14.91) 15.54% Tolerable (Very Heavy)	O: 91 (17.42) 19.21% Excessive
35	B: 88 (11.57) 13.07% Nominal	F: 96 (16.55) 17.24% Tolerable (Moderate)	J: 88 (11.59) 13.19% Tolerable (Heavy)	N: 95 (11.53) 12.11% Tolerable (Very Heavy)
20	A: 89 (12.34) 13.94% Nominal	E: 89 (10.06) 11.27% Nominal	I: 92 (14.76) 16.05% Tolerable (Moderate)	M: 88 (11.34) 12.89% Tolerable (Heavy)

Figure 5: Anticipatory heart rate responses (bt.min^{-1}) prior to each condition.
(Means with standard deviations in brackets, %=coefficient of variation).

“Working” Heart Rates

Working heart rate responses during the “nominal” stress conditions were low and ranged from 101 bt.min^{-1} to 105 bt.min^{-1} (Figure 6). There was no statistical difference in working heart rates in those conditions in which subjects were working at less than 60% of the age-predicted mean maximum heart rate (HR_{max}) of the group. At the other extreme, the three excessive stress conditions (shown at the top right of the matrix; Figure 6) elicited heart rate responses greater than 160 bt.min^{-1} during the sixth minute. Subjects were, under these conditions, working at greater than 80% of the age-predicted mean maximum heart rate of the group, and expectedly, there was a significant increase in working heart rates between the third and sixth minutes.

Working heart rates under the 10 “tolerable” stress conditions exhibited a broad range of 116 bt.min^{-1} to 158 bt.min^{-1}. This is to be expected and was why this general tolerable category was further broken down into three levels of stress. Noteworthy is the fact that there was no significant difference in working heart rate within each of the three levels of “moderate” (Conditions C, F and I), “heavy” (Conditions D, G, J and M) and “very heavy” (Conditions H, K and N) stressors. Additionally, there was no significant difference in working heart rate between the three “moderate” and four “heavy” conditions. Only once speed and load were increased to the “very heavy” stress level were significant increases in working heart rate observed. The three “very heavy” conditions (H, K and N) elicited heart rate responses between 150 bt.min^{-1} and 158 bt.min^{-1} which were significantly ($p<0.05$) higher than the other seven conditions within the “tolerable” category.

Load (kg)	3.5 km.h⁻¹ *Minute 3*	3.5 km.h⁻¹ *Minute 6*	4.5 km.h⁻¹ *Minute 3*	4.5 km.h⁻¹ *Minute 6*	5.5 km.h⁻¹ *Minute 3*	5.5 km.h⁻¹ *Minute 6*	6.5 km.h⁻¹ *Minute 3*	6.5 km.h⁻¹ *Minute 6*
65	D 131 (24.50) 18.68%	D 137* (24.71) 17.98%	H 151 (16.07) 10.61%	H 156* (19.39) 12.43%	L 156 (19.19) 12.27%	L 160* (18.05) 11.27%	P 166 (10.54) 6.33%	P 173* (8.27) 4.78%
	Tolerable (Heavy)		Tolerable (Very Heavy)		Excessive		Excessive	
50	C 123 (18.11) 14.67%	C 127* (18.83) 14.88%	G 126 (14.77) 11.71%	G 130* (15.16) 11.67%	K 143 (16.69) 11.64%	K 150* (18.06) 12.06%	O 159 (14.52) 9.11%	O 164* (15.37) 9.34%
	Tolerable (Moderate)		Tolerable (Heavy)		Tolerable (Very Heavy)		Excessive	
35	B 104 (12.99) 12.47%	B 105 (15.36) 14.63%	F 120 (16.02) 13.31%	F 122 (16.54) 13.54%	J 125 (19.47) 15.57%	J 127 (20.68) 16.64%	N 155 (14.35) 9.28%	N 158* (16.26) 10.27%
	Nominal		Tolerable (Moderate)		Tolerable (Heavy)		Tolerable (Very Heavy)	
20	A 102 (10.80) 10.60%	A 103 (11.53) 11.19%	E 101 (12.65) 12.54%	E 101 (10.77) 10.65%	I 116 (14.52) 12.49%	I 118 (15.05) 12.74%	M 126 (17.31) 13.73%	M 129* (17.30) 13.41%
	Nominal		Nominal		Tolerable (Moderate)		Tolerable (Heavy)	

Speed ($km.h^{-1}$)

Figure 6: Working Heart Rate responses ($bt.min^{-1}$) recorded during each of the experimental conditions.
(Means with standard deviations in brackets, %=coefficient of variation)
*(**Note:** Working heart rates were recorded during the third and sixth minutes of exertion; *denotes statistical difference between minute 3 and 6)*

Related t-test analysis revealed that during 6 of the 16 conditions no significant difference in working heart rate was observed between the third and sixth minutes (See Figure 6). This in all probability is an indication that a steady-state heart rate response was achieved by the third minute under the following conditions:

- *Marching at 3.5 km.h^{-1} with a 20kg load (A).*
- *Marching at 3.5 km.h^{-1} with a 35kg load (B).*
- *Marching at 4.5 km.h^{-1} with a 20kg load (E).*

"Nominal" Stress

- *Marching at 4.5 km.h^{-1} with a 35kg load (F).*
- *Marching at 5.5 km.h^{-1} with a 20kg load (I).*
- *Marching at 5.5 km.h^{-1} with a 35kg load (J).*

"Tolerable" Stress

Under all loaded conditions in which speeds were higher than 5.5 km.h^{-1} there was a significant ($p<0.05$) increase in heart rate response between minutes three and six; and when the load was increased to 50kg, irrespective of speed, significant differences were noted between the third and sixth minutes. Steady-state was therefore not achieved during the following conditions; marked with an asterisk in Figure 6:

- *Marching at 3.5 km.h^{-1} with a 50kg load (C).*
- *Marching at 3.5 km.h^{-1} with a 65kg load (D).*
- *Marching at 4.5 km.h^{-1} with a 50kg load (G).*
- *Marching at 4.5 km.h^{-1} with a 65kg load (H).*
- *Marching at 5.5 km.h^{-1} with a 50kg load (K).*
- *Marching at 6.5 km.h^{-1} with a 35kg load (N).*
- *Marching at 6.5 km.h^{-1} with a 20kg load (M).*

"Tolerable" Stress

- *Marching at 5.5 km.h^{-1} with a 65kg load (L).*
- *Marching at 6.5 km.h^{-1} with a 50kg load (O).*
- *Marching at 6.5 km.h^{-1} with a 65kg load (P).*

"Excessive" Stress

The present findings suggest that loads up to 50% of body mass will in all probability result in the attainment of steady-state if speed is not in excess of $5.5km.h^{-1}$. This is in contrast to other authors who suggest that loads should not exceed 30-45% of body weight to ensure soldiers remain in steady-state (Cathcart **et al.**, 1923; Kinoshita, 1985; Haisman, 1988; Scott and Ramabhai, 2000). It is therefore suggested that the three “nominal” stress conditions will in all probability result in the attainment of steady-state, whereas achievement of steady-state is highly improbable under the three “excessive” conditions. Within the “tolerable” conditions, as here defined, prediction is less certain and depends to some extent upon the physical conditioning of the subjects.

Quesada **et al.** (2000) recently demonstrated significant increases in heart rate between minutes 1, 5, 10, 20 and 40. Their soldiers, when marching at 6 $km.h^{-1}$ while carrying 30% of body weight were, at minutes 1, 5 and 40 working at 56%, 61% and 66% of HR_{max} respectively. This is in contrast to their O_2 uptake results which plateaued after five minutes. It could therefore be hypothesised that had marching continued for a further 30-40 minutes in the present study, there might have been approximately a 10% increase in working heart rate in response to exercise duration. It is thus argued that a six-minute data collection period is insufficient to suggest that heart rate would have remained in steady-state for up to four hours as has previously been suggested (Sagiv **et al.**, 1994).

VENTILATORY RESPONSES

During physical activity homeostasis demands increased ventilation brought about by changes in tidal volume (V_T) and breathing frequency (F_B). As a result the amount of air moved per minute (V_E) in response to an increased oxygen demand is increased. This increase in ventilation is required to maintain proper alveolar ventilation for the increased exchange of oxygen and carbon dioxide (Berger, 1982; McArdle **et al.**, 1996). An increase in V_E can therefore be a result of either increasing F_B or V_T, or a combination of both. During the six-minute treadmill march ventilatory responses (V_T, F_B and V_E) were recorded in the third and sixth minutes.

Breathing Frequency (F_B)

Figure 7 shows the mean breathing frequency responses under each experimental condition. Breathing frequency was below 30 br.min^{-1} during the three "nominal" stress conditions and the lowest response, recorded under Condition E (4.5 km.h^{-1} with a 20kg backpack), was 26.4 br.min^{-1}. During seven of the "tolerable" conditions which fell within the "moderate" and "heavy" levels of exertion, F_B was not significantly different and ranged from 30 br.min^{-1} to 35 br.min^{-1}. Only once the intensity of marching increased to the levels "very heavy" and "excessive" did F_B increase substantially, to above 39 br.min^{-1}. The highest frequency (52 br.min^{-1}) was recorded during the most strenuous condition (walking at 6.5 km.h^{-1} with a 65kg backpack).

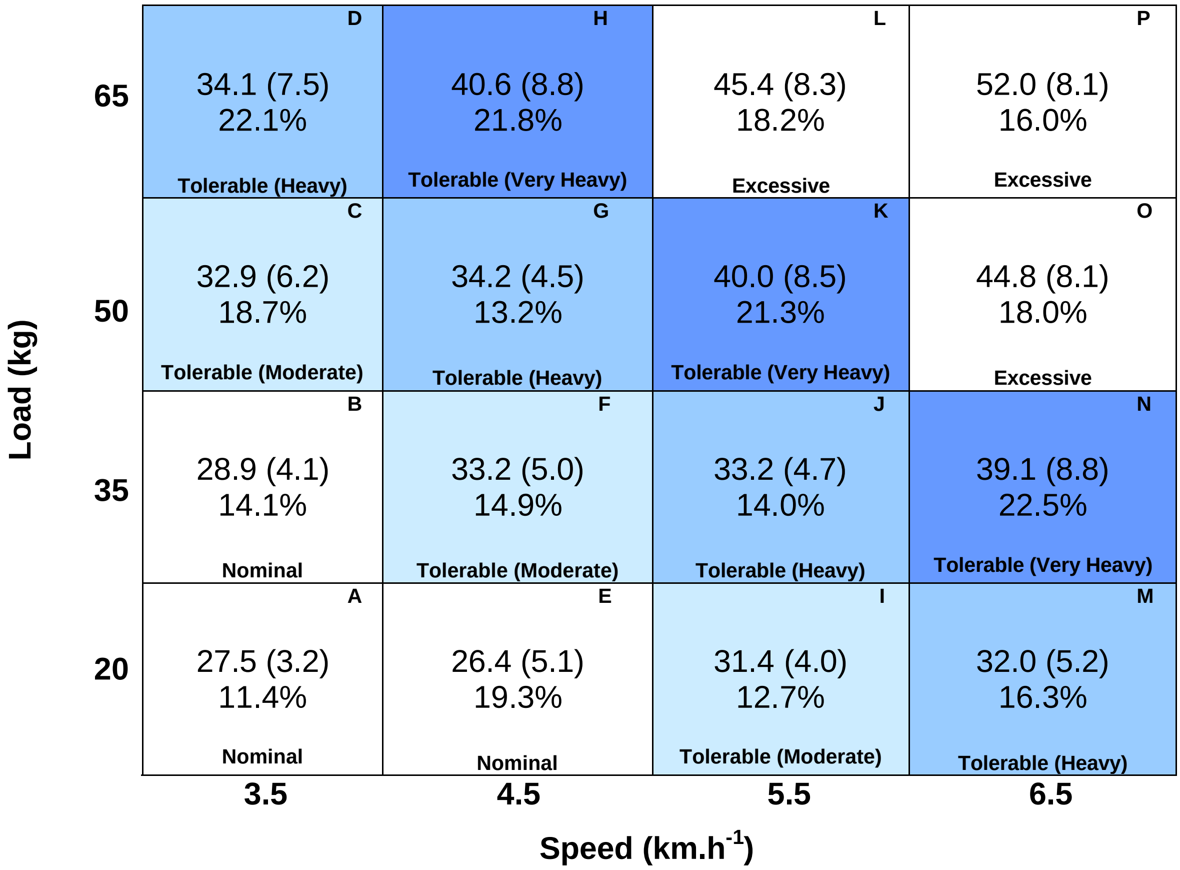


Figure 7: **Breathing frequency (F_B) responses to increments in speed and load.**
(Means with standard deviations in brackets, %=coefficient of variation).

Breathing frequency increased more in response to loading than to speed; on average a 1.5-fold increase from carrying 20kg to 65kg. In response to speed increments however, there was on average a 1.4-fold increase in F_B between marching at 3.5 km.h^{-1} and 6.5 km.h^{-1}. There was a 51% increase in F_B with an increase in speed and load to the most strenuous condition.

Tidal Volume (V_T)

Tidal Volume (V_T) is defined as the volume of air moved by the lungs with each normal breath (Astrand and Rodahl, 1977; McArdle **et al**., 1996). These authors report that a typical value for males at rest is approximately 0.5L. Presented in Figure 8 are the mean V_T values under each experimental condition. In contrast to the F_B response, V_T increased more in response to speed than load. There was a 1.5-fold increase in V_T in response to increases in speed compared to a 1.3-fold increase in response to increasing load.

The volume of air moved per breath was below 1L for each of the three "nominal" stress conditions, which was not statistically different when speed and load were increased to the "tolerable" level. This however excludes Conditions J (5.5 $km.h^{-1}$ with 35kg) and M (6.5 $km.h^{-1}$ with 20kg) during which V_T was significantly higher than during the "nominal" stress marches and remaining seven "tolerable" stress marches. Both these conditions included the two highest speeds combined with the two lightest loads of the "tolerable" stress category. There were further significant increases in V_T as speed and load moved to the "excessive" category. The highest V_T was recorded during Condition P (6.5 $km.h^{-1}$ with a 65kg load) and the lowest was recorded when subjects were exposed to Condition A (walking at 3.5 $km.h^{-1}$ with a 20kg load). A 58% increase in V_T was therefore evident when both speed and load were increased to the most stressful condition.

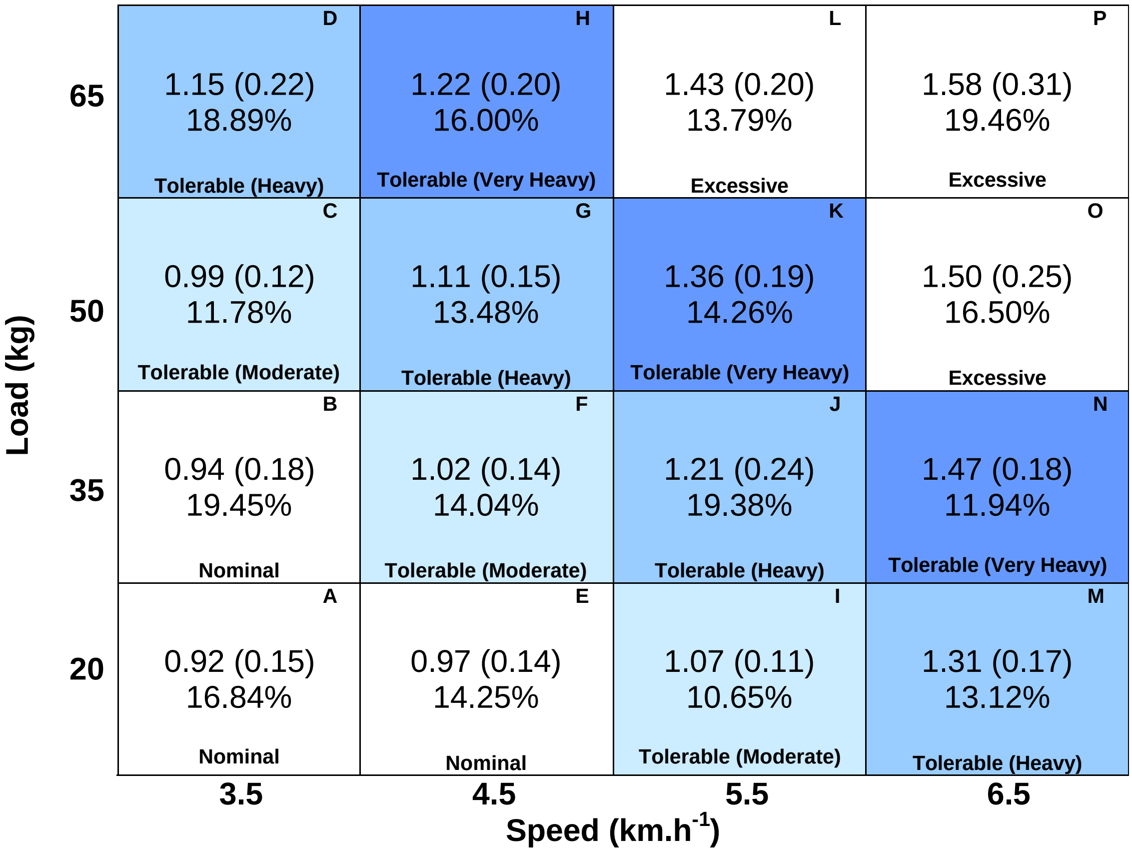


Figure 8: **Tidal Volume (V_T) responses to increases in speed and load.**
(Means with standard deviations in brackets, %=coefficient of variation).

There was no significant difference in either F_B or V_T under all loaded conditions when increasing speed from 3.5 to 4.5 km.h^{-1}. However, when speed was increased from 3.5km.h^{-1} to 5.5 km.h^{-1} there was a significant ($p>0.05$) increase in V_T irrespective of load. This was only evident with F_B when increasing load to 50kg and above. Both ventilatory responses increased significantly under the two lowest loads between 5.5 km.h^{-1} and 6.5 km.h^{-1}. In contrast, both responses showed no statistical difference under the two heaviest loaded conditions when this speed increment was made.

An increase in V_T, as opposed to F_B, results in a substantial drop in wasted ventilation. With submaximal aerobic training V_T becomes larger and F_B is considerably reduced (Jirka and Adamus, 1965; Fringer and Stull, 1974). This increase in V_T, minimises wasted dead-space ventilation which is an advantage during any form of physical activity as most of the air taken in participates in alveolar ventilation (V_A). At approximately 60% of vital capacity V_T can no longer increase efficiently resulting in an increase in F_B and hence dead-space ventilation. This is a response to maintain alveolar ventilation and thus V_E must increase. Therefore, at higher exercise intensities the increase in F_B will result in decreased efficiency. This increase in V_T rather than F_B is a training phenomenon, and unconditioned individuals often tend to increase F_B. Although the present subjects appeared not to be well trained (mean $VO_{2\ max}$ values were 40 $ml.kg^{-1}.min^{-1}$), increases in speed particularly when combined with a low load resulted in a more efficient ventilatory pattern as opposed to increments in load. Therefore, although numerous studies have shown that increases in speed impart a greater energetic cost than increases in load (Soule **et al.**, 1978; Charteris **et al.**, 1989) the ventilatory responses of the subjects in this project reflected otherwise.

Alternatively, these ventilatory responses could be attributed to the backpack load. Most trained individuals will increase V_T up to 60-65% of Vital Capacity (VC) which is the volume of air that can be voluntarily moved in one breath from full inspiration to maximal expiration. Although values vary considerably with body size and body position while testing, average values for healthy men when standing are 4-5L. During this study subjects did not reach 60% of their VC, and the highest percentage recorded was during

Condition P (6.5 $km.h^{-1}$ with a 65kg load) when subjects were working at 35% of their estimated VC (based on an estimated average of 4.5L). A possible explanation for this is that as load increased, depth of breathing was restricted due to the increased compression of the backpack straps on the chest wall, forcing subjects to take quicker and shallower breaths.

Minute Ventilation (V_E)

Minute Ventilation (V_E) is the product of V_T and breathing rate per minute (Tortora and Grabowski, 1996). An average V_E is approximately 6$L.min^{-1}$ for a healthy young male. Figure 9 represents the mean V_E responses under all conditions.

Minute ventilation was below 30 $L.min^{-1}$ under the three “nominal” stress conditions and between 30 $L.min^{-1}$ and 45 $L.min^{-1}$ in the “moderate” and “heavy” conditions in the “tolerable” category. Minute ventilation was significantly increased when subjects were exposed to the “very heavy” conditions and ranged between 45 $L.min^{-1}$ to 55 $L.min^{-1}$. There was also a significant increase in V_E when speed and load were increased to the three “excessive” conditions during which V_E was above 60 $L.min^{-1}$. The highest V_E, 80.99 $L.min^{-1}$ was recorded during condition P (6.5 $km.h^{-1}$ with a 65kg load), a finding indicative of a maximal effort.

Load (kg) \ Speed (km.h^{-1})	3.5	4.5	5.5	6.5
65	D: 41.37 (8.13) 19.66% Tolerable (Heavy)	H: 49.00 (8.93) 18.23% Tolerable (Very Heavy)	L: 64.28 (11.56) 18.00% Excessive	P: 80.99 (13.06) 16.13% Excessive
50	C: 32.74 (5.36) 16.26% Tolerable (Moderate)	G: 37.77 (4.97) 13.15% Tolerable (Heavy)	K: 53.14 (7.71) 14.51% Tolerable (Very Heavy)	O: 66.26 (12.31) 18.57% Excessive
35	B: 26.77 (5.12) 19.11% Nominal	F: 33.12 (4.63) 13.97% Tolerable (Moderate)	J: 40.02 (8.67) 21.65% Tolerable (Heavy)	N: 52.71 (13.46) 23.53% Tolerable (Very Heavy)
20	A: 24.96 (3.34) 13.37% Nominal	E: 25.42 (3.96) 15.57% Nominal	I: 33.49 (4.30) 12.82% Tolerable (Moderate)	M: 41.73 (7.33) 17.57% Tolerable (Heavy)

Figure 9: Minute ventilation (V_E) responses to increases in speed and load.
(Means with standard deviations in brackets; %=coefficient of variation).

Comparison of these responses to findings of an earlier study by Ramabhai (1999) *in situ* is useful. When marching in the field under a similar condition (4.5 km.h^{-1} with a 35kg load), Ramabhai's subjects increased V_T to a far greater extent than the present subjects. Although $VO_{2\ max}$ was not estimated in the previous study, comparison of body composition results suggest that her subjects were better conditioned than the subjects in the present study (12% body fat compared to 17%). This, together with the impact of exercise duration, could have resulted in different responses to very similar workloads.

In the previous study, subjects had been marching for three hours on a flat terrain at approximately 55% $VO_{2\ max}$ when the measurements were made. Researchers have shown that during endurance exercise at 55-70% of $VO_{2\ max}$ there is an initial steady-state response in ventilation. However, after 30-60 minutes there is a progressive increase in ventilation termed the 'hyperventilatory drift' (Martin **et al.**, 1981; Hanson **et al.**, 1982). These authors showed that this response is brought about by a slow increase in F_B and the V_D/V_T ratio while VCO_2 and V_T remain constant. There is, therefore, an increase in dead-space ventilation and an inefficient pattern of breathing. One proposed mechanism suggested by these authors includes the effects of an increase in body temperature with increased exercise duration. Prolonged marching above 55-70% of $VO_{2\ max}$ would therefore eventually result in an inefficient pattern of breathing that will ultimately increase the energetic demand of the task. It is highly probable that over longer periods, breathing patterns during the conditions when VO_2 was between 55% and 70% of maximum would have become progressively less efficient.

METABOLIC RESPONSES

During the six-minute treadmill march detailed metabolic data were collected between minutes two and three and minutes five and six using the Metamax portable Ergospirometry System.

Oxygen Consumption Responses

Due to the linear relationship identified between body mass and the energy required to move at a given rate (Wyndham **et al.**, 1971; McArdle **et al.**, 1996), O_2 uptake values of each condition are expressed relative to body mass ($ml.kg^{-1}.min^{-1}$) in Figure 10.

At 3.5 $km.h^{-1}$ these soldiers were working at less than 56% of maximum aerobic capacity regardless of the load carried. A difference of carrying 20kg compared to 50kg is associated with only a 13% increase in VO_2 when marching at this speed. There was a further 11% increase when load was increased from 50kg to 65kg, a load which amounted to 95% of the mean body weight of the group. In contrast, when speed was increased from 3.5 $km.h^{-1}$ to 6.5 $km.h^{-1}$, irrespective of the load, there was on average a 38% increase in VO_2. Increases in speed therefore resulted in a more substantial increase in VO_2 as opposed to increments in load.

Carrying the 20kg and 35kg loads while maintaining a speed of 4.5 $km.h^{-1}$ resulted in a VO_2 response below 50% of maximum, but which went above 50% when carrying the 50kg and 65kg loads. The difference between carrying 20kg and 50kg at this speed was still barely 20% of VO_2 and only increased to a 27% difference when 65kg was transported. At the highest speed of 6.5 $km.h^{-1}$ VO_2 was consistently above 60% of maximum even when carrying the 20kg load: and when carrying the two heaviest loads at this speed, subjects were performing at greater than 85% of $VO_{2\ max}$. The majority of these soldiers were working at an intensity equivalent to their maximal oxygen consumption values when marching at 6.5 $km.h^{-1}$ and transporting the 65kg load.

Although Soule **et al.** (1978) reported similar findings, less sensitive responses to increments in load were noted in their study. These authors reported that the difference between carrying a 35kg and 70kg load was only 11% and 16% of $VO_{2\ max}$ when marching at 3.2 $km.h^{-1}$ and 4.8 $km.h^{-1}$ respectively.

Oxygen consumption responses in the present investigation were low when marching at slower speeds combined with lighter loads. Conditions classified as "nominal" stress (below 40% $VO_{2\ max}$) are shown at the lower left of the matrix (See Figure 10). These combinations of speed and load should be able to be maintainable for prolonged marches without undue fatigue of the cardiorespiratory system and include the following combinations of marching speed and backpack load:

- *3.5 $km.h^{-1}$ with a 20kg backpack load (A).*
- *3.5 $km.h^{-1}$ with a 35kg backpack load (B).*
- *4.5 $km.h^{-1}$ with a 20kg backpack load (E).*

"Nominal" Stress

At the other end of the range, conditions that elicited responses greater than 80% of $VO_{2\ max}$ are reflected at the top right of the matrix (Figure 10). These speed and load combinations are not recommended, as premature fatigue will inevitably occur. These include the following three conditions:

- *5.5 $km.h^{-1}$ with a 65kg load (L).*
- *6.5 $km.h^{-1}$ with a 50kg load (O).*
- *6.5 $km.h^{-1}$ with a 65kg load (P).*

"Excessive" Stress

What is evident here is a disproportionate increase in energy cost with these three excessive speed and load combinations, a finding which supports the results of other authors (Hughes and Goldman, 1970; Soule **et al.**, 1978). Although it is unlikely that such excessive combinations would be employed on a regular basis by the military there may be times when soldiers would be required to march at high speeds with heavy backpacks. The consequence of these combinations is the onset of premature fatigue and a concomitant decrease in combat efficiency.

Load (kg) \ Speed ($km.h^{-1}$)	3.5	4.5	5.5	6.5
65	D 23.71 (3.68) 55% Tolerable (Heavy)	H 26.76 (5.04) 63% Tolerable (Very Heavy)	L 34.43 (4.39) 81% Excessive	P 42.75 (5.60) 100% Excessive
50	C 18.96 (3.52) 44% Tolerable (Moderate)	G 23.95 (3.09) 56% Tolerable (Heavy)	K 29.07 (4.03) 68% Tolerable (Very Heavy)	O 36.78 (5.05) 86% Excessive
35	B 15.69 (2.46) 37% Nominal	F 19.71 (3.04) 46% Tolerable (Moderate)	J 23.64 (3.37) 55% Tolerable (Heavy)	N 30.98 (2.99) 72% Tolerable (Very Heavy)
20	A 13.39 (1.19) 31% Nominal	E 15.43 (2.42) 36% Nominal	I 19.78 (2.70) 46% Tolerable (Moderate)	M 26.75 (2.99) 63% Tolerable (Heavy)

Figure 10: Mean Oxygen uptake ($mlO_2.kg^{-1}.min^{-1}$) measurements with percentages of predicted $VO_{2\ max}$ indicated.
(Standard deviations in brackets).

The most physiologically taxing condition (P) involved marching at 6.5 $km.h^{-1}$ with a 65kg backpack load. Comparison of the O_2 uptake responses under this condition and the submaximal predicted $VO_{2\ max}$ test results (40 $ml.kg^{-1}.min^{-1}$) revealed no significant difference. It is thus reasonable to assume that under this condition subjects were effectively at $VO_{2\ max}$; this was evident from data recorded during both the third and sixth minutes.

Identification of “tolerable” combinations of speed and load for prolonged marches in this study includes those conditions during which VO_2 remained within a 40-75% range of maximum, although three of these conditions (H, K and N) are classified as “very heavy” (See Figure 10). Support for a 40-60% range for the development of steady-state is provided by Casaburi **et al.** (1987), Epstein **et al.** (1988) and McArdle **et al.** (1996). In contrast however, other studies have expressed more caution and suggested that for prolonged marches VO_2 must remain within 30-40% of maximum (Astrand, 1967; Myles and Saunders, 1979). If that were the case, then all marches classified as “nominal” stress activities in the present study would be ideal, but unfortunately, militarily unrealistic.

Although in laboratory-controlled research it is possible to propose a theoretical ideal, when determining what speed-load combinations need to be employed for prolonged marches a compromise may have to be made between unnecessary strain placed on a soldier and achieving the military objective. Although those marches classified as “nominal” stress place little strain on a soldier, these combinations of speed and load may not meet the requirements of the military. The three levels of "tolerable" stress were therefore selected based on physiological cost, but at the same time recognising common military needs. However, cognisance should always be taken of adequate work-to-rest ratios, particularly when marching at these intensities for prolonged periods, a practice common in the military. The following conditions elicited VO_2 responses between 40-75% of maximum:

"Moderate" Stress:

- *3.5 $km.h^{-1}$ with a 50kg load (C).*
- *4.5 $km.h^{-1}$ with a 35kg load (F).*
- *5.5 $km.h^{-1}$ with a 20kg load (I).*

"Heavy" Stress:

- *3.5 $km.h^{-1}$ with a 65kg load (D).*
- *4.5 $km.h^{-1}$ with a 50kg load (G).*
- *5.5 $km.h^{-1}$ with a 35kg load (J).*
- *6.5 $km.h^{-1}$ with a 20kg load (M).*

"Very heavy" Stress:

- *4.5 $km.h^{-1}$ with a 65kg load (H).*
- *5.5 $km.h^{-1}$ with a 50kg load (K).*
- *6.5 $km.h^{-1}$ with a 35 kg load (N).*

These three levels reveal that only during the "moderate" stress conditions was VO_2 between 40-50% of maximum. This increased to 50-65% $VO_{2\ max}$ during the "heavy" stress conditions (excluding Condition H) and between 60-75% $VO_{2\ max}$ during the "very heavy" conditions. The three "moderate" intensity conditions are therefore "ideal" for prolonged marching, but the notion of "tolerable" stress levels can be extended to the other two levels in isolated incidences depending on military objectives, bearing in mind the cost in terms of post-march fatigue.

The range of speed and load combinations with the attributions “moderate” to “very heavy” within the tolerable stress category demonstrate that speeds of 6.5 $km.h^{-1}$ can be utilised as long as load is reduced to 20kg. It also appears that carrying 65kg can be managed if speed is dropped to 3.5 $km.h^{-1}$. It should be noted that oxygen consumption responses were statistically higher when subjects were assessed under Condition M as opposed to the other conditions classified as “heavy”. Arguably then, a high speed combined with a low load results in a higher energetic cost than a heavy load combined with a slow speed. Essentially however these results demonstrate that the combined demands of speed and load determine the cost to the individual.

VO_2/V_E Relationship

At any given marching speed, as backpack loads increase O_2 demand is met primarily by more rapid breathing. For any given backpack load as speed of marching is increased the higher O_2 demand is met more by deeper breathing. There was also a 3.3-fold increase in V_E with increments in speed and load. In the present study, a linear relationship was identified between air moved and O_2 taken up with a coefficient of determination (r^2), of 0.98.

Metabolic Equivalent (MET)

Intensity of workload is often expressed in MET units, a multiple of the average adult resting metabolic rate which is approximately 3.50 $mlO_2.kg^{-1}.min^{-1}$. Illustrated in Figure 11 is the MET equivalent of each of the 16 conditions. The average output during the “nominal” stress marches was 3.8-4.5 METS. In contrast, conditions shown at the top right of the matrix required work outputs above 9.0 METS, while the “tolerable” conditions required work outputs in the range of 5.0-9.0 METS.

MET rates under 5.0 are desirable, those above 5.0 and below 7.0 are acceptable and those between 7.0 and 9.0 METS should only be tolerated if consideration is given to work-to-rest ratio settings commensurate with minimising cumulative fatigue effects. On average the metabolic equivalent increased more in response to speed (1.9-fold increase from 3.5 $km.h^{-1}$ to 6.5 $km.h^{-1}$) than to load (1.7-fold increase from 20kg to 65kg).

The McArdle **et al.** (1996) five-level classification table is based on the energy required by untrained men and women to perform different tasks. This table suggests that unduly heavy work is being performed when the MET rate approaches 10. Conditions P (6.5 $km.h^{-1}$ with a 65kg load), O (6.5 $km.h^{-1}$ with a 50kg load) and L (5.5 $km.h^{-1}$ with a 65kg load) are therefore combinations of speed and load that would not be acceptable even for very short periods.

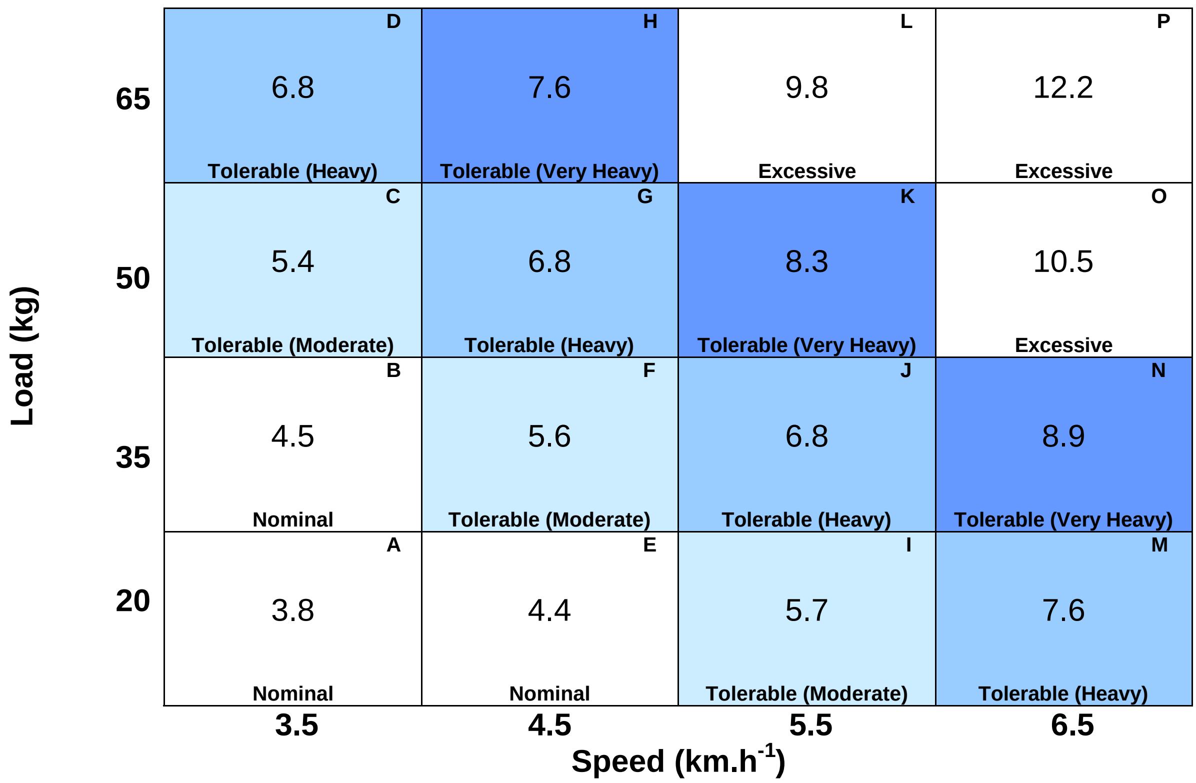


Figure 11: Mean energetic cost of each condition expressed as MET units.

Although McArdle **et al.** (1996) classify "light" work as those involving activities which have an average output of 1.6-3.9 METS, foot-soldiers are considered to be in substantially better physical condition than the average sedentary individual and hence "nominal" stress marches in the present project were considered to be those which elicited a MET response of about 5.0. Furthermore, the recommendations made by McArdle **et al.** (1996) do not take into account the concept of work-to-rest ratios that enable the intensity of the task to be moderately increased while at the same time ensuring cumulative fatigue is reduced by giving soldiers adequate rest breaks.

Metabolic carbon dioxide production (VCO_2)

It is well accepted that carbon dioxide (CO_2) is an end product of cellular oxidation and hence an increase in metabolic CO_2 production (VCO_2) is a typical response when the intensity of an activity is increased (McArdle **et al.**, 1996). The responses of VCO_2 to increments in marching speed and backpack load tended to be closely paralleled by the other physiological variables considered in this study. Conditions were classified according to the intensity of the march and the attributions “nominal to “excessive” paralleled those of the VO_2 responses (See Figure 12).

Load (kg)	3.5	4.5	5.5	6.5
65	D 22.93 (4.41) 19.22% Tolerable (Heavy)	H 27.11(5.67) 20.91% Tolerable (Very Heavy)	L 35.76 (6.41) 17.93% Excessive	P 46.97 (6.48) 13.80% Excessive
50	C 19.00 (3.67) 19.34% Tolerable (Moderate)	G 22.35 (3.33) 14.92% Tolerable (Heavy)	K 29.55 (4.87) 16.40% Tolerable (Very Heavy)	O 39.84 (10.25) 25.73% Excessive
35	B 14.46 (2.88) 19.91% Nominal	F 19.16 (3.20) 16.70% Tolerable (Moderate)	J 22.32 (4.28) 19.18% Tolerable (Heavy)	N 32.15 (6.51) 20.26% Tolerable (Very Heavy)
20	A 12.78 (1.23) 9.60% Nominal	E 14.10 (2.39) 16.97% Nominal	I 19.81 (2.50) 12.62% Tolerable (Moderate)	M 25.37(4.34) 17.11% Tolerable (Heavy)

Speed ($km.h^{-1}$)

Figure 12: Carbon dioxide production ($ml.kg^{-1}.min^{-1}$) during each condition.
(Means with standard deviations in brackets, %=coefficient of variation).

There were significant increases in VCO_2 responses to increments in both speed and load. On average there was a 2-fold increase in VCO_2 when increasing speed from 3.5 $km.h^{-1}$ to 6.5 $km.h^{-1}$, while responses to load were somewhat lower with an average 1.8-fold increase evident when increasing load from 20kg to 65kg (See Figure 12).

Respiratory Exchange Ratio

Measuring the respiratory quotient (RQ) is useful during rest and submaximal steady-state activity as it provides an estimation of the fuels being oxidised (Goedecke **et al.**, 2000). However, certain conditions can alter the normal metabolic relationship between oxygen and carbon dioxide, the two measurements used to calculate RQ. These conditions include hyperventilation and in particular exhaustive or "non-steady-state" activities (McArdle **et al.**, 1996). Under these circumstances RQ is shown as the respiratory exchange ratio (R) and cannot provide an estimation of substrate utilisation. Illustrated in Figure 13 are the mean R-values under each of the experimental conditions.

The attenuation of fat oxidation shown by the higher R values during the steady-state conditions reflected in Figure 13 suggest that carbohydrate was the dominant fuel source of the subjects in this study. These conditions include the following six combinations of speed and load:

- *3.5 $km.h^{-1}$ with a 20kg load (A).*
- *3.5 $km.h^{-1}$ with a 35kg load (B).*
- *4.5$km.h^{-1}$ with a 20kg load (E).*

"Nominal" Stress

- *4.5 km.h^{-1} with a 35kg load (F).*
- *5.5 km.h^{-1} with a 20kg load (I).*
- *5.5 km.h^{-1} with a 35kg load (J).*

"Tolerable" Stress

Load (kg) \ Speed (km.h^{-1})	3.5	4.5	5.5	6.5
65	D 0.96 (0.06) 6.20% Tolerable (Heavy)	H 1.01 (0.04) 3.98% Tolerable (Very Heavy)	L 1.02 (0.06) 15.49% Excessive	P 1.10 (0.04) 3.35% Excessive
50	C 1.00 (0.03) 3.48% Tolerable (Moderate)	G 0.94 (0.04) 4.69% Tolerable (Heavy)	K 1.01 (0.05) 4.56% Tolerable (Very Heavy)	O 1.03 (0.06) 6.09% Excessive
35	B 0.92 (0.05) 13.77% Nominal	F 0.97 (0.03) 3.31% Tolerable (Moderate)	J 0.94 (0.06) 6.05% Tolerable (Heavy)	N 1.03 (0.06) 6.09% Tolerable (Very Heavy)
20	A 0.95 (0.06) 5.96% Nominal	E 0.91 (0.04) 3.93% Nominal	I 1.00 (0.04) 6.05% Tolerable (Moderate)	M 0.94 (0.06) 6.92% Tolerable (Heavy)

Figure 13: Respiratory Exchange Ratio (R) values recorded during the third and sixth minutes.
(Means with standard deviations in brackets; %=coefficient of variation).

During mild-to-moderate intensity exertion it is widely believed that an increased capacity to utilise free fatty acids (FFA) and triglycerides (TG) is a response to endurance training (Gollnick, 1985). The net result is a sparing of glycogen and increased exercise endurance. There are four sets of findings which support the idea that endurance training increases lipid oxidation during submaximal exercise. These are that training increases the mitochondrial content of muscle (Davies **et al.**, 1981), decreases the R (Gollnick, 1985), spares muscle glycogen (Baldwin **et al.**, 1975) and lowers circulating blood catecholamine and lactate levels (Brooks, 1985).

The R results of the present sample, during the steady-state conditions, could therefore be interpreted to mean that they were not well trained. This could be attributed to inadequate training or sub-optimal health status and is corroborated by the low $VO_{2\ max}$ estimates derived from the submaximal predictive test. More in-depth methods of measuring substrate storage and oxidation where however not possible in this study and therefore no conclusive statements can be made.

A progressive increase in intensity of exertion results in a crossing over from the use of fats to carbohydrates (Brooks and Mercier, 1994). This crossing over of the two fuels results in an increase in the respiratory exchange ratio, reflecting a greater use of carbohydrates. An R-value greater than 1.00, indicative of high intensity activity (McArdle **et al.**, 1996) was recorded under the following conditions:

- *4.5km.h^{-1} with a 65kg load (H).*
- *5.5km.h^{-1} with a 50kg load (K).* — *"Very heavy" Stress*
- *6.5km.h^{-1} with a 35kg load (N).*

- *5.5km.h^{-1} with a 65kg load (L).*
- *6.5km.h^{-1} with a 50kg load (O).* *"Excessive" Stress*
- *6.5km.h^{-1} with a 65kg load (P).*

Under these conditions R can no longer provide an estimation of substrate utilisation. A maximal R-value was obtained during condition P (R=1.13) when soldiers marched at 6.5 km.h^{-1} with a 65kg load, a further finding to suggest that these soldiers were at maximum during this condition.

Energy Expenditure

The metabolic cost of the 16 combinations of speed and load is presented in Figure 14. This illustrates that increments in speed and load exacerbate the energy requirements of the task, with load exerting a lesser effect than speed.

At any given speed the 65kg load is carried at approximately 1.7 times the kilocalorie cost of the 20kg load, but under any given load, increasing the speed from 3.5 km.h^{-1} to 6.5 km.h^{-1} increases the energy cost by over 1.9 times. Condition A (3.5 km.h^{-1} with a 20kg load) is considered the only "light" intensity task according to the McArdle five-level classification table (McArdle **et al.**, 1996). It has been suggested, however, that these classification tables should be interpreted with caution as those activities considered to be "light" intensity by one author may be considered to be a "moderate" intensity task by another. In the present study, the "light" intensity or "nominal" stress tasks were considered to be those during which the energy expenditure was below 22 kJ.min^{-1}, which resulted in a caloric cost of 5 kcal.min^{-1} and below. There was no statistical difference in metabolic cost between Conditions B and E although Condition A, combining the slowest speed and lightest load, elicited a significantly lower cost than the other two "nominal" stress condition.

Load (kg)	3.5 kJ.min^{-1}	3.5 kcal.min^{-1}	4.5 kJ.min^{-1}	4.5 kcal.min^{-1}	5.5 kJ.min^{-1}	5.5 kcal.min^{-1}	6.5 kJ.min^{-1}	6.5 kcal.min^{-1}
65	D 32 (5.0) 15%	D 7.6 (1.1) 15%	H 36 (9.0) 23%	H 8.7 (2.0) 23%	L 48 (8.0) 16%	L 11.4 (1.8) 16%	P 59 (9.0) 15%	P 14.0 (2.1) 15%
	Tolerable (Heavy)		Tolerable (Very Heavy)		Excessive		Excessive	
50	C 26 (6.0) 24%	C 6.0 (1.5) 24%	G 32 (6.0) 19%	G 7.8 (1.5) 19%	K 40 (7.0) 17%	K 9.6 (1.7) 17%	O 51 (7.0) 13%	O 12.0 (1.6) 13%
	Tolerable (Moderate)		Tolerable (Heavy)		Tolerable (Very Heavy)		Excessive	
35	B 21 (2.0) 12%	B 5.0 (0.6) 12%	F 27 (5.0) 20%	F 6.4 (1.3) 20%	J 33 (6.0) 20%	J 7.8 (1.5) 20%	N 43 (9.0) 21%	N 10.3 (2.1) 21%
	Nominal		Tolerable (Moderate)		Tolerable (Heavy)		Tolerable (Very Heavy)	
20	A 18 (2.0) 12%	A 4.3 (0.5) 12%	E 21 (3.0) 16%	E 5.0 (0.8) 16%	I 27 (5.0) 17%	I 6.5 (1.1) 17%	M 37 (6.0) 16%	M 8.8 (1.4) 16%
	Nominal		Nominal		Tolerable (Moderate)		Tolerable (Heavy)	

Speed (km.h^{-1})

Figure 14: Mean metabolic cost of each experimental condition in kilojoules per minute and kilocalories per minute.
(Standard deviations in brackets, %=coefficient of variation).

During the conditions designated as "tolerable", the energy expended had a broad range between 25 kJ.min^{-1} and 43 kJ.min^{-1}, and between 6.0 and 11.0 kcal.min^{-1}. These, according to the McArdle and co-authors' 1996 five-level classification table, are considered "moderate" to "very heavy" tasks paralleling the levels of stress in this study.

Within the "tolerable" category, all the "moderate" stress marches were statistically the same. This was similar during the "heavy" stress marches excluding Condition M which had a significantly higher cost compared to Conditions D, G and J. Similarly, Condition H was statistically lower in cost than Conditions K and N in the "very heavy" stress level. This demonstrates that Conditions H and M virtually stand alone in terms of metabolic cost and fall somewhere between the "heavy" and "very heavy" stress levels. Those conditions during which the energy expended was above 45 $kJ.min^{-1}$, and which elicited a caloric cost greater than 11 $kcal.min^{-1}$, were considered "excessive" tasks, an interpretation in agreement with the McArdle classification.

The wattage demand of a task reflects the physical work done under the time constraints in which it is performed. In order to have a tangible measure of the work output of the soldiers the marches were next classified into three broad categories on the basis of their power output: "nominal" power output (under 400w), "tolerable" power output (400W-750w) and "excessive" power output (above 750w). The higher the power requirements of the task the sooner the onset of fatigue and the shorter the duration over which work at this rate can be sustained. The wattage demands of the various combinations of speed and load are reflected in Figure 15.

Power Output responses were naturally statistically the same as those measured as kilojoule and kilocalorie costs; once again demonstrating that Conditions M and H are very similar in task demands and not entirely consonant with the broad attributions of categories in which they were placed.

Load (kg) \ Speed (km.h^{-1})	3.5	4.5	5.5	6.5
65	D 532 (81) 15% Tolerable (Heavy)	H 606 (142) 23% Tolerable (Very Heavy)	L 792 (128) 16% Excessive	P 982 (149) 16% Excessive
50	C 431 (105) 24% Tolerable (Moderate)	G 541 (103) 19% Tolerable (Heavy)	K 669 (119) 17% Tolerable (Very Heavy)	O 842 (112) 13% Excessive
35	B 350 (42) 12% Nominal	F 446 (90) 20% Tolerable (Moderate)	J 544 (107) 20% Tolerable (Heavy)	N 716 (149) 21% Tolerable (Very Heavy)
20	A 302 (37) 12% Nominal	E 347 (56) 16% Nominal	I 456 (79) 17% Tolerable (Moderate)	M 615 (98) 16% Tolerable (Heavy)

Figure 15: Power Output (W) responses during each experimental condition. *(Means with standard deviations in brackets, %=coefficient of variation).*

When soldiers carry backpack loads, they not only move the external load, but also their own body weight. It is thus useful to express energy expenditure in terms of the total load moved as this provides information regarding the individual cost to each soldier.

During condition F, when subjects were marching at 4.5 $km.h^{-1}$ and carrying 35kg, the heaviest subject (whose body mass was 97kg) was carrying a load equivalent to 36% of body mass. The lightest subject (who weighed 53kg) was, under the same condition, carrying 66% of body mass. Analyses revealed that although the lighter subject was carrying a larger proportion of body weight these two soldiers were not substantially differentially taxed. The heavier subject was expending 16.20 $kJ.\Sigma kg^{-1}.h^{-1}$ while the lighter subject was expending 17.10 $kJ.\Sigma kg^{-1}.h^{-1}$. This finding is in contrast to those of many studies which suggest that load weight be made relative to total body mass in order to ensure that soldiers are not differentially taxed (Cathcart **et al.**, 1923; Kinoshita, 1985; Haisman, 1988). This response can however be explained by recent research suggesting that load weight be dependent on an individual's lean body mass rather than total mass. Studies have reported that the amount of body fat, or "dead weight", a soldier is carrying has a significant impact on the energetic cost of load carriage (Scott and Ramabhai, 2000). The heaviest subject in this study had a higher body fat content (31%) than the lightest subject (18%). The lighter subject also appeared to be in better physical condition with a predicted maximal oxygen consumption value of 55 $ml.kg^{-1}.min^{-1}$, whereas the heavier subject had a predicted $VO_{2\ max}$ of 30 $ml.kg^{-1}.min^{-1}$. The physical condition of the smaller subject was therefore superior and could be due to genetic make-up together with differences in training status. These factors enable the leaner and better cardiovascularily trained individual to be more efficient despite a smaller morphology.

GAIT KINEMATIC RESPONSES

STEP-RATE AND STEP LENGTH

Speed of walking is a product of both step-rate (cadence) and step length; changes in one or both will result in an increase in walking speed. Under any given load, increments in speed resulted in increases in step-rate (See Figure 16). Increasing speed from 3.5 $km.h^{-1}$ to 6.5 $km.h^{-1}$ resulted in a 1.3-fold increase in step-rate. Increasing load from 20kg to 65kg resulted in a 1-fold increase in step-rate.

Load (kg) \ Speed ($km.h^{-1}$)	3.5	4.5	5.5	6.5
65	D: 109 (10) 9.32% Tolerable (Heavy)	H: 121 (9) 7.37% Tolerable (Very Heavy)	L: 125 (5) 4.26% Excessive	P: 140 (5) 3.66% Excessive
50	C: 103 (7) 6.63% Tolerable (Moderate)	G: 114 (6) 5.26% Tolerable (Heavy)	K: 126 (6) 4.64% Tolerable (Very Heavy)	O: 134 (7) 4.92% Excessive
35	B: 101 (8) 7.46% Nominal	F: 116(5) 4.67% Tolerable (Moderate)	J: 123 (6) 4.84% Tolerable (Heavy)	N: 137 (8) 5.67% Tolerable (Very Heavy)
20	A: 104 (7) 6.36% Nominal	E: 113 (5) 4.32% Nominal	I: 123 (5) 3.67% Tolerable (Moderate)	M: 131 (4) 3.30% Tolerable (Heavy)

Figure 16: Step-rate ($steps.min^{-1}$) responses to increases in speed and load.
(Means with standard deviations in brackets, %=coefficient of variation).

There was an increase in stride length (sum of consecutive left and right steps) with the first increment in walking speed with all loads and with the first increment in backpack load with the two slowest speeds (See Figure 17). Stride length did not increase with this load increment at the two faster speeds. Stride length then decreased as load increased to the maximum load of 65kg. In contrast, increasing speed from 3.5 $km.h^{-1}$ to 6.5 $km.h^{-1}$ regardless of load resulted in an increase in stride length. There was, on average, a 1.4-fold increase in stride length with increasing speed.

Load (kg) \ Speed ($km.h^{-1}$)	3.5	4.5	5.5	6.5
65	D 1.07 (0.54) 13.28% Tolerable (Heavy)	H 1.24 (0.62) 6.84% Tolerable (Very Heavy)	L 1.47 (0.73) 12.98% Excessive	P 1.55 (0.77) 9.91% Excessive
50	C 1.13 (0.57) 6.39% Tolerable (Moderate)	G 1.32(0.66) 6.94% Tolerable (Heavy)	K 1.45 (0.73) 16.21% Tolerable (Very Heavy)	O 1.62 (0.81) 13.52% Excessive
35	B 1.16 (0.58) 5.82% Nominal	F 1.29 (0.65) 6.54% Tolerable (Moderate)	J 1.49 (0.75) 11.10% Tolerable (Heavy)	N 1.58 (0.79) 7.00% Tolerable (Very Heavy)
20	A 1.12 (0.56) 5.06% Nominal	E 1.33 (0.66) 6.23% Nominal	I 1.49 (0.75) 7.73% Tolerable (Moderate)	M 1.65 (0.83) 9.60% Tolerable (Heavy)

Figure 17: Stride length responses to increases in speed and load.
(Means with standard deviations in brackets, %=coefficient of variation).

Overall, subjects increased both cadence and stride length in order to increase speed of walking; a normal response. However, subjects progressively decreased stride length when load was increased to 50kg and took significantly shorter strides when carrying 65kg, irrespective of the speed. Cavanagh and Williams (1982), Holt **et al.** (1991) and Bunc and Dlouha (1997) have all reported that increasing stride length more than step rate is associated with greater increases in energy cost. Other authors have also reported that increases in speed result in a greater energetic cost than increases in load (Soule **et al.**, 1978; Charteris **et al.**, 1989).

PSYCHOPHYSICAL RESPONSES

RATING OF PERCEIVED EXERTION

The Rating of Perceived Exertion (RPE) Scale, developed by Borg in 1970, provides a measure of individual perceptual responses to task demands (See Figure 18). Although a linear relationship between heart rate and RPE has been demonstrated when participating in a progressively increased workload activity, these ratings are still individualised responses and thus what one individual perceives to be a difficult task another may perceive to be less demanding. Personality type, motivation and personal involvement in the activity are known to influence perceptions of exertion; hence when working with a diverse group of subjects such as in the army the responses are highly likely to vary substantially.

Conditions A (3.5 $km.h^{-1}$ with a 20kg load), B (3.5 $km.h^{-1}$ with a 35kg load) and E (4.5 $km.h^{-1}$ with a 20kg load), identified as “nominal” intensity task demands, elicited mean “Central” RPE ratings of 10 (±2.0), 11 (±2.3) and 10 (±2.0). This corresponds to a mean heart rate of between 101 bt.min^{-1} and 105 bt.min^{-1} (See Figure 19). As the task demands increased so heart rates were elevated and there was an associated increase in both “Central” and “Local” ratings.

RATINGS OF PERCEIVED EXERTION

Load (kg)	Central	Local	Central	Local	Central	Local	Central	Local
65	D 13 (2.2) 16.64%	D 15 (2.4) 16.39%	H 13 (2.3) 17.23%	H 13 (3.0) 21.16%	L 14 (2.3) 10.71%	L 15 (1.7) 11.19%	P 15 (3.0) 20.45%	P 15 (3.1) 19.91%
	Tolerable (Heavy)		Tolerable (Very Heavy)		Excessive		Excessive	
50	C 11 (2.0) 18.02%	C 11 (3.0) 22.77%	G 13 (2.0) 16.38%	G 14 (2.4) 18.28%	K 13 (2.0) 12.82%	K 14 (2.0) 13.60%	O 14 (1.8) 12.56%	O 15 (2.2) 14.53%
	Tolerable (Moderate)		Tolerable (Heavy)		Tolerable (Very Heavy)		Excessive	
35	B 11 (2.3) 20.62%	B 11 (2.3) 20.01%	F 11 (2.0) 17.25%	F 11 (2.2) 19.18%	J 12 (2.3) 19.39%	J 12 (3.0) 21.16%	N 12 (2.3) 19.72%	N 12 (3.2) 26.27%
	Nominal		Tolerable (Moderate)		Tolerable (Heavy)		Tolerable (Very Heavy)	
20	A 10 (2.0) 19.92%	A 11 (2.2) 21.18%	E 10 (2.0) 18.71%	E 10 (2.0) 18.16%	I 10 (2.0) 16.20%	I 11 (2.0) 17.16%	M 12 (3.0) 21.65%	M 11 (2.3) 20.26%
	Nominal		Nominal		Tolerable (Moderate)		Tolerable (Heavy)	
Speed (km.h^{-1})	**3.5**		**4.5**		**5.5**		**6.5**	

Figure 18: **“Central” and “Local” Ratings of Perceived Exertion during each experimental condition.**
(Means with standard deviations in brackets, %=coefficient of variation).

Within the “tolerable” category, conditions identified as “moderate” stress elicited “Central” ratings of 10 and 11, which corresponded to a heart rate range of 118 bt.min^{-1} to 127 bt.min^{-1} (See Figure 19). The “heavy” stress conditions elicited “Central” ratings of 12 and 13 with a heart rate response of 127 bt.min^{-1} to 137 bt.min^{-1}. “Central” ratings were similar for the “very heavy” marches (12 and 13), but heart rates were significantly higher and ranged from 150 bt.min^{-1} to 158 bt.min^{-1}. In the present study there was a moderate correlation (r=0.4) between working heart rate and “Central” RPE during the “moderate” and “very heavy” marches, but a strong correlation (r=0.8) during the marches classified as tolerable, but “heavy”.

The highest RPE rating, a mean of 15 (±3.0) for “Central” perceptions and 15 (±3.1) for “Local” perceptions, was recorded during Condition P (6.5 km.h^{-1} with a 65kg load). The mean heart rate during Condition P was 173 bt.min^{-1} (±8.27) which is approximately 20 bt.min^{-1} higher than would be expected when consideration is given to the linear relationship shown previously between these two variables (Figure 19). It thus appears that in general the RPE responses during the more taxing conditions may have been suppressed. However, it is worth noting that the highest individual rating was 19 although this was an atypical response as most soldiers rated this condition between 14 and 16.

There were no significant increases in either “Central” or “Local” ratings with loads up to 50% of body mass while marching at the two slowest speeds. Once speed was increased above this, significant increases in “Central” RPE were observed with all load increments. When load was increased above 50% of body mass significant increases ($p<0.05$) in perceptions of exertion were evident with increases in speed.

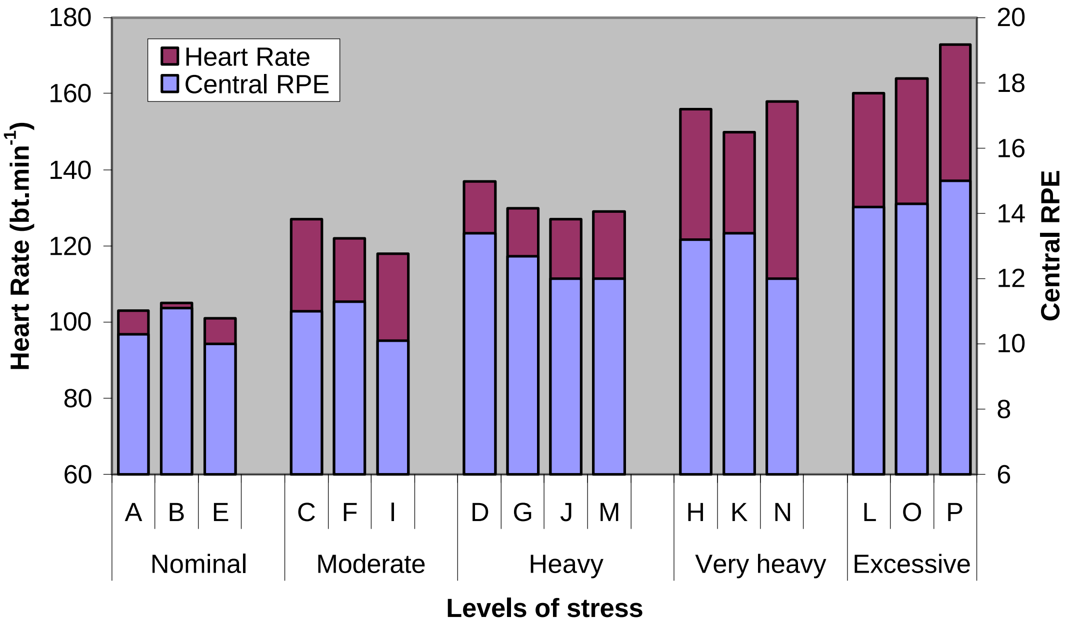


Figure 19: Comparison of "Working" heart rate responses in relation to "Central" Ratings of Perceived Exertion in response to each condition.

Contrary to these findings, Quesada **et al.** (2000) reported changes in perceptual responses as soon as loads were above 15% of body mass, this reiterating that the present sample appears either to have adapted to carrying heavy loads and hence did not perceive them to be particularly taxing, or to be underrating their perceptions of exertion possibly due to military "machismo effect". Robertson **et al.** (1982) demonstrated that loads of 15% of body mass and above resulted in a greater number of cues from the legs as opposed to the cardiovascular system. However, in this study, soldiers did not perceive the lower limbs to be taking more strain than the cardiovascular system and thus dominance from one area was not evident.

The differences in perceptions of exertion between the lightest and heaviest soldiers became greater as speed and load were increased. The lightest soldier (53kg) perceived the speed-load combination of 6.5 $km.h^{-1}$ with 65kg to be Very, Very Hard (19), while the heaviest subject (97kg) perceived this condition to be Fairly Light (11). Despite this, the heavier subject's heart rate was 181 $bt.min^{-1}$ compared to the lighter subject whose heart rate was 168 $bt.min^{-1}$. It could be argued, as suggested above, that the larger subject was in fact suppressing his perceptions of exertion, while the lighter subject's perceptions were more accurate and more closely reflected heart rate response. These findings could also be attributed to differences in cardiovascular training status and fat mass of the subjects. In 1996 Travlos and Marisi reported a stronger correlation between RPE and heart rate for "fitter" individuals. The heavier subject was less well conditioned (30 $ml.kg^{-1}.min^{-1}$) than the lighter subject (50 $ml.kg^{-1}.min^{-1}$), and had almost double the amount of fat (30% compared to 17%) which could in all probability have contributed to the different perceptions. Furthermore, it is argued that most of the sample were not well trained (mean predicted submaximal $VO_{2\ max}$ of 40 $ml.kg^{-1}.min^{-1}$) and thus more likely to suppress perceptions of exertion, supporting the finding of Travlos and Marisi (1996).

BODY DISCOMFORT

On completion of each condition subjects straddled the treadmill and were required to identify and rate areas of discomfort from the Body Discomfort (BD) map (Corlett and Bishop, 1976). Due to the large number of experimental conditions (16) and 27 available locations on the BD map, only the two most prevalent sites under each condition were calculated as a percentage of the total citings per condition and are presented in Figure 20.

While carrying the lightest load (20kg) at all speeds, very few soldiers reported any discomfort. Thereafter it appears that independent of the load mass the majority of soldiers reported discomfort in the posterior shoulders. This is in accordance with Holewijn (1990) and Ramabhai (1999) who reported that pressure from the shoulder straps is a limiting factor during marching. The number of citings for the posterior shoulder region also increased marginally as the combined demands of speed and load were increased. While very few reported discomfort in the thoracic region when carrying the 20kg load, as load increased, thoracic discomfort became more prevalent, after which discomfort from both areas was consistent throughout.

There was very little respondent consistency in respect of intensity of discomfort. Ratings tended to be low-to-moderate (from 3 to 5) for the two slowest speeds (3.5 $km.h^{-1}$ and 4.5 $km.h^{-1}$) when combined with the two lightest loads (20kg and 35kg). These intensity scores were raised as the combined demands of speed and load increased above this and ranged from moderate-to-high (from 6 to 8) with very few ratings above 8 reported.

BODY DISCOMFORT

Load (kg) \ Speed ($km.h^{-1}$)	3.5	4.5	5.5	6.5
65	D: Shoulders (27%) Thoracic (20%) — Tolerable (Heavy)	H: Thoracic (33%) Shoulders (20% — Tolerable (Very Heavy)	L: Shoulders (20%) Thoracic (7%) — Excessive	P: Shoulders (20%) Thoracic (20%) — Excessive
50	C: Thoracic (20%) Non-specific — Tolerable (Moderate)	G: Lumbar (20%) Thoracic (13% — Tolerable (Heavy)	K: Thoracic (33%) Knees (13%) — Tolerable (Very Heavy)	O: Knees (20%) Shoulders (13%) — Excessive
35	B: Shoulders (20%) Thoracic (13%) — Nominal	F: Thoracic (53%) Shoulders (27%) — Tolerable (Moderate)	J: Thoracic (20%) Shoulders (20%) — Tolerable (Heavy)	N: Shoulders (40%) Knees (13%) — Tolerable (Very Heavy)
20	A: Non-specific — Nominal	E: Shoulders (13%) Non-specific — Nominal	I: Cervical (20%) Thoracic (20%) — Tolerable (Moderate)	M: Knees (27%) Non-specific — Tolerable (Heavy)

Figure 20: Areas of body discomfort (as a % of total citings per condition) with the area of most discomfort listed at the top.
(NOTE: All regions refer to the posterior aspect of the body).

There were three conditions (K, N and O) in which any area of the lower limbs was cited as taking strain and these were all when speed was either 5.5 $km.h^{-1}$ or 6.5 $km.h^{-1}$. There was thus a tendency for discomfort to shift from the posterior shoulder region and thoracic spine to the posterior aspect of the lower limbs as speed increased from

3.5 km.h^{-1} to 6.5 km.h^{-1}. It could therefore be argued that higher speeds would in all probability result in discomfort shifting from the shoulders to the lower limbs. However, this was not a consistent finding and hence definitive statements cannot be made. Longer duration marches are needed in order to investigate this further.

A recent report by Ramabhai (1999) showed that perceptions of discomfort shift as the duration of a march is increased. This author demonstrated that during the first hour of marching at a speed of 4 km.h^{-1} with a 40.5kg load, most discomfort was experienced in the posterior shoulders. As the duration of the march increased up until three hours, discomfort shifted to the feet. It could therefore be postulated that had marching continued for a prolonged period of time in this study, the present soldiers may have experienced more discomfort in the lower limbs with higher speeds exacerbating the discomfort. A 6-minute data collection period is therefore insufficient to suggest that discomfort would have remained in any one particular area.

INTEGRATED DISCUSSION

The physiological and perceptual results of this study indicate that the three “nominal” and three “excessive” strain combinations of speed and load represent the extremes of military requirements.

The “nominal” stress marches imposed a light strain on the soldier (See Figure 21). Effectively, marching at 4.5 km.h^{-1} or less with 20kg or lower may be regarded as equivalent to unloaded walking; the 35kg load at 3.5 km.h^{-1} being minimally more stressful. Figure 21 illustrates that the physiological and perceptual responses for these three conditions were very similar. Although a statistical difference was evident in VO_2 responses between Condition A, and Conditions B and E, there was no statistical difference when comparing the other physiological and perceptual variables. The lower VO_2 responses could be a reflection of the intensity of the workload as Condition A is the extreme of an unnaturally slow speed combined with a very light load.

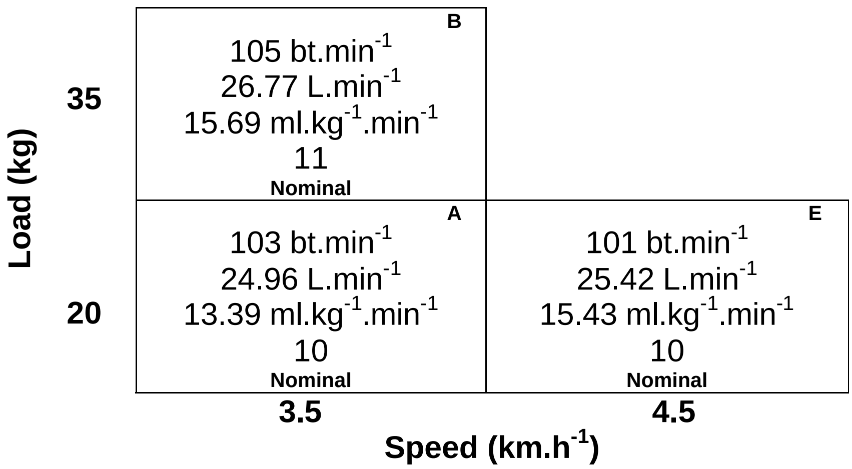


Figure 21: Selected physiological and perceptual responses to the three "nominal" stress marches.
(Responses are: working heart rate, V_E, VO_2 and Central RPE)

Conditions L, O and P reflect such excessive physical demands that it is strongly recommended that these combinations are avoided in military operations (Figure 22). Conditions L and O were statistically similar in responses, but when exposed to Condition P subjects responses (VO_2, V_E and RPE) were significantly higher than the other two "excessive" conditions, the reason being that Condition P is the other extreme of a very high speed combined with a very heavy load. Under these "excessive" conditions subjects are operating at well over 80% of maximal capacity and early-onset fatigue indicators are clearly evident within six minutes. This, although evident with the physiological responses, was not reflected in ratings of exertion. Subjects clearly suppressed how they felt under these excessive conditions and no significant difference in RPE ratings between these conditions was observed.

Load (kg)	Speed ($km.h^{-1}$) 5.5	Speed ($km.h^{-1}$) 6.5
65	L 160 $bt.min^{-1}$ 64.28 $L.min^{-1}$ 34.43 $ml.kg^{-1}.min^{-1}$ 14 Excessive	P 173 $bt.min^{-1}$ 80.99 $L.min^{-1}$ 42.75 $ml.kg^{-1}.min^{-1}$ 15 Excessive
50		O 164 $bt.min^{-1}$ 66.26 $L.min^{-1}$ 36.78 $ml.kg^{-1}.min^{-1}$ 14 Excessive

Figure 22: Selected physiological and perceptual responses to the three "excessive" strain conditions.
(Responses are: working heart rate, V_E, VO_2 and Central RPE)

"Tolerable" Stress Conditions

Recognising that military operations, by their nature, call for levels of contribution dictated by the urgency of the situation and the often dire consequences of failure, it is to be expected that military demands are not those of every day life. "Tolerable" levels in the military context, therefore, are not synonymous with "optimal" levels in the industrial context. The present study identified three discrete levels of stress which, depending upon circumstances, could be tolerated (to greater or lesser extents) as operational circumstances dictate. Obviously from an Ergonomics point of view the aim should be to strive for the level of least strain in this category. These levels were as follows and are presented in Figure 23:

Most tolerable conditions:

3.5 km.h^{-1} with a 50kg load (C).	
4.5 km.h^{-1} with a 35kg load (F).	*"Moderate" Stress*
5.5 km.h^{-1} with a 20kg load (I).	

Tolerable Conditions:

3.5 km.h^{-1} with a 65kg load (D).	
4.5 km.h^{-1} with a 50kg load (G).	
5.5 km.h^{-1} with a 35kg load (J).	*"Heavy" Stress*
6.5 km.h^{-1} with a 20kg load (M).	

Least Tolerable Conditions:

4.5 km.h^{-1} with a 65kg load (H).	
5.5 km.h^{-1} with a 50kg load (K).	*"Very Heavy" Stress*
6.5 km.h^{-1} with a 35kg load (N).	

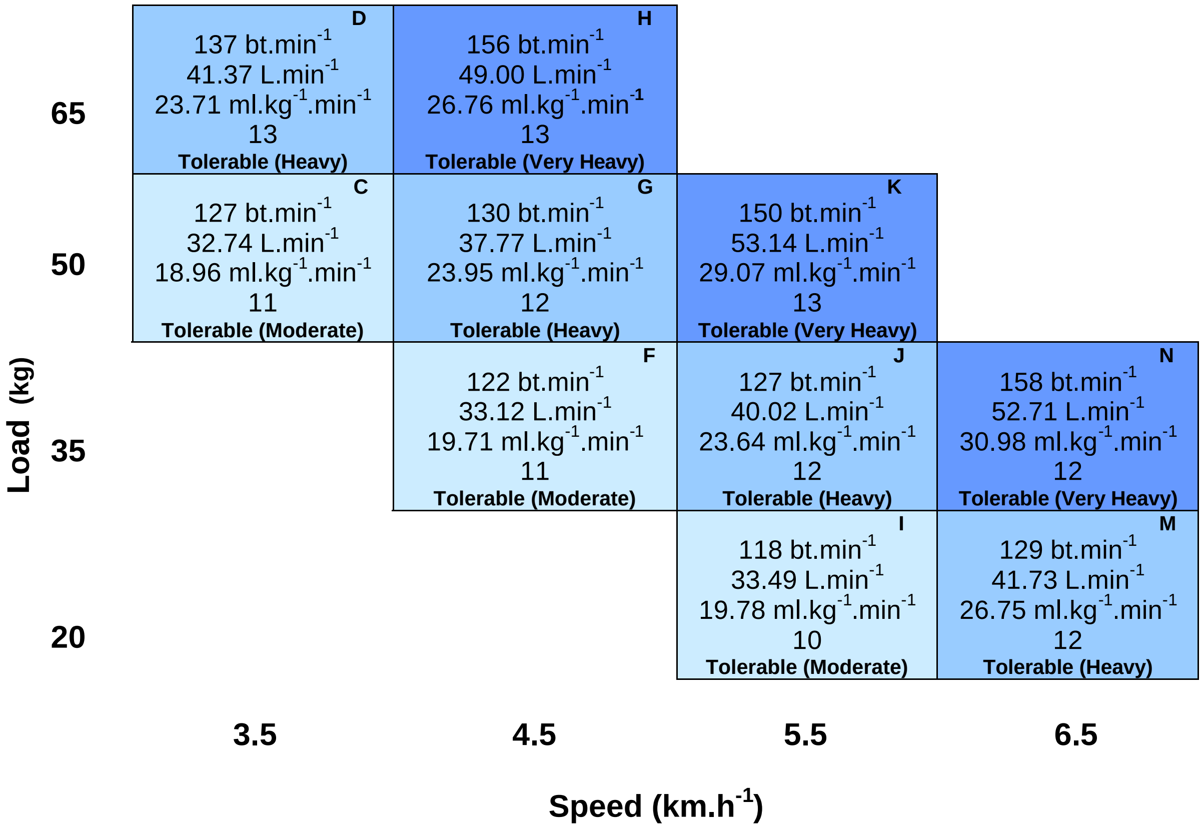


Figure 23: Selected physiological and perceptual responses to the "tolerable" strain conditions.
(Responses are: working heart rate, V_E, VO_2 and Central RPE).

Statistical analysis revealed no significant difference in physiological and perceptual responses between the three "moderate" stress marches (Conditions C, F and I). Combinations of speed ranging from 3.5 km.h^{-1} to 5.5 km.h^{-1}, with loads ranging from 20kg to 50kg, require the same cost if consideration is given to correct combinations of these two variables. In other words, soldiers are able to carry loads of 50 kg (73% of the mean body weight of the present group) providing speed is reduced to 3.5 km.h^{-1}, and speed can be increased to 5.5 km.h^{-1}, but only if load is reduced to 20kg; the energy cost to the individual being very similar in these suggested combinations. There was only a modest correlation (r=0.4) between heart rate and "Central" RPE ratings under these conditions, suggesting that subjects were suppressing how they felt.

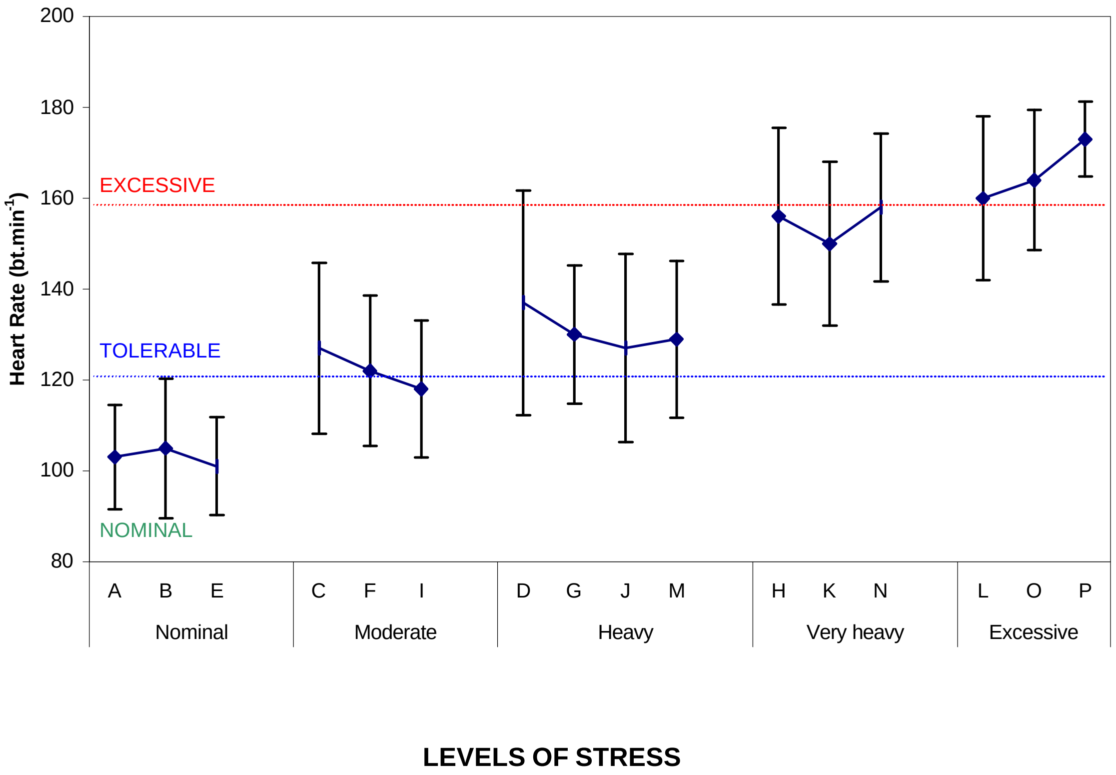


Figure 24: Mean Working heart rate responses to the levels of stress imposed by varying combinations of marching speed and backpack load.

Conditions D, G, J and M exerted the same energetic cost to the individual, effectively demonstrating that a load as high as 65kg can be transported, and that a speed of 6.5 km.h^{-1} is tolerable, but only if speed is reduced to 3.5 km.h^{-1} in the first instance, and the load to 20kg in the second example; once again reiterating the importance of correct combinations. There was a strong correlation (r=0.8) between heart rate and "Central" RPE during these "heavy" stress marches.

Although physiological responses under Conditions H, K and N ("very heavy" stresses) tended to be significantly higher than the other two stress levels, subjects' perceptions of exertion were not significantly elevated, with only a modest correlation between heart rate and "Central" RPE (r=0.4). Although these three conditions can be utilised it should only be in isolated incidences as subjects were working between 60-75% of maximal capacity. In all likelihood "physiological drift" would occur over time, resulting in the premature onset of fatigue.

Depending on military requirements any combination of speed and load within each of the "tolerable" intensity levels can be utilized. Extended duration marches should preferably include any of the three "moderate" intensity combinations of speed and load. As duration becomes less important the "heavy" and "very heavy" combinations of speed and load could be utilized. All these intensity levels comprise varying combinations of speed and load; reflective of the fact that military objectives will change as circumstances dictate.

Figures 24 and 25 demonstrate the lower physiological responses (heart rate and oxygen consumption responses respectively) when soldiers are exposed to the three "nominal" stress marches, plus the excessively high responses when required to perform conditions H, K and N. Areas of "moderate-to-high" physiological responses are reflected in the central area of Figures 24 and 25 and are classified as "tolerable".

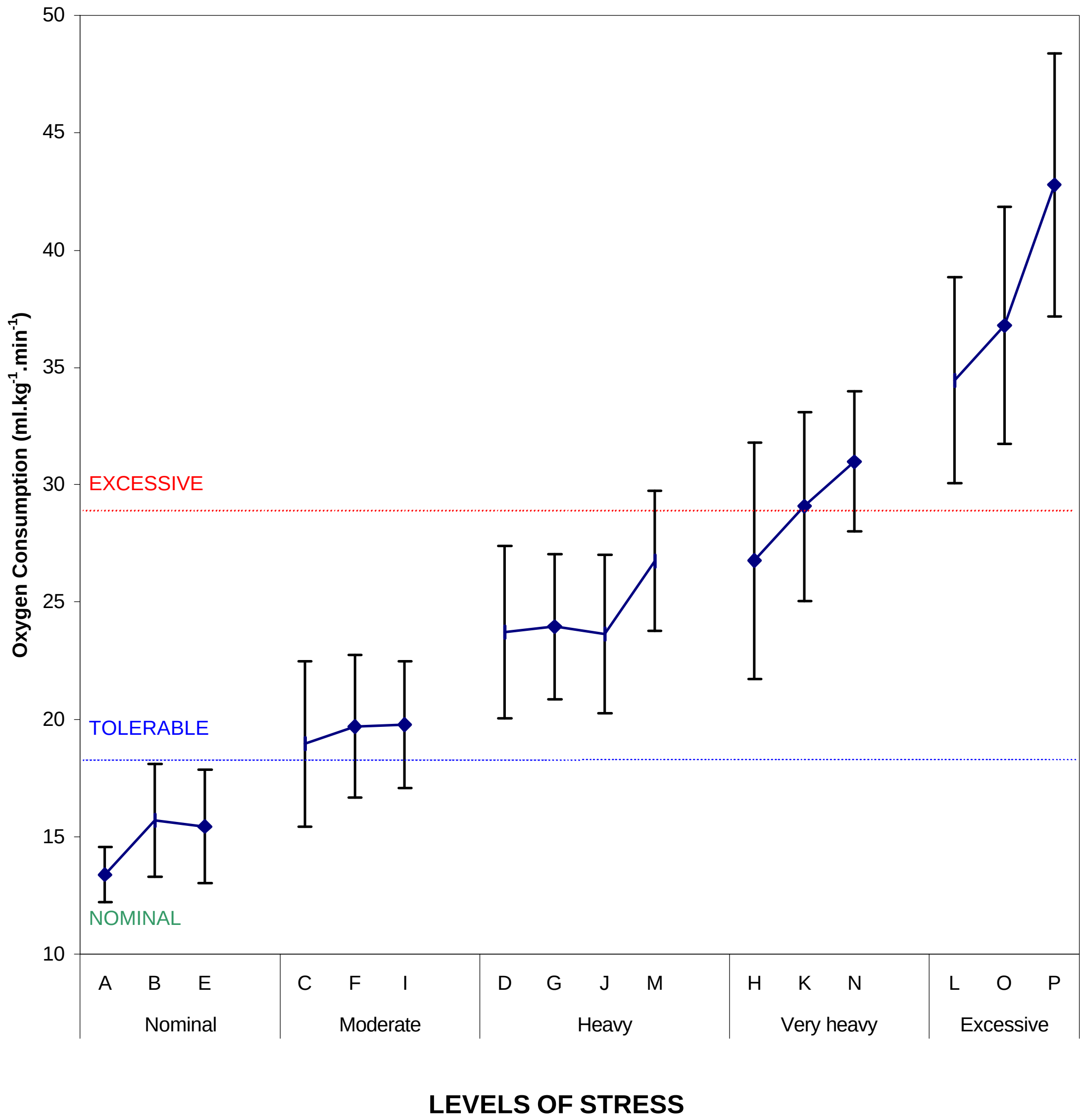


Figure 25: Mean oxygen uptake responses to the levels of stress imposed by varying combinations of marching speed and backpack load.

Furthermore, although perceptual responses tended to parallel those of the physiological responses they were often suppressed (See Figure 26). While perceptions of exertion progressively increased with each stress level, it is evident from Figures 24 to 25 that these did not accurately reflect the associated increase in the physiological responses.

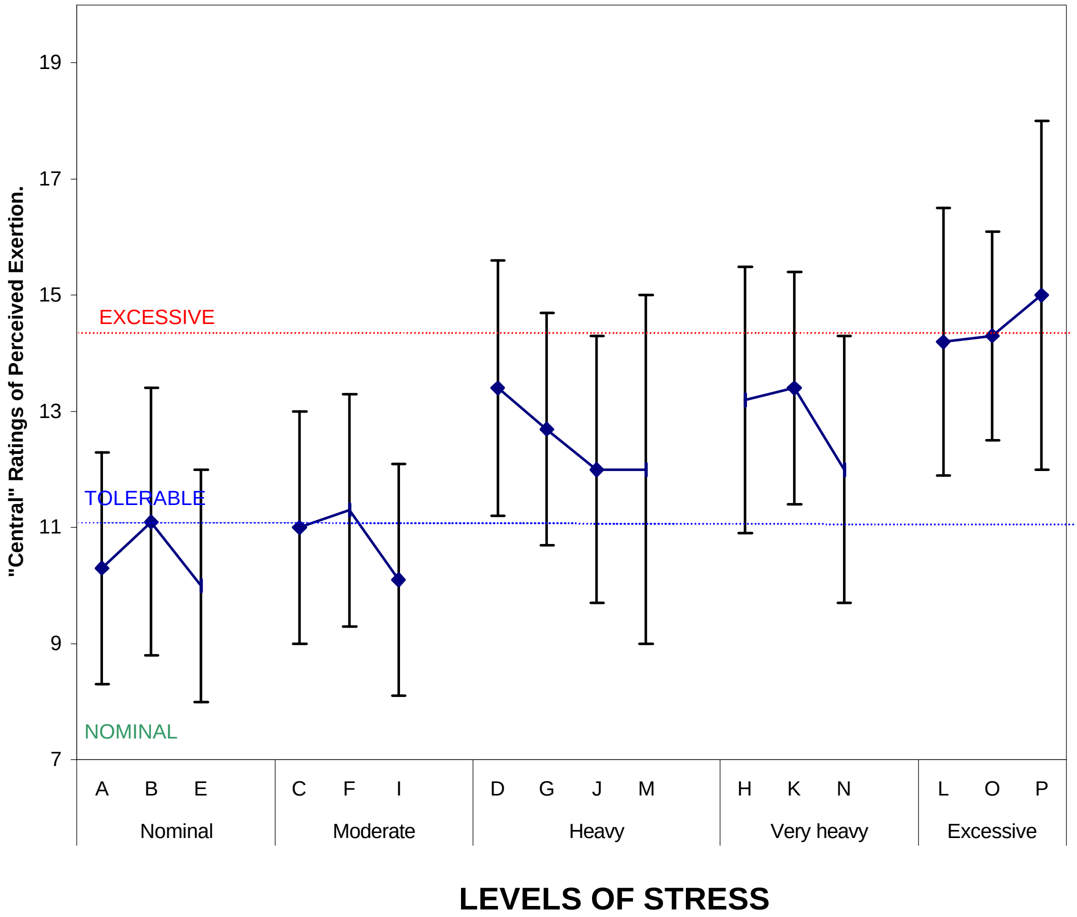


Figure 26: **Mean "Central" RPE responses to the levels of stress imposed by varying combinations of marching speed and backpack load.**

As speed became the primary focus subjects tended to rate the condition as less stressful. This is shown in Figure 26 where, within each stress category, the following conditions had the highest speeds, yet the lowest perceptual ratings: the "nominal" stress category, Condition E; the "moderate", Condition I; "heavy", Condition M and “very heavy”, Condition N. The only categories in which this was not evident involved the combinations of speed and load categorised as “excessive”. Whereas physiological responses showed a marginally greater increase with faster marching speeds combined with lighter loads, perceptions of exertion reflected otherwise. Soldiers perceived that heavier loads were more taxing than faster speeds.

It is apparent that a multi-disciplinary approach to investigations into military activities will strengthen the ultimate recommendations made. Practical applications based on an extensive range of measurements will all contribute to an in depth understanding of what the soldiers experience when participating in intensive military exercises. These results demonstrate five distinguishable categories of strain, with 10 of the 16 conditions representing three tolerable gradings of “moderate”, “heavy” and “very heavy” demands. These three levels of exertion accentuate that in order to meet marching requirements there is a need to modify the speed of the march and/or the load to be carried in order to minimise fatigue during prolonged marches and so ensure efficiency of performance and ultimately combat effectiveness.

CHAPTER V

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

INTRODUCTION

Establishing a balance between the physical and mental demands imposed on a soldier and the objectives of the military poses a unique challenge and has been the focus of extensive research over the years (Cathcart **et al.**, 1923; Soule **et al.**, 1978; Patton **et al.**, 1991; Quesada **et al.**, 2000). There does however appear to have been limited investigation into the relationship between marching speed and backpack load, and there is a need to categorise optimal combinations of these two variables to meet the requirements of different military situations. This is particularly evident during route marches when military requirements may, at times, surpass soldier capabilities. The main objective therefore should be to determine which combinations of speed and load result in the least cost to an individual, while at the same time ensuring military objectives are achieved.

This study undertook a multi-disciplinary approach to investigate 16 combinations of speed and load. It was hypothesised that there would be a progressive increase in physiological and perceptual responses as combinations of speed and load increased from the slowest speeds combined with the lightest loads, to the fastest speeds combined with the heaviest loads. The objective was to identify optimal combinations required to meet the various operational objectives specific to the South African military.

SUMMARY OF PROCEDURES

The present study was conducted in a laboratory environment at the Department of Human Kinetics and Ergonomics at Rhodes University. Sixteen experimental conditions were selected using different combinations of four marching speeds (3.5, 4.5, 5.5 and 6.5 $km.h^{-1}$) and four backpack loads (20, 35, 50 and 65 kilograms). These speeds and loads were decided upon after consultation and discussions with army personnel. The external load consisted of a battle jacket and helmet, which were the same under all conditions, and a backpack load which was adjusted to achieve the required four loads.

The 30 male soldiers recruited from a local infantry base had a mean body weight of 68.2kg (with 17.4% body fat), a mean BMI of 23.81 $kg.(m^2)^{-1}$ and a mean predicted $VO_{2\ max}$ of 40 $ml.kg^{-1}.min^{-1}$. The subjects were assigned to either of two equally taxing grids (A or B), as outlined in the methodology, each of which comprised eight conditions of varying combinations of speed and load. Preceding the experimental sessions basic data including age, military experience, stature, mass, body composition and reference heart rate were collected on the soldiers. Three treadmill habituation sessions were undertaken prior to the experimental procedures, to ensure subjects were familiar with marching on the treadmill with various loads and at different speeds. Each subject then participated in a predicted submaximal $VO_{2\ max}$ test to provide an estimation of cardiovascular condition.

During the experimental period subjects reported to the laboratory on four separate occasions to be tested under two conditions at each session. Each condition consisted of a six-minute treadmill march. On arrival at the laboratory each subject was fitted with a polar heart rate monitor, the battlejacket, face-mask, helmet and relevant backpack. The face-mask was then attached to the portable ergospirometer, the Metamax. As subjects straddled the treadmill to begin the six-minute march, anticipatory heart rate was recorded. During the third and sixth minutes, detailed physiological data were recorded by the Metamax and reflected on a PC. These data included the following:

- Breathing frequency (F_B);
- Tidal Volume (V_T);
- Minute Ventilation (V_E);
- Oxygen Consumption (VO_2);
- Metabolic carbon dioxide production (VCO_2); and
- Respiratory Exchange Ratio (R).

The following energy expenditure (EE) variables were then derived from the VO_2 measurement:

- $kJ.min^{-1}$
- $kJ.\Sigma kg^{-1}.min^{-1}$
- $kcal.min^{-1}$
- Power output (W)

While marching on the treadmill cadence was recorded with a cadence meter and at minute three and six, working heart rate and "Central" and "Local" RPE ratings were recorded. On completion of the march the subject straddled the treadmill and identified sites and intensities of body discomfort on a body discomfort map.

SUMMARY OF RESULTS

The results obtained in this study provide some insights into the demographics of the current SANDF, and the physiological and perceptual responses of South African soldiers marching under varied speed and load combinations. Due to the diversity of soldiers who make up the SANDF it is evident from Table IV (Chapter III) that there is a wide range of measures for morphological parameters; stature (1711±61.64mm), mass (68.2±8.69kg), percent body fat (17.38±3.87%), and cardiovascular condition (predicted $VO_{2\ max}$ of 40±7.64 $ml.kg^{-1}.min^{-1}$), of the group under investigation. Maximal oxygen consumption values were 10% lower than measures obtained over 30 years ago by Wyndham **et al.** (1971) on South African miners. Furthermore, Christie and Todd (2001) recently reported that $VO_{2\ max}$ values of South African soldiers are more than 10 $ml.kg^{-1}.min^{-1}$ lower than those measured on soldiers internationally. It could be argued that exposure to poor living conditions and dietary patterns which in turn will affect the general health status of individuals in South Africa is likely to impact on the cardiorespiratory performance of these soldiers (O'Keefe **et al.**, 1983; Steyn **et al.**, 1998).

The results propose that the majority of responses recorded revealed five unequivocal categorisations of the 16 combinations of speed and load investigated. Three combinations (See Figure 21, Chapter IV) were categorised as "nominal" stress demands during which subjects were minimally taxed (below 40% of maximum). Although these combinations may, from an ergonomics perspective, be considered optimal for an 8-hour working shift they are impractical in a military situation and unlikely to be selected by the army. At the other extreme the heavy loads of 50kg and 65kg when combined with high speeds resulted in disproportionate increases in energy expenditure and higher ratings of perceived exertion comparable to the findings of Soule **et al.** (1978). During these marches subjects were taxed well above 80% of maximum, sufficient to categorise these combinations as “excessive”; it is strongly recommended that these combinations are not utilised.

Although the 10 marches reflected in Figure 23 (Chapter IV) are considered “tolerable”, there are three discrete categories (“moderate”, “heavy” and “very heavy”) within this general classification. Preferably, the three “moderate” stress marches are considered to be “ideal” for prolonged marching as subjects were working below 50% of maximal capacity and had reached a steady-state. Statistically there was no difference between the soldiers’ responses to the three speed and load combinations within this category with similar working heart rate (range of 118 $bt.min^{-1}$ to 127 $bt.min^{-1}$), V_E (range of 32.74 $L.min^{-1}$ to 33.49 $L.min^{-1}$), VO_2 (range of 18.96 $ml.kg^{-1}.min^{-1}$ to 19.78 $ml.kg^{-1}.min^{-1}$) and ratings of perceived exertion (“Central” ratings of 10 and 11). It is therefore proposed that marching at 5.5 $km.h^{-1}$ with a 20kg backpack load, or at 4.5 $km.h^{-1}$ with a 35kg load, or at 3.5 $km.h^{-1}$ with a 50kg load, are combinations suitable for extended marches with all three speed-load combinations inflicting the same physiological and psychophysical cost on the soldier.

However, because “ideal” combinations of speed and load may not always be militarily realistic, marching speed and load carried could be increased to the combinations categorised as “heavy” workloads during which subjects were working between 50% and 65% of maximum. Working heart rate (range of 127 $bt.min^{-1}$ to 137 $bt.min^{-1}$), V_E (range of 37.77 $L.min^{-1}$ to 41.73 $L.min^{-1}$), VO_2 (range of 23.64 $ml.kg^{-1}.min^{-1}$ to 26.75 $ml.kg^{-1}.min^{-1}$) and perceptual (“Central” ratings of 12 and 13) responses revealed no statistical difference between these marches with a strong correlation (r=0.8) between working heart rate and “Central” RPE. Thus, contrary to some findings (Haisman, 1988; Patton **et al.**, 1991), it is argued that soldiers can carry loads up to 65kg providing speed is reduced, and speed can be increased to 6.5 $km.h^{-1}$, but only if load is reduced.

Recognising that certain military situations may place considerably greater demands on soldiers it is suggested that, in exceptional incidences, the three marches categorised as “very heavy” may be utilised. As with the previous categorisations the responses were statistically similar for all three conditions with physiological responses of working heart rate (range of 150 $bt.min^{-1}$ to 158 $bt.min^{-1}$), V_E (range of 49.00 $L.min^{-1}$ to 53.14 $L.min^{-1}$) and VO_2 (range of 26.76 $ml.kg^{-1}.min^{-1}$ to 30.98 $ml.kg^{-1}.min^{-1}$) being comparable, as were the “Central” perceptual responses (ratings of 12 and 13). As soldiers could be taxed close to 80% of maximum during these marches, it is strongly recommended that the duration of the march be given careful consideration. Adequate work-to-rest ratios should be implemented in order to diminish cumulative fatigue effects.

Within this broad “tolerable” category, the two outer ranges of “moderate” and “very heavy” workloads reflected a modest correlation (r=0.4) between working heart rate and “Central” RPE, while the “heavy” stress combinations exhibited a strong correlation (r=0.8) between these two variables. It is therefore argued that during the two extremes of this broad category (the light and demanding marches) soldiers tended to suppress how they felt, yet when working between 50% and 65% of maximum, their perceptions of exertion closely reflected physiological cost.

HYPOTHESES

The hypotheses are discussed with reference to responses recorded during the sixth minute of treadmill marching. As 16 conditions were investigated the rejection or tentative acceptance of the hypotheses will be based on the majority of significant responses which have been identified as a percentage of the total number of responses.

Physiological responses were lowest during the conditions classified as "nominal" intensity, whereas they were more pronounced during the "moderate", "heavy" and "very heavy" intensity marches, and were highest during the "excessive" marches. In general, increases in speed had a marginally greater impact on physiological responses compared to increases in load. Excessive speed and load combinations resulted in subjects working at, or close to maximum.

Therefore with respect to the physiological responses, the null hypothesis (H_o 1: a, b and c) is rejected. Statistical analysis revealed significant differences in the majority of the cardiac (78%), V_E (82%), V_T (76%) and F_B (76%) responses. Metabolic responses (VO_2, VCO_2, RER, kcal and kJ) showed a statistical increase for 85% of the variables, except for RER which showed a statistical increase for 72% of the conditions.

In respect of the second hypothesis dealing with perceptual responses, the results similarly force rejection of the null hypothesis. Generally perceptions of exertion paralleled those of the physiological responses with 63% of the “Central” RPE responses and 77% of the “Local” RPE responses showing a significant change between conditions.

In respect of the third hypothesis, there is a further rejection of the null hypothesis as in the majority of the conditions (67% to 72%) there was a significant change in both step-rate and stride length with changes in speed and load.

CONCLUSIONS

These results emphasise the need to carefully consider the objectives of a march prior to the selection of a particular speed and load combination. The 10 marches constituting the broad “tolerable” category signify that if heavier loads need to be transported then a slow speed must be employed. At the other end of the range if speed is of the essence then load must be reduced, ensuring similar costs to individuals within each of the three stress levels making up the “tolerable” category.

Recognizing that the duration of the march will be a major causative factor to long term metabolic cost, as “physiological drift” is likely to occur over time, it is strongly recommended that the military employ the three combinations recognised as “moderate” strain for prolonged marches. However, when duration is reduced, combinations of speed and load may be increased to the “heavy” stress level and in special circumstances and over short distances with the appropriate rest intervals, the speed/load combinations classified as “tolerable”, but “very heavy” may be used with caution.

RECOMMENDATIONS

Future investigations into the physiological and perceptual responses of varying combinations of speed and load should consider the following recommendations:

1) Further laboratory investigations, where the majority of factors can be rigorously controlled, are required in order to gain a greater understanding of the energetic and psychophysical responses to marching. These laboratory investigations should include:

    a) Longer duration marches in order to investigate the concept of “physiological drift” more closely. “Ideal” combinations of speed and load proposed in this study thus need to be investigated over extended periods.

    b) The impact of positive and negative gradients on the “ideal” combinations of speed and load, and from this it will be possible to determine optimal speed, load and gradient combinations for different marching conditions.

c) Nutritional studies in order to determine whether dietary intake is sufficient to meet the energy requirements of military operations. This should also include assessment of the traditional ration packs issued to soldiers.

d) Due to the increasing number of females being recruited to the SANDF, future studies need to investigate female responses to the same workloads investigated in this study and to the above recommendations.

2) However, because it is difficult to extrapolate “sterile” laboratory findings to “real world” application, the above recommendations should also be investigated *in situ*, as it may not always be valid to extrapolate results from the artificial nature of a laboratory testing environment to the reality of long term field conditions. Recommendations 1 (a) to (c) should therefore be investigated in a field setting with both male and female soldiers.

In conclusion, it is contended that the results of this research demonstrate that the interplay between marching speed and backpack load plays a crucial role in ensuring that similar metabolic and psychophysical demands are retained at a bearable level to meet specific military circumstances. Acknowledging the diversity of military operations three stress levels have been proposed in the broad “tolerable” categorisation. However, when investigating responses of soldiers who are required to operate under extremely diverse, challenging and critical conditions and where combat effectiveness is a matter of life and death, it is important that ongoing laboratory and *in situ* investigations are conducted. In this way the well-being of soldiers will be continuously monitored while at the same time ensuring a combat efficient defence force.

REFERENCES

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

American College of Sports Medicine (ACSM) (1986). **Guidelines for Exercise Testing and Prescription,** Fourth Edition. Philadelphia: Lea and Febiger.

Astrand I (1967). Degree of strain during building work as related to individual aerobic work capacity. **Ergonomics,** 10 (3): 293-303.

Astrand PO and Rodahl K (1977). **Textbook of Work Physiology.** Second Edition. New York: McGraw Hill Company Publishers.

Baldwin KM, Fitts RH, Booth FW, Winder WW and Holloszy JO (1975). Depletion of muscle and liver glycogen during exercise: protective effect of training. **Plugers Archive,** 354: 203-212.

* Basset DR, Giese MD, Nagel FJ, Ward A, Raab DM and Balke B (1985). Aerobic requirements of overground versus treadmill running. **Medicine and Science in Sports and Exercise,** 17: 477-481. (See White **et al.**, 1998).

Basset DR and Howley ET (2000). Limiting factors for maximum oxygen uptake and determinants of endurance performance. **Medicine and Science in Sports and Exercise,** 32 (1): 70-84.

Berger RA (1982). **Applied Exercise Physiology.** Philadelphia: Lea and Febiger.

Bergh U, Ekblom B and Astrand PO (2000). Maximal oxygen uptake “classical” versus “contemporary” viewpoints. **Medicine and Science in Sports and Exercise,** 32 (1): 85-88.

Bhambhani Y, Buckley S and Maikala R (1997). Physiological and biomechanical responses during treadmill walking with graded loads. **European Journal of Applied Physiology,** 76 (6): 544-551.

Bink B (1962). The physical working capacity in relation to working time and age. **Ergonomics,** 5: 25-28.

Bobbert AC (1960). Energy expenditure in level and grade walking. **Journal of Applied Physiology,** 15: 1015-1021.

[*] Bobet J and Norman RW (1984). Effects of load placement on back muscle activity in load carriage. **European Journal of Applied Physiology,** 53: 71-75. (See Quesada **et al.**, 2000).

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

Borg G (1971). **The Perceptions of Physical Work.** In: Shephard RJ (Ed.). Frontiers of Fitness. Springfield, Illinois: C Thomas Publishers.

Borg GA (1973). Perceived exertion: a note on “history” and methods. **Medicine and Science in Sports and Exercise,** 5 (2): 90-93.

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

Bosch AN, Dennis SC and Noakes TD (1993). Influence of carbohydrate loading on fuel substrate turnover and oxidation during prolonged exercise. **Journal of Applied Physiology,** 74 (4): 1921-1927.

Brooks GA (1985). Anaerobic threshold: review of the concept and directions for future research. **Medicine and Science in Sports and Exercise,** 17: 22-31.

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

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

[*] Buskirk E and Taylor HL (1957). Maximal oxygen intake and its relation to body composition, with special reference to chronic physical activity and obesity. **Journal of Applied Physiology,** 11 (1): 72-78. (See Haisman, 1988).

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

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

Cathcart EP, Richardson DT and Campbell W (1923). On the maximum load to be carried by the soldier. **Journal of the Royal Army Medical Corps,** 40: 435-443; 41: 12-24: 41: 87-98; 41: 161-178.

Cavanagh PR and Williams KR (1982). The effect of stride length variation on oxygen uptake during distance running. **Medicine and Science in Sports and Exercise,** 14, 30-35.

Charteris J, Cooper LA and Bruce JR (1976). Human Kinetics: a conceptual model for studying human movement. **Journal of Human Movement Studies,** 2: 233-238.

Charteris J and Taves C (1978). The process of habituation to treadmill walking: a kinematic analysis. **Perceptual and Motor Skills,** 47 (2): 659-666.

Charteris J (1982). Human gait cyclograms: conventions, speed relationships and clinical applications. **International Journal of Rehabilitation Research,** 5 (4): 507-518.

Charteris J, Wall JC and Nottrodt JW (1982). Pliocene hominid gait: new interpretations based on available footprint data from Laetoli. **American Journal of Physical Anthropology,** 58: 133-144.

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

Christie CJ and Todd AI (2001). Enhancing military efficiency: A South African perspective. **Ergonomics SA,** (in press).

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

Costill DL, Thomason H and Roberts E (1973). Fractional utilisation of the aerobic capacity during distance running. **Medicine and Science in Sports and Exercise,** 5: 248-252.

Costill DL, Fink WJ, Flynn M and Kirwan J (1987). 'Muscle fibre composition and enzyme activities in elite female distance runners'. **International Journal of Sports Medicine,** 8 (Suppl.3), 103-106.

Cureton KJ, and Sparling PB (1980). 'Distance running performance and metabolic responses to running in men and women with excess weight experimentally equated'. **Medicine and Science in Sports and Exercise,** 12, 288-294.

Daniels JT (1985). A physiologist's view of running economy. **Medicine and Science in Sports and Exercise,** 17 (3): 332-338.

Datta SR and Ramanathan NL (1971). Ergonomic comparison of seven modes of carrying loads on the horizontal plane. **Ergonomics,** 14 (2): 269-278.

Davies KJA, Packer L and Brooks GA (1981). Biochemical adaptation of mitochondria, muscle and whole-animal respiration to endurance training. **Archives of Biochemistry and Biophysics,** 209: 539-554.

* Davies KJA, Packer L and Brooks GA (1982). 'Exercise bio-energetics following sprint training'. **Archives of Biochemistry,** 215: 260-265. (See Noakes, 1992).

Dempsey JA, Vidruk EH and Mastenbrook SM (1980). Pulmonary control systems in exercise. **Federation Proceedings,** 39: 1498-1505.

* Dill DB, Edwards HT and Talbott JH (1930). Studies in muscular activity, VI, responses of several individuals to a fixed task. **Journal of Physiology (London),** 69: 267-305. (See Daniels, 1985).

di Pramperor PE (1985). Metabolic and Circulatory limitations to $VO_{2\ max}$ at the whole animal level. **Journal of Experimental Biology,** 115: 319-331.

Duff-Raffaele M, Kerrigan DC, Corcoran PJ and Saini M (1996). The proportional work of lifting the centre of mass during walking. **American Journal of Physical Medicine and Rehabilitation,** 75 (5): 375-379.

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

* Ekblom B and Goldbarg AN (1971). The influence of physical training and other factors on the subjective rating of perceived exertion. **Acta Physiologica Scandinavica,** 83: 399-406. (See Goslin and Rorke, 1986).

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

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

Fleg JL and Lakatta EG (1988). 'Role of muscle loss in the age-associated reduction in $VO_{2\,max}$'. **Journal of Applied Physiology,** 65 (3): 1147-1151.

* Fringer MN and Stull GA (1974). Changes in cardiorespiratory parameters during periods of training and detraining in young adult females. **Medicine and Science in Sports and Exercise,** 6: 20-25. (See McArdle **et al.**, 1996).

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

Garcin M, Vautier JF, Vandewallet H, and Monod H (1998). Ratings of perceived exertion (RPE) as an index of aerobic endurance during local and general exercises. **Ergonomics,** 41 (8): 1105-1114.

Givoni B and Goldman RF (1971). Predicting metabolic energy cost. **Journal of Applied Physiology,** 30 (3): 429-433.

Goedecke JH, Christie C, Wilson G, Dennis SC, Noakes TD, Hopkins WG and Lambert EV (1999). Metabolic adaptations to a high fat diet in endurance cyclists. **Metabolism,** 48 (12): 1509-1517.

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

Goldman RF and Iampietro PF (1962). Energy cost of load carriage. **Journal of Applied Physiology,** 17 (4): 675-776.

Gollnick PD (1985). Metabolism of substrates: energy substrate metabolism during exercise and as modified by training. **Federation Proceedings,** 44 (2): 353-357.

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

Goslin BR (1985). Economy and efficiency of human locomotion. **Ph.D. Thesis,** Rhodes University, Grahamstown, South Africa.

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

Grieve DW and Gear RJ (1966). The relationship between length of stride, step frequency, time of swing and speed of walking for children and adults. **Ergonomics,** (5): 379-399.

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

Holewijn M (1990). Physiological strain due to load carrying. **European Journal of Applied Physiology and Occupational Physiology,** 61: 237-245.

Hanson P, Claremont A, Dempsey J, Reddan W (1982). Determinants and consequences of ventilatory responses to competitive endurance running. **Journal of Applied Physiology,** 52: 615-623.

* Hermansen L, Hultman E, Saltin B (1967) Muscle glycogen during prolonged severe exercise. **Acta Physiologica Scandinavica,** 71: 129-139 (See Noakes, 1992).

Hill AV and Lupton H (1923). Muscular exercise, lactic acid, and the supply and utilisation of O_2. **Quarterly Journal of Medicine,** 16: 135-171.

* Hogberg P (1952a). How do stride length and stride frequency influence the energy-output during running? **Arbeitsphysiologie,** 14: 437-441 (See Goslin, 1985).

Holt KG, Hamill J, and Andres RO (1991). Predicting the minimal energy cost of human walking. **Medicine and Science in Sports and Exercise,** 23 (4): 491-498.

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

Ivy JL, Withers RT, Van Handel PJ, Elger DH and Costill DL (1980). Muscle respiratory capacity and fibre type as determinants of the lactate threshold. **Journal of Applied Physiology,** 48 (3): 523-527.

* Jirka Z and Adamus M (1965). Changes of ventilation equivalents in young people in the course of three years by training. **Journal of Sports Medicine,** 5: 1. (See McArdle **et al.**, 1996).

Johnson RF, Knapik JJ and Merullo DJ (1995). Symptoms during load carrying: effects of mass and load distribution during a 20 km road march. **Perceptual and Motor Skills,** 81: 331-338.

Kinoshita H (1985). Effects of different loads and carrying systems on selected biomechanical parameters describing walking gait. **Ergonomics,** 28 (9): 1347-1362.

Kirkwood SP, Munn EA and Brooks GA (1986). Mitochondrial reticulum in limb skeletal muscle. **American Journal of Physiology,** 251: C395-C402.

Knapik J (1989). **Loads carried by soldiers: Historical, physiological, biomechanical and medical aspects.** Report No. T19-89. US Army Research Institute of Environmental Medicine. Natick, Massachusetts.

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

* Komiya S and Masuda T (1990). Estimation of human body composition by bioelectrical impedance measurements: equation for estimating total body water in Japanese subjects. **Japanese Journal of Physical Fitness and Sports Medicine,** 39:53-59. (See Liang **et al.**, 2000).

Kotler DP, Burastero S, Wang J and Pierson RN (1996). Prediction of body cell mass, fat-free mass, and total body water with bioelectrical impedance analysis: effects of race, sex, and disease. **American Journal of Clinical Nutrition,** 64 (Suppl): 489S-497S.

Kraemer WJ, Noble BJ, Clarke MJ and Culver BW (1987). Physiological responses to heavy-resistance exercise with very short rest periods. **International Journal of Sports Medicine,** 8: 247-252.

Kruss J, Gordon J, Myburgh KH and Noakes TD (1989). The influence of inborn athletic potential and choice of profession and exercise habits of paramedical students. **South African Medical Journal,** 18, 76 (10): 538-541.

Lambert MI and Noakes TD (1989). Dissociation of changes in $VO_{2\ max}$, muscle QO_2, and performance with training in rats. **Journal of Applied Physiology,** 66: 1620-1625.

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

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

Legg SJ, Perko L and Campbell P (1997). Subjective perceptual methods for comparing backpacks. **Ergonomics,** 40(8): 809-817.

Lemura LM, von Duvillard SP and Mookerjee S (2000). The effects of physical training of functional capacity in adults Ages 46 to 90: a meta-analysis. **Journal of Sports Medicine and Physical Fitness,** 40 (1): 1-10.

Liang MTC and Norris S (1993). Effects of skin blood flow and temperature on bioelectric impedance after exercise. **Medicine and Science in Sports and Exercise,** 25: 1231-1239.

Liang MTC, Su HF and Lee NY (2000). Skin temperature and skin blood flow affect bioelectric impedance study of female fat-free mass. **Medicine and Science in Sports and Exercise,** 32 (1), 221-227.

Lloyd R and Cooke CB (2000). The oxygen consumption associated with unloaded walking and load carriage using two different backpack designs. **European Journal of Applied Physiology and Occupational Physiology,** 81(6), 486-492.

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

Marti B and Howard H (1990). 'Long term effects of physical training on aerobic capacity: Controlled study of former elite athletes'. **Journal of Applied Physiology,** 69: 1451-1459.

Martin BJ, Morgan EJ, Zwillich CW, Weil JV (1981). Control of breathing during prolonged exercise. **Journal of Applied Physiology,** 50: 27-31.

Martin PE, Heise GD and Morgan DW (1993). Interrelationships between mechanical power, energy transfers, and walking and running economy. **Medicine and Science in Sports and Exercise,** 25: 508-515.

McArdle WD, Katch FI and Katch VL (1996). **Exercise Physiology. Energy, Nutrition, and Human Performance.** Fourth Edition. Baltimore: Williams and Wilkins.

Myles WS and Saunders PL (1979). The physiological cost of carrying light and heavy loads. **European Journal of Applied Physiology,** 42: 125-131.

Noakes TD (1988). Implication of exercise testing for prediction of athletic performance: a contemporary perspective. **Medicine and Science in Sports and Exercise,** 20: 319-330.

Noakes (1992). **Lore of Running**. Third Edition, Oxford University Press Southern Africa.

O'Keefe SJ, Thusi D and Epstein S (1983). The fat and the thin-a survey of nutritional status and disease patterns among urbanized Black South Africans. **South African Medical Journal,** 63 (18): 679-683.

Pandolf KB, Burse RL and Goldman RF (1975). Differentiated ratings of perceived exertion during conditioning of older individuals using leg-weight loading. **Perceptual Motor Skills,** 40 (2): 563-574.

Pandolf KB, Givoni B and Goldman RF (1977). Predicting energy expenditure with loads while standing or walking very slowly. **Journal of Applied Physiology: Respiration, Environmental, and Exercise Physiology,** 43 (4): 577-581.

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

Pandolf KB (1982). Differentiated ratings of perceived exertion during physical exercise. **Medicine and Science in Sports and Exercise,** 14: 397-405.

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

Perronet F, Thibault G, Rhodes EC, McKenzie DC (1987). Correlation between ventilatory threshold and endurance capability in marathon runners. **Medicine and Science in Sports and Exercise,** (19): 610-615.

Pierrynowski MR, Winter DA and Norman RW (1981). Metabolic measures to ascertain the optimal load to be carried by man. **Ergonomics,** 24 (5): 393- 399.

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

Pimental NA, Shapiro Y and Pandolf KB (1982). Comparison of uphill and downhill walking and concentric and eccentric cycling. **Ergonomics,** 25 (5): 373-380.

Quesada PM, Mengelkoch LJ, Hale RC and Simon SR (2000). Biomechanical and metabolic effects of varying backpack loading on simulated marching. **Ergonomics,** 43 (3): 293-309.

Ramabhai LI (1999). The effect of load carriage on selected metabolic and perceptual responses of military personnel. **MSc Thesis,** Department of Human Kinetics and Ergonomics, Rhodes University, Grahamstown, South Africa.

Redfearn JWT, Crampton RF, Williams TD and Mitchell B (1956). The metabolic cost of load-carrying: a discussion of experimental findings, Report 4/56, **Army Operational Research Group.**

Robertson RJ, Caspersen CJ, Allison TG, Skrinar GS, Abbot RA and Metz KF (1982). Differentiated perceptions of exertion and energy cost of young women while carrying loads. **European Journal of Applied Physiology,** 49 (1): 69-78.

Rogers MA, Hagberg JM, Martin JM, Martin WH, Ehsani AA and Holloszy JO (1990). 'Decline in $VO_{2\ max}$ with ageing in master athletes and sedentary men'. **Journal of Applied Physiology,** 68: 2195-2199.

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

Sabiene F (1990). The mechanisms for minimising energy expenditure in human locomotion. **European Journal of Clinical Nutrition,** 44 (1): 65-71.

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

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

Saltin B and Strange S (1992). Maximal oxygen uptake: “old” and “new” arguments for a cardiovascular limitation. **Medicine and Science in Sports and Exercise,** 24 (1): 30-37.

* Saunders M, Inman VT and Eberhart HD (1953). Major determinants in normal and pathological gait. **The Journal of Bone and Joint Surgery,** 35-A, 543-558. (See Goslin, 1985).

Scott PA (1986). The ratings of perception of exertion in a multi-ethnic society: a review of the problem and some preliminary solutions. **Proceedings: First Annual Conference of the Ergonomics Society of Southern Africa.** Pretoria, 5-6 February.

Scott PA and Christie C (2000). Cardiac responses under diverse combinations of marching speed and backpack load. **Ergonomics SA,** (12) 1: 49-60.

Scott PA and Ramabhai L (2000). Comparison of male and female responses to carrying absolute and relative loads while on a three hour military march. **Proceedings of the IEA 2000/HFES 2000 Congress.** San Diego, California, 29 July – 4 August.

* Snook SH and Ciriello VM (1974). The effects of heat stress on manual handling tasks. **American Industrial Hygiene Association Journal,** 35 (11): 681-685. (See Haisman, 1988).

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

Soule RG and Goldman RF (1972). Terrain coefficients for energy cost predictions. **Journal of Applied Physiology,** 32 (5): 706-708.

Soule RG, Pandolf KB and Goldman RF (1978). Energy expenditure of heavy load carriage. **Ergonomics,** 21 (5): 373-381.

Steyn K, Fourie JM and Shepherd J (1998). Detection and measurement of hypercholesterolemia in South Africans attending general practioners in private practice – the cholesterol monitor. **South African Medical Journal,** 88 (12): 1569-1574.

* Taylor CR, Heglund NC, McMahon TA and Looney TR (1980). 'Energetic cost of generating muscular force during running. A comparison of large and small animals'. **Journal of Experimental Biology,** 86: 9-18. (See Knapik **et al.**, 1996).

Taylor CR and Heglund NC (1982). Energetics and mechanics of terrestrial locomotion. **Annual Review of Physiology,** 44: 97-107.

Travlos AK and Marisi DQ (1996). Perceived exertion during physical exercise among individuals high and low in fitness. **Perceptual Motor Skills,** 82 (2): 419-424.

van Loan MD (1990). Bioelectrical impedence analysis to determine fat-free mass, total body water and body fat. **Sports Medicine,** 10 (4): 205-217.

* Van Ingen Schenau GJ (1980). Some fundamental aspects of the biomechanics of overground versus treadmill locomotion. **Medicine and Science in Sports and Exercise,** 12: 257-261. (See White **et al.**, 1998).

Vogel JA, Patton JF, Mello RP and Daniels WL (1986). An analysis of aerobic capacity in a large United State population. **Journal of Applied Physiology,** 60: 494-600.

Wagner DR and Heyward VH (1999). Techniques of body composition assessment: a review of laboratory and field methods. **Research Quarterly in Exercise and Sport,** 70 (2): 135-149.

Wagner DR and Heyward VH (2000). Measures of body composition in blacks and whites: a comparative review. **American Journal of Clinical Nutrition,** 71(6): 1392-1402.

Wareham NJ, Hennings SJ, Prentice AM and Day NE (1997). Feasibility of heart-rate monitoring to estimate total level and pattern of energy expenditure in a population-based epidemiological study: the Ely Young Cohort Feasibility Study 1994-5. **British Journal of Nutrition,** 78(6): 889-900.

Wall JC and Charteris J (1980). The process of habituation to treadmill walking at different velocities. **Ergonomics,** 23: 425-435.

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

Wells CL, and Plowman (1983). 'Sexual differences in athletic performance: Biological or behavioural. **Physician and Sportsmedicine,** (11): 52-63.

White SC, Yack J, Tucker CA and Hsin-Ying L (1998). Comparison of vertical ground reaction forces during overground and treadmill walking. **Medicine and Science in Sports and Exercise,** 30 (10): 1537-1542.

Williams KR and Cavanagh PR (1983). A model for the calculation of mechanical power during distance running. **Journal of Biomechanics,** 16: 115-128.

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

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

Yannakoulia M, Keramopoulos A, Tsakalakos N and Matalas AL (2000). Body composition in dancers: the bioelectrical impedance method. **Medicine and Science in Sports and Exercise,** 32 (1): 228-234.

Zatsiorky VM, Werner SL and Kaiman MA (1994). Basic kinematics of walking: A review. **The Journal of Sports Medicine and Physical Fitness,** 34 (2): 109-134.

BIBLIOGRAPHY

NOTE: During the conceptual growth of this dissertation the author consulted the following sources. While not specifically cited, these works did play an important role in establishing the basis upon which this research was developed.

Brisswalter J, Fougeron B and Legros P (1997). Variability in energy cost and walking gait during race walking in competitive race walkers. **Medicine and Science in Sports and Exercise,** 30 (9): 1451-1455.

Holden JP, Chou G and Stanhope SJ (1997). Changes in knee joint function over a wide range of walking speeds. **Clinical Biomechanics,** 12 (6): 375-382.

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

Morrissey SJ and Liou YH (1984). Metabolic costs of load carriage with different container sizes. **Ergonomics,** 27 (8): 847-853.

Nigg BM, De Boer RW and Fisher V (1994). A kinematic comparison of overground and treadmill running. **Medicine and Science in Sports and Exercise,** 27 (1): 98-105.

Rayson MP, Davies A, Bell DG and Rhodes-James ES (1995). Heart rate and oxygen uptake relationship: a comparison of loaded marching and running in women. **Journal of Applied Physiology,** 71: 405-408.

Spelman CC and Pate RR (1993). Self-selected exercise intensity of habitual walkers. **Medicine and Science in Sports and Exercise,** 25 (10): 1174-1179.

Taylor CR (1985). Force development during sustained locomotion: a determinant of gait, speed and metabolic power. **Journal of Experimental Biology,** 115: 253-262.

White SC, Yack J, Tucker CA and Lin H (1998). Comparison of vertical ground reaction forces during overground and treadmill running. **Medicine and Science in Sports and Exercise,** 30 (10): 1537-1542.

Williams AG, Rayson MP and Jones DA (1999). Effects of basic training on material handling ability and physical fitness of British Army recruits. **Ergonomics,** 42 (8): 1114-1124.

<u>APPENDICES</u>

APPENDIX A: GENERAL INFORMATION

Equipment Check List

Details of Testing Schedule

Letter to Subject

Subject Consent Form

Metamax Preparation

EQUIPMENT CHECK LIST

ADMINISTRATION

Letter to Subject

Informed Consent Form

General Information Data Sheet

Subject Data Sheet

Instructions to subject for RPE

Instructions to subject for Body Discomfort

STATIONARY

Clipboard

Examination Pad

Pens/Pencils/Eraser/Sharpener

Masking Tape

COMPUTER EQUIPMENT

Laptop

Printer

Multiple Adapter

Storage discs

DATA COLLECTION EQUIPMENT

Toledo Scale

Stadiometer

Bioelectrical Impedance Analysis

Metamax and accessories – including calibration equipment

Heart Rate Monitors

Cadence Meter

RPE Scale

Body Discomfort Scale

OTHER EQUIPMENT

Milton disinfectant

Tissues

Cotton wool

DETAILS OF TESTING SCHEDULE

1999

Briefing: Tuesday 14th September
14:00 – 15:00 All subjects

Habituation: Wednesday 15th September
14:00 – 16:00

Thursday 16th September
14:00 – 16:00

Submaximal Testing: Monday 20th September
14:00 – 15:30 Group M_1
15:30 - 17:00 Group M_2

Tuesday 21st September
14:00 – 15:30 Group M_3
15:30 – 17:00 Group M_4

Wednesday 22nd September
14:00 – 15:30 Group F_1
15:30 – 17:00 Group F_2

Thursday 23rd September
14:00 – 15:30 Group F_3
15:30 – 17:00 Group F_4

DETAILS OF TESTING SCHEDULE

<u>Experimental Data Collection Sessions</u>

(Two conditions per session)

DATES	10:00 – 12:30	14:00 – 16:30
Tuesday 28/09/99	Group M_1	Group F_1
Wednesday 29/09/99	Group F_2	Group M_2
Thursday 30/09/99	Group M_3	Group F_3
Tuesday 05/10/99	Group F_4	Group M_4
Wednesday 06/10/99	Group M_1	Group F_1
Thursday 07/10/99	Group F_2	Group M_2
Tuesday 12/10/99	Group M_3	Group F_3
Wednesday 13/10/99	Group F_4	Group M_4
Thursday 14/10/99	Group M_1	Group F_1
Friday 15/10/99	Group F_2	Group M_2
Thursday 21/10/99	Group M_3	Group F_3
Friday 22/10/99	Group F_4	Group M_4
Tuesday 26/10/99	Group M_1	Group F_1
Wednesday 27/10/99	Group F_2	Group M_2
Thursday 28/10/99	Group M_3.	Group F_3
Tuesday 02/11/99	Group F_4	Group M_4

- Each Subject is therefore tested under 8 of the sixteen conditions.

LETTER TO SUBJECT

Dear _____________________________

Thank you for participating as a subject in my Masters thesis entitled:

PHYSIOLOGICAL AND PERCEPTUAL RESPONSES OF SANDF PERSONNEL TO VARYING COMBINATIONS OF MARCHING SPEED AND BACKPACK LOAD.

The focus of the present project is to investigate the influence of different load weights and walking speeds on the energy cost of SANDF soldiers. The main objective is to investigate responses to different combinations of speed and load regardless of duration. The optimal load and speed can then be identified to ensure efficiency of performance in a military setting. The study will include both males and females, recognising the growing level of female participation in all aspects of military activities.

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

You will be required to come to the Human Kinetics and Ergonomics Department at Rhodes University on eight (8) separate occasions. The first session serves as 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 the treadmill, each subject will be required to come in on two occasions to habituate to treadmill walking. This will familiarise you with the equipment to be used when we collect the data. At the fourth session you will undergo basic demographic and morphological measurements including age, stature, body mass, and body composition. Each subject will also undergo a submaximal treadmill test in order to estimate what we call your $VO_{2\ max}$. This will give us an indication as to what intensity you are working in relation to your 'maximum' effort.

The last four sessions involve actual data collection. You will be divided into groups and at each session will be one of four people being tested. On each occasion you will be tested twice for a period of six minutes. You will have a face-mask on which will be attached to a machine called the Metamax. In this way we will be able to analyse your air breathed in and out to determine how much energy your are expending (how difficult the task is for you physiologically). You will also be fitted to 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 psycho-physical rating scales called the Rating of Perceived Exertion (RPE) scale and the Body Discomfort scale which will be explained to you in detail.

Following completion of 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 helps to eliminate competition between subjects and to standardise data collection. Thank you for your interest shown and for agreeing to participate in this research protocol. If you have any questions please do not hesitate to contact me at the Human Kinetics and Ergonomics Department.

Yours Sincerely

CANDICE CHRISTIE

(MSc student – Department of Human Kinetics and Ergonomics)

SUBJECT CONSENT FORM

I, MAJ K. M /a/001 having been fully informed of the research project entitled:

EFFECTS OF LOAD CARRIAGE AND WALKING SPEED ON SELECTED PHYSIOLOGICAL AND PERCEPTUAL RESPONSES

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 associated with 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 of Rhodes University, from any and all claims resulting from personal injuries sustained whilst partaking in the investigation. This waiver shall be binding upon my heirs and personal representatives. I realise that it is necessary for me to promptly report to the researchers any signs or symptoms indicating any abnormality or distress. I am aware that I may withdraw my consent and may withdraw from participation in the research at any time. I am aware that my anonymity will be protected at all times, and agree that all the information collected may be used and published for statistical or scientific purposes.

I have read the information sheet accompanying this form and understand it. Any questions which may have occurred to me have been answered to my satisfaction.

SUBJECT (OR LEGAL REPRESENTATIVE):

K. MALOOI		3/4/99
(Print name)	(Signed)	(Date)

PERSON ADMINISTERING INFORMED CONSENT:

C J Christie		03/11/1999
(Print name)	(Signed)	(Date)

WITNESS:

L. I. RAMABHAI	Ramabhai	03/11/99
(Print name)	(Signed)	(Date)

METAMAX PREPARATION

Gas and Volume calibration

Connect leads to Metamax

Fit subject with heart rate monitor belt – HR and event marker

Connect gas analysis tube to volume transducer which connects to the mask

Connect gas analysis and volume transducer tubes to Metamax

Place mask on subject and check for any leaks

APPENDIX B: DATA COLLECTION

Rating of Perceived Exertion Scale

Instructions to Subject for RPE

Body Discomfort Scale

Instructions to Subject for Body Discomfort

Subject Data Sheet

RATING OF PERCEIVED EXERTION SCALE

Borg's (1971) Rating of Perceived Exertion (RPE) Scale.

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	

(after: Borg G (1971). **The Perception of Physical Work.** In: Shephard RJ (Ed.) Frontiers of Fitness, Springfield, Illinois: C Thomas).

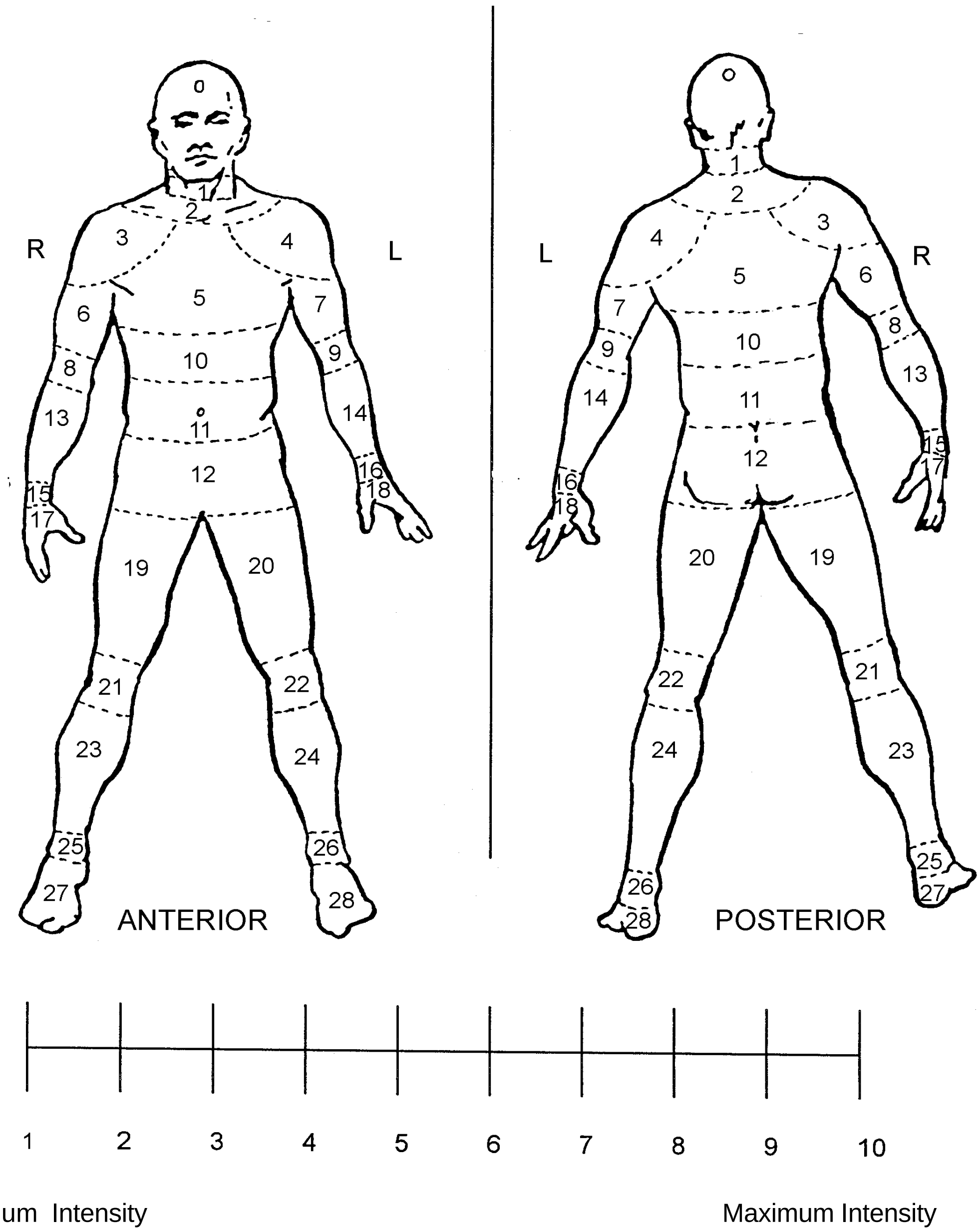
INSTRUCTIONS TO SUBJECT FOR RPE

Whilst you are marching on the treadmill we want you to try and estimate how hard you feel you are working, your degree of perceived exertion. You will be asked to point to a number on the scale, which corresponds to how you are feeling. It is important that you don't talk, as this will affect the recordings of the Metamax. You will first be asked how you are feeling in terms of your heart and breathing and this is called your 'central' RPE. The second rating will be how your legs are feeling and is referred to as your 'local' RPE. The ratings tell us how you are feeling and your RPE rating will therefore be different to everyone else in the group.

It is important that you be as objective as possible and do not under-or-overestimate the degree of exertion you feel. You will be asked to give these ratings twice during the 6-minute period on the treadmill. A rating of six (6) corresponds to how you are feeling now, sitting quietly, whereas a rating of twenty (20) reflects how you would feel if you were pushed to your maximum and needed to stop.

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

Once you have finished walking on the treadmill, you will be requested to ‘straddle’ the treadmill. You will now be able to talk as we ask you if you felt any discomfort or pain in any part of your body whilst marching. You will be required to point to the site(s) of body discomfort on this body map. The sites are numbered 0-27 and then you will be asked to rate the intensity of discomfort at each identified site. The intensity rating is on a ten (10) point scale where one (1) refers to “very comfortable work” and ten (10) refers to “extreme discomfort”.

Once again, be as objective as possible and do not over-or-underestimate your degree of discomfort or pain.

SUBJECT DATA SHEET

Code:__________

Name:____________________ Age:___________

Stature:_______mm Leg length:_______mm

Body weight:_______kg VO_2 max:_________

Speed:__________________ Load:___________________

Variable	Min 1	Min 2	Min 3	Min 4	Min 5	Min 6
Heart Rate						
RPE						
Cadence						

Body Discomfort: Site:__________________________Rating:_______________
Site:__________________________Rating:_______________
Site:__________________________Rating:_______________

Speed:_____________________Load:_________________

Variable	Min 1	Min 2	Min 3	Min 4	Min 5	Min 6
Heart Rate						
RPE						
Cadence						

Body Discomfort: Site:_________________________Rating:________________
Site:_________________________Rating:________________
Site:_________________________Rating:________________

Name:____________________Code:___________

Speed:__________________Load:___________________

Variable	Min 1	Min 2	Min 3	Min 4	Min 5	Min 6
Heart Rate						
RPE						
Cadence						

Body Discomfort: Site:_____________________Rating:__________________
Site:_____________________Rating:__________________
Site:_____________________Rating:__________________

Speed:______________Load:_______________

Variable	Min 1	Min 2	Min 3	Min 4	Min 5	Min 6

Body Discomfort: Site:_____________________Rating:__________________
Site:_____________________Rating:__________________
Site:_____________________Rating:__________________

Speed:_______________Load:_____________

Variable	Min 1	Min 2	Min 3	Min 4	Min 5	Min 6
Heart Rate						
RPE						
Cadence						

Body Discomfort: Site:____________________Rating:___________________
Site:____________________Rating:___________________
Site:____________________Rating:___________________

Name:____________________________Code:____________

Speed:_______________Load:______________

Variable	Min 1	Min 2	Min 3	Min 4	Min 5	Min 6
Heart Rate						
RPE						
Cadence						

Body Discomfort: Site:____________________Rating:_____________________
Site:____________________Rating:_____________________
Site:____________________Rating:_____________________

Speed:___________________Load:________________

Variable	Min 1	Min 2	Min 3	Min 4	Min 5	Min 6
Heart Rate						
RPE						
Cadence						

Body Discomfort: Site:___________________Rating:______________________
Site:___________________Rating:______________________
Site:___________________Rating:______________________

Speed:__________________Load:____________________

Variable	Min 1	Min 2	Min 3	Min 4	Min 5	Min 6
Heart Rate						
RPE						
Cadence						

Body Discomfort: Site:___________________Rating:______________________
Site:___________________Rating:______________________
Site:___________________Rating:______________________

APPENDIX C: SUMMARY REPORTS

Physiological Formulae and Variables

Polar Heart Rate Monitor printout

Metamax Report

Statistics Printout

Statistical Table

PHYSIOLOGICAL FORMULAE AND VARIABLES

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

HR_{max} = 220 – age (in years)

Basal Metabolic Rate (BMR) in $kj.day^{-1}$:

The energy expended under relaxed, resting conditions, unaffected by extra external loads such as digestion. It reflects the energy requirements of cardiac and respiratory muscles, other vital organs and the maintenance of normal body temperature.

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

Amount of breaths per minute

Carbon Dioxide Production (VCO_2) in $ml.kg^{-1}.min^{-1}$:

The amount of carbon dioxide produced by the body each minute.

Coefficient of Variability (CV) in %:

Measures the relative variability and allows for comparisons of different data.

$$CV = \frac{\text{standard deviation}}{\text{mean}} \times 100$$

Energy Expenditure (EE):

VO_2 ($L.min^{-1}$) x 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)

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

The number of times per minute that the heart beats.

Metabolic Equivalent (MET):

Multiple of resting metabolic rate. 1 MET = 3.5 $ml.kg^{-1}.min^{-1}$.

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

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

V_E = Breathing frequency x Tidal Volume

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

The amount of oxygen consumed by the body each minute.

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

Respiratory Exchange Ratio (R):

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

Standard Deviation (SD):

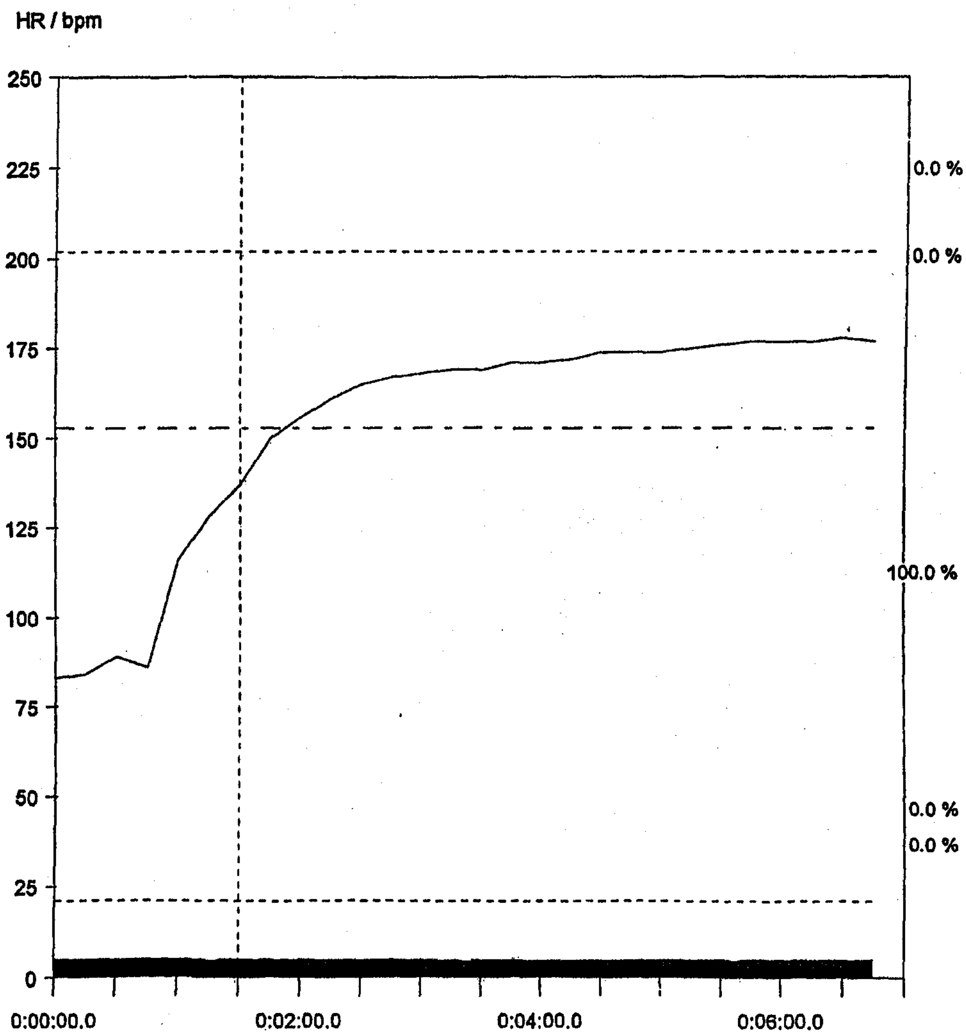
68% of score in a normal distribution fall within 1SD of the mean.

Tidal Volume (V_T) in L:

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

POLAR HEART RATE MONITOR

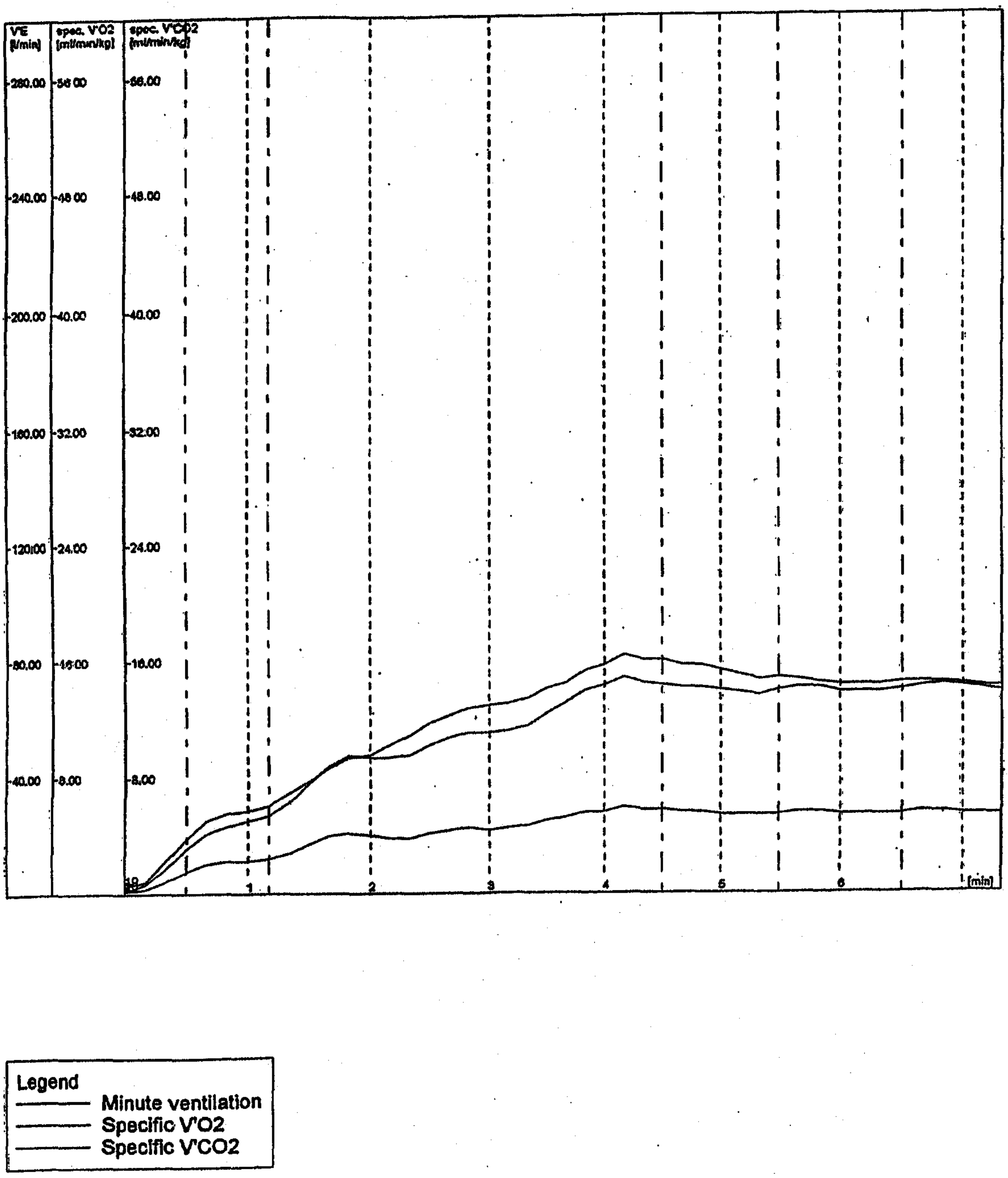
Example print-out from the polar heart rate monitor during the most stressful condition.



METAMAX

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

CORTEX GmbH



STATISTICS

Sample print-out from the STATGRAPHICS programme.

19/11/99 10:41:42 AM

Variable:	Age	Milexp
Sample size	30	30
Average	29.2	6.93333
Median	29	6
Mode	32	6
Geometric mean	29.0487	6.49956
Variance	9.13103	6.54713
Standard deviation	3.02176	2.55874
Standard error	0.551695	0.467159
Minimum	24	3
Maximum	35	14
Range	11	11
Lower quartile	27	5
Upper quartile	32	9
Interquartile range	5	4
Skewness	0.108299	0.714513
Standardized skewness	0.242165	1.5977
Kurtosis	-0.855667	0.446285
Standardized kurtosis	-0.956664	0.498962
Coeff. of variation	10.3485	36.9048
Sum	876	208

19/11/99 10:42:27 AM

Variable:	Stature	Leglength	BM1
Sample size	30	30	30
Average	1711.4	909.2	68.1513
Median	1716	907.5	67.04
Mode	1699	897	66.62
Geometric mean	1710.33	908.424	67.6502
Variance	3799.97	1451.48	75.515
Standard deviation	61.6439	38.0982	8.68994
Standard error	11.2546	6.95576	1.58655
Minimum	1595	813	52.94
Maximum	1864	986	96.5
Range	269	173	43.56
Lower quartile	1675	891	62.2
Upper quartile	1755	930	71.7
Interquartile range	80	39	9.5
Skewness	0.0415951	-0.137563	1.17707
Standardized skewness	0.0930096	-0.307601	2.632
Kurtosis	0.0434557	0.558331	2.72982
Standardized kurtosis	0.0485849	0.624233	3.05204
Coeff. of variation	3.60196	4.1903	12.7509
Sum	51342	27276	2044.54

STATISTICAL TABLE

Two-way analysis of variance of responses to varying combinations of marching speed and backpack load covering the 16 conditions (A-P).

Measure	Variance Analysis Source	SS	DF	MS	F	P
"Working" Heart Rate ($bt.min^{-1}$)	**Between:** **Within:**	118521.40 63046.53	15 224	7901.4267 281.4577	28.073	.0000*
VO_2 ($ml.kg^{-1}.min^{-1}$)	**Between:** **Within:**	15154.872 3159.622	15 224	1010.3248 14.1055	71.627	.0000*
VCO_2 ($ml.kg^{-1}.min^{-1}$)	**Between:** **Within:**	20836.297 5594.2448	15 224	1389.0864 24.974307	55.621	.0000*
V_T (L)	**Between:** **Within:**	10.539747 8.124387	15 224	.7026498 .0362696	19.373	.0000*
F_B ($br.min^{-1}$)	**Between:** **Within:**	11300.031 9561.426	15 224	753.33524 42.68494	17.649	.0000*
V_E ($L.min^{-1}$)	**Between:** **Within:**	59677.165 15643.969	15 224	3978.4776 69.8391	56.966	.0000*
RER	**Between:** **Within:**	.5970629 .5689333	15 224	.0398042 .0025399	15.672	.0000*
"Central" RPE	**Between:** **Within:**	536.0000 1009.3333	15 224	35.733333 4.505952	7.930	.0000*
"Local" RPE	**Between:** **Within:**	721.8958 1271.0667	15 224	48.126389 5.674405	8.481	.0000*
Step-rate ($Steps.min^{-1}$)	**Between:** **Within:**	33715.450 9595.7333	15 224	2247.6967 42.838095	52.470	.0000*

NOTE: Significant differences between conditions are discussed within the text, and in Chapter V with the rejection or tentative acceptance of the hypotheses.