THE EFFECT OF LOAD CARRIAGE ON SELECTED METABOLIC AND PERCEPTUAL RESPONSES OF MILITARY PERSONNEL

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ABSTRACT

Taking a multi-disciplinary, integrated approach, the present study sought to examine selected physiological and psycho-physical parameters related to load carriage involving a 12 km march under military conditions. Military constraints hampered, but did not entirely inhibit the secondary aim of the study which concerned the effectiveness of relativising loads in order to normalise responses for all soldiers, irrespective of morphological diversity.

Forty three subjects were measured in six groups using a test-retest experimental protocol. They were involved in a rest-broken 12 km march at 4 km.h^{-1} under 40.5 kg absolute total load and under a relative load of 37% of body mass. Heart rates, ratings of perceived exertion (RPE) as well as area and intensity of discomfort were monitored for all subjects. Ten subjects were measured more extensively with regard to physiology using the Metamax, a portable ergospirometry system that provides all the data needed for a complete functional analysis of lung, heart, circulation and metabolic activity.

Physiological responses (f_c; f_b; $\dot{V}_T$; $\dot{V}_E$; $\dot{V}O_2$; EE; $\dot{V}CO_2$; R; T°) indicated subjects were not severely physically taxed and that the loads imposed constituted a sub-maximal demand. Moreover, there appeared to be a limited cumulative effect over the 3.5 h. Data from the first and third hours were similar, while the significantly higher responses in the second hour reflected the challenge of the undulating terrain encountered during

this section of the march. All responses during the **Relative** load conditions mirrored those of the **Absolute** load condition but, because the demands were less, the trends occurred at a reduced level. Furthermore, the reduction in inter-individual variability indicates that relativised load carriage tends to stress the soldiers in a more uniform manner.

All "local" RPE responses were higher than "central" ratings, suggesting soldiers were in good cardiovascular condition and experienced marginally more strain in the lower limbs. There was increased perceived strain corresponding to the increase in gradient, with little cumulative effect over the three hours. The shoulders and feet were the two regions in which most discomfort was experienced; the shoulders being the worst area in the first hour and the feet being rated the worst after the third hour of marching.

This study clearly demonstrates the probability of a significant improvement in mean combat-readiness following loaded marching by showing that, if loads are set at levels commensurate with individual capabilities to carry them without undue strain, unnecessary physical demands experienced by smaller, more gracile soldiers are reduced.

DEDICATION

As an expression of my love and gratitude for their prayers, many sacrifices, tireless encouragement, and unconditional love, I dedicate this thesis to Iswarlal and Sarda Ramabhai for being exceptional parents. Dedication is also made to my brothers Hanish, Vinay, Vinod, Ketan; and my uncle Rajesh Ramabhai for their prayers, love and unfailing belief in me.

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CHAPTER I

INTRODUCTION

BACKGROUND TO THE STUDY

Throughout recorded history the transportation of loads from place to place using carrying devices such as yokes, rucksacks and backpacks has been a characteristic of every civilisation. Today, despite technological advances, this basic form of man-powered transportation remains a feature of many occupational tasks and daily life activities (Kinoshita, 1985). Nowhere is the problem of load carrying more evident than in the army. During military engagement foot-soldiers often carry extremely heavy backpacks and march long distances, after which they are required to perform critical military tasks. Renbourn (1954) argued that the soldier's load was probably a poor compromise between what was physiologically optimal for him and what was operationally essential in the performance of his duties.

As early as 1869, Parkes pointed out that for greatest efficiency and stability the load should be kept as close to the trunk and centre of mass of the body as possible, and should not exceed about a third of body weight. More than a century later, although Legg (1985) supported the concept that efficiency of load carriage is dependent on the position of the load, he stressed that there is no single best way to carry a load. Such diverse factors as the subject's physique and clothing, the shape and size of the load, terrain and climate will all influence the method of load carriage adopted by the soldier and the optimal mass to be carried.

Combat efficiency, a key element in any army, is affected by numerous factors, load carried being one of the most important. It has been reported that marching with heavy loads is a significant cause of reduced efficiency in tasks performed by foot soldiers (Renbourn, 1954). Increased energy cost and consequential fatigue, plus a decrement in post-march combat efficiency, are characteristic of recruits after an extended march even without a load. That these detrimental effects are exaggerated following the same march with a heavy load, suggests a need for detailed investigation followed by some sort of ergonomic intervention.

In the past it has been universally accepted that all military personnel be required to carry virtually the same absolute load regardless of morphology or body composition. However, Haisman (1988) has shown that relating the maximum preferred load to body mass is an idea of long standing, and over 70 years ago Cathcart **et al.** (1923) presented clear evidence that a critical point in the cost of load carriage existed with a load equal to 40% of an individual's body mass. Although there is a growing acceptance of the principles of relative load at this stage, there are no universally accepted guidelines, with suggestions ranging from 33% body mass (Haisman, 1988; Knapik, 1989; Kirk and Schneider, 1992) to 40% body mass (Cathcart **et al.**, 1923; Legg and Mahanty, 1985) for fighting foot-soldiers.

Traditionally research into load carrying efficiency has been conducted through the relatively tunnel-visioned approaches of individual disciplines such as physiology (Goldman and Iampietro, 1962; Soule and Goldman, 1969; Holt **et al.**, 1991; Bunc and Dlouha, 1997) and biomechanics (Kinoshita, 1985; Martin and Nelson, 1986; Knapik **et al.**, 1996). Very little research on the psycho-physical domain exists, and yet an individual's personal perceptions of physical demands is known to have a substantial influence on how the person will cope with the situation (Borg, 1970 and 1982; Scott, 1986). While each approach contributes something to one's understanding of load carrying efficiency in isolation, each will fail in establishing an understanding of the overall responses which would be particularly useful in field-operational conditions. In an attempt to produce an holistic profile of soldiers' responses morphological, physiological and psycho-physical parameters were included for testing in the present investigation.

Many studies of load carriage have focussed largely on energy cost, and mathematical models have been developed to estimate energy expenditure (Cathcart **et al.**, 1920; Bobbert, 1960; Goldman and Iampietro, 1962; Givoni and Goldman, 1971). It is generally accepted that the energy expenditure, per kilogram of load carried, is equal to the energy expenditure per kilogram of body weight for loads up to at least 30 kg (Goldman and Iampietro, 1962; Soule and Goldman, 1969). However, it has been postulated that carrying increasingly heavy loads (as is often the case in military situations) would be less efficient and that energy expenditure would increase sharply, consequently leading to the early onset of fatigue.

Although the main focus in the past has been on the physiological responses to load carriage, it is important to include the assessment of psychological responses of individual recruits. Effective psycho-physical measures such as the Rating of Perceived Exertion

(RPE) scale (Borg, 1970) and an adapted Corlett and Bishop Body Discomfort scale (Wilson and Corlett, 1990) have been commonly used in various physically demanding situations. RPE is a means of acquiring an objective measure of a subjective experience, allowing for the prediction of individual reactions under different conditions, thus enhancing an understanding of how individuals will cope with the pressures placed on them. Wherever military personnel are required to carry heavy loads over considerable distances, differential ratings for "muscular" and "cardiovascular" exertion could be useful in identifying the individual's perception of the physical demands, and to identify where the greatest strain is being experienced.

While extensive research has been conducted on American and British troops, limited research has been conducted on South African troops. This void in critical local information, together with the recent dramatic change in the demographics of personnel within the army, identifies the necessity to build up a data-base of information relevant to the present South African National Defence Force (SANDF). This would establish essential basic standards and guidelines relative to the manual moving of military material.

Even though research conducted under laboratory conditions is rigorously controlled, and the majority of variables not being studied held constant, the results of laboratory investigations may be somewhat "sterile" and not truly reflective of what happens when the same activity is carried out under field conditions. On the other hand, during **in situ** investigations many factors, especially environmental conditions and other external influences, cannot be as rigorously controlled. For instance, in the present study, the loads carried, the speed and distance of the march and the terrain were all selected by Army personnel as being representative of "normal" marching conditions. Ambient weather conditions, moreover, were not identical for the duration of data collection in the present study. Nevertheless, Oborne (1987) has argued that field studies may have greater validity in terms of relating back directly to the situation under analysis. In the present study research was conducted **in situ** in order to establish an holistic profile of conditions under which the SANDF soldiers routinely march.

This research project aimed to investigate the energy expenditure and psycho-physical responses of infantry troops in order to ascertain guidelines on appropriate loads for practical implementation. Specific emphasis was placed on establishing the benefits of carrying loads relative to body morphology of individual soldiers, so as to enhance the efficiency of the South African foot-soldier.

STATEMENT OF THE PROBLEM

The present SANDF situation requires that all soldiers carry virtually the same absolute load. However, there is a need to address the problem posed by recognition of human variability, for while a platoon marches as one unit, it must be acknowledged that this unit is comprised of unique individuals with their own physical and mental strengths and limitations. Hence, each individual will be taxed differentially and yet be expected subsequently to execute the required military task(s) with precision. The main focus of the present study was to address the problem of soldiers of varying morphology carrying similar loads, by investigating the load-bearing efficiency of soldiers carrying **Absolute** and

Relative loads on a routine march. An holistic assessment of morphological, physiological and concomitant perceptual parameters was conducted during a 3 h march in the field.

RESEARCH HYPOTHESES

It was hypothesised that, whether under **Absolute** or **Relative** loads, there would be a deterioration in performance, as inferred from higher cardiorespiratory, metabolic and perceptual responses, as the march progressed.

STATISTICAL HYPOTHESES

1(a) The null hypothesis proposed is that the physiological responses will be constant throughout the three hour march, under Full Marching Order with the **Absolute** load.

$$\text{Ho} : \mu\ \text{responses}_{\text{Physio1}} = \mu\ \text{responses}_{\text{Physio2}} = \mu\ \text{responses}_{\text{Physio3}}$$
$$\text{Ha} : \mu\ \text{responses}_{\text{Physio1}} \neq \mu\ \text{responses}_{\text{Physio2}} \neq \mu\ \text{responses}_{\text{Physio3}}$$

1(b) The perceptual responses will remain unchanged throughout the three hour march, under Full Marching Order with the **Absolute** load.

$$\text{Ho} : \mu\ \text{responses}_{\text{Perc1}} = \mu\ \text{responses}_{\text{Perc2}} = \mu\ \text{responses}_{\text{Perc3}}$$
$$\text{Ha} : \mu\ \text{responses}_{\text{Perc1}} \neq \mu\ \text{responses}_{\text{Perc2}} \neq \mu\ \text{responses}_{\text{Perc3}}$$

2(a) The second null hypothesis states that the physiological responses will remain unaltered throughout the three hour march, under Full Marching Order with the **Relative** load.

$$\text{Ho}: \mu\ \text{responses}_{\text{Physio1}} = \mu\ \text{responses}_{\text{Physio2}} = \mu\ \text{responses}_{\text{Physio3}}$$
$$\text{Ha}: \mu\ \text{responses}_{\text{Physio1}} \neq \mu\ \text{responses}_{\text{Physio2}} \neq \mu\ \text{responses}_{\text{Physio3}}$$

2(b) The perceptual responses will be constant throughout the three hour march, under Full Marching Order with the **Relative** load.

$$\text{Ho}: \mu\ \text{responses}_{\text{Perc1}} = \mu\ \text{responses}_{\text{Perc2}} = \mu\ \text{responses}_{\text{Perc3}}$$
$$\text{Ha}: \mu\ \text{responses}_{\text{Perc1}} \neq \mu\ \text{responses}_{\text{Perc2}} \neq \mu\ \text{responses}_{\text{Perc3}}$$

Where: $\text{responses}_{\text{Physio1; Physio2; Physio3}}$ = physiological responses during the first, second and third hours of data collection, respectively.
$\text{responses}_{\text{Perc1; Perc2; Perc3}}$ = perceptual responses during the first, second and third hours of data collection, respectively.

DELIMITATIONS

A sample of 60 subjects was selected from a group of volunteer foot-soldiers at the Infantry School at Oudtshoorn. Subjects who agreed to participate in the study were given a letter informing them of the basic aims, requirements and procedures of the study. In addition, all were medically examined (administered by Army Medical Personnel) to ensure they were in good physical condition and were suitable subjects for the present study. The Colonel in charge of the Base was required to sign an informed consent on behalf of all of the subjects, acknowledging the Army's approval for the soldiers participation in the study.

In an attempt to minimise the effects of age and sex on the data, the sample consisted of males aged 17-27 years. Subjects were organised into six groups of ten, allowing for data to be collected in smaller groups. A 12 km route march which took 3.5 h (3 h marching with 15 min rest periods after the first and second hours) was used as a basis for data collection. Clothing worn during data collection was standard military uniform for all subjects. The troops were required to march the same route under two different conditions which were randomly assigned. These were Full Marching Order with an **Absolute** load of 40.5 kilograms, and a **Relative** load at 37% of body mass. Each group marched at the same time of day to minimise the effects of diurnal factors. Cardiorespiratory, metabolic and perceptual data were collected at regular intervals throughout the march.

Initial basic reference data were collected on all subjects. From this sample, ten soldiers were randomly selected for detailed physiological assessment. The Metamax, a portable ergospirometer (with associated cardiac, respiratory, metabolic and thermo-regulatory technology) was used to log physiological data from the selected 10 subjects during the march. The basic physiological responses of the other 50 recruits were inferred by telemetric heart rate monitoring. Psycho-physical rating scales of RPE and Body Discomfort were utilised as a means of assessing perceptual responses of all 60 subjects.

LIMITATIONS

While every effort was made to ensure rigorous control of as many influential factors as possible, it must be borne in mind that when investigating individual physiological and perceptual responses there is such a broad network of causality that it is impossible to control all impinging influences. Therefore, when examining implications and subsequent conclusions from these experimental results, cognisance must be taken of the following limitations:

1) Subjects were not randomly selected, but were volunteers who were approached with an explanation of the experimental procedures. Although every effort was made to ensure that each subject's attitude towards the experiment was positive and that his motivation level was constant throughout the study, this factor could not be evaluated objectively. However, the size of the sample (n=43) contributed to reducing negative influences in this regard.

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

3) One of the limitations of using psycho-physical category scales is that researchers must presume that verbal / diagrammatic categories are appraised in a similar manner by all subjects. Although clear and detailed instructions were given to the group as a

whole and individually, and questions were encouraged, the problems associated with the validity of "self reports" remains.

4) 4 km.h^{-1} (1.11 m.s^{-1}) was recommended by the Army personnel because it is the required pace for "Patrol Marching". However, this was considered slow by all the troops participating in the study, and the soldiers were clearly not fatigued at the end of the march. Also, 15 min breaks at the end of each hour nullified any cumulative fatigue effects that might otherwise have been evident.

5) Similarly, the load of 40.5 kg was selected by the SANDF, and the recruits commented that this was lighter than usual; for experimental purposes it would have been ideal to maximise the variables under investigation and to have imposed a heavier **Absolute** load.

6) It was not possible to monitor the fluid intake / output as accurately as was necessary for further metabolic investigations.

7) Although attempts were made to test all subjects in similar environmental conditions in the field, variations in temperature and wind speed were evident and had to be accepted.

CHAPTER II

REVIEW OF RELATED LITERATURE

INTRODUCTION

Domestication of large pack animals, motorisation of draught vehicles and explosive increases in technology have not eliminated the age-old problem of personal lift-and-carry stresses. Nowhere is the problem of load carrying more evident than in the army, where the road march is a critical aspect of a military operation, and because of the equipment needed, soldiers carry very heavy loads. This equipment typically includes communication gear, weapon systems, site preparation material, subsistence items and protective gear.

Knapik (1989) pointed out that prior to the 18th Century soldiers carried total loads that seldom exceeded 15 kg. Extra equipment was moved by auxiliary transport including assistants, camp followers, horses and carts. After the 18th Century this auxiliary transport was de-emphasised and more disciplined armies assured that troops carried their own loads. Since then total loads have progressively increased far beyond those carried in pre-Napoleonic times (Knapik, 1989; Knapik **et al.**, 1990(a) and (b)).

Assessing soldier overloading in Grenada, Dubik and Fullerton (1987) cited Marshall's (1952) three false beliefs that cause commanders to allow the overloading of soldiers: overloading with ammunition is good for battle morale; ammunition shortages have often been the cause of tactical disarrangement; the soldier should be prepared for every contingency that might confront him. In addition, increases in loads carried may be due to technological developments that have increased soldier firepower and protection at the expense of the heavier load. Such reasoning ignores the fact that overloading troops with ammunition and equipment may well lead to excessive fatigue, increasing the likelihood of injuries and impairment of the soldier's ability to perform combat tasks efficiently.

The United States Army doctrine recommends maximum combat loads of 22 kg. This load level is based on historical experience (Knapik, 1989) and confirmed by energy cost studies which suggest that loads in this range are carried most economically per unit distance covered (Cathcart **et al.**, 1923; Hughes and Goldman, 1970; Holt **et al.**, 1991). To date there is limited information on the indigenous population of South Africa working under local environmental conditions, hence the importance of the present study which focussed on load carriage in the South African National Defence Force (SANDF).

LOAD FACTORS

OPTIMAL LOADS

Ramaswamy and Sivaraman (1956) defined the "optimum load" as the load which will not appreciably impair the operational efficiency at the end of the march. The issue of the "optimal" load to be carried is complicated because the value cited depends on the experimental conditions imposed upon the subjects, the manner of presentation of the data, and whether there is a non-linearity in the metabolic rate / load curve.

Borghols **et al.** (1978) investigated loads up to 30 kg carried on the back and showed that each kg of weight increased oxygen consumption by 33.5 mℓ.min^{-1}, heart rate by 1.1 bt.min^{-1} and pulmonary ventilation by 0.6 L.min^{-1}. These demonstrate the physiological strain experienced with increased loads, and undoubtedly, after a limit (specific to each individual), performance would be hindered.

Borghols and co-workers (1978) corroborated the earlier finding of Goldman and Iampietro (1962) that the energy cost.kg^{-1} is not different whether the weight being carried is personal body mass or an external additional load, so long as the weight distribution was optimised. In addition to this, Soule **et al.** (1978) walked loaded carriers at slow-to-moderate speeds (0.89 m.s^{-1} and 1.33 m.s^{-1}) and demonstrated that the net energy expenditure, after deducting the "no cost load" was relatively constant at each speed. The ratio of energy cost to total mass moved was not changed as load increased, at any given speed. However, the cost did increase as speed increased, although load carriage was not progressively less efficient as loads increased. The findings of Charteris **et al.** (1989) confirm this for head-loading, the relationship being highly comparable. However, Pierrynowski **et al.** (1981) argued that the critical point of concern was the definition of the load, that is, the load carried or load carried plus body mass. They suggest the greater the credit that is given to the carrier for carrying himself, the lower the optimum backpack load; when the backpack load only was taken into account, they recommended 40 kg as an optimal load decreasing to 7 kg when the defined load included the entire body mass.

Haisman (1988) has shown that relating the maximum load to body mass is an idea of long standing, and over 70 years ago Cathcart **et al.** (1923) presented definite evidence that a critical point in the cost of load carriage existed with a load equal to 40% of an individual' s body mass. Despite the growth of research in the area, there are no universally accepted guidelines; suggestions range from 33% body mass (Haisman, 1988; Knapik, 1989; Kirk and Schneider, 1992) to 40% body mass (Cathcart **et al.**, 1923; Legg and Mahanty, 1985) for foot-soldiers.

The literature confirms that there is no easy solution in the definition of maximal load because of widely varying circumstances. Identifying an "optimal" load would involve a similar compromise between the persons capabilities and requirements of the task which may in some circumstances have important implications for health and safety.

LOAD PLACEMENT

The mode of load carriage adopted will be determined by factors such as weight, shape and size of the load, the duration for which the load has to be carried, the terrain, the climate, the physical characteristics, condition and clothing of the individual, as well as personal preferences.

Cook and Neumann (1987) reported that metabolic energy requirements for various methods of load carriage have been studied under a variety of conditions. The general principle that has evolved from these studies is that in order to minimise energy expenditure the load should be located as closely as possible to the centre of mass of the individual (Parkes, 1869; Malhotra and Gupta, 1965; Soule and Goldman, 1969). For example, one study of seven different modes of load carriage (Datta and Ramanathan, 1971) found that in terms of oxygen consumption (VO_2), carrying 14 kg on the head was approximately half as demanding as carrying 7 kg in each hand.

Head-loading

Maloiy **et al.** (1986) analysed pooled data from East African women under head-loading and head-strapping conditions and concluded that metabolic efficiency was high compared to backpacking, and for light loads, below 20% of the individuals own body mass, there was an energetic "free ride" in the sense that no significant increment in energetic cost over unloaded walking values could be detected. Also, there was no difference in cadence (thus inferring stride time and stride length) observed under head-loading as compared to unloaded walking at the same speed.

While Charteris **et al.** (1989) support the notion of a "free ride" metabolically, they have consistently found differences in head-loaded walking kinematics. This and other investigations argue for the relative metabolic efficiency of head-loading (Balogun **et al.**, 1986; Maloiy **et al.**, 1986) and the impression may be gained from some that occupational head-loading is preferential to other modes of load bearing even when criteria extend beyond metabolic factors. Soule and Goldman (1969) identified the limiting factor in carrying heavy loads on the head to be the mechanical load tolerated by the musculature, and the restriction of body movement. However, they found the method to be very suitable for light loads over short distances.

Backpacks

Kirk and Schneider (1992) found there was no difference in metabolic, cardiorespiratory or perceptual responses of carrying either the internal or external frame backpack with 33% of body mass. This indicates that as long as the load is carried on the back, differences in back-frame designs are not great enough to produce significant differences in energy consumption or perception of carrying a moderately heavy load.

Double Packs

The double pack has the load equally divided in two packs and strapped across the shoulder, one in front and the other on the back. Datta and Ramanathan (1971) and Kinoshita (1985) showed that compared with the backpack system, a double pack was more effective, especially for heavy loads (40% of body mass), because the forward lean was reduced and gait characteristics were closer to unloaded walking.

Knapik and associates (1993) had 21 Special Operations Forces (SOF) soldiers perform six road marches (20 km) in which they carried three loads (34, 48, 61 kg) using two different pack systems, a large all purpose lightweight individual carrying equipment (ALICE) pack with frame, and an experimental double pack. They reported that when soldiers carried the double pack, they had a lower estimated energy expenditure than when they carried the ALICE pack. After adjustments for march time, heart rate was also lower for the double pack and the double pack resulted in less low back discomfort and fewer incidents of blisters at higher loads. A year later Frykman **et al.** (1994) also found that the double pack resulted in a more normal upright posture under heavy load than a backpack, but did not correct for the effects of fatigue on posture. With increasing load, the double pack reduced the degree of forward trunk lean, increased stride frequency, and reduced stride length (the latter two have been theorised to reduce load-induced biomechanical stress on the musculo-skeletal system).

In contrast to this, Johnson **et al.** (1995) found the double pack's front compartment served as a barrier to heat loss by means of reduced evaporation of sweat in the chest area, which in turn may have impaired thermo-regulation with very heavy loads, an important factor to consider in the South African situation where the heat in summer can be extreme. Legg (1985) and Knapik **et al.** (1996) reported that double packs are useful in many situations, but backpacks appear to provide greater versality. The double pack can inhibit movement, limit field of vision in front of the body and it seems burdensome to put on and remove. With the military this may restrict tasks like firing weapons and putting on protective masks.

It is clear that backpacking is a relatively low energy cost method of load carriage. Under certain conditions members of the armed forces use the lower cost (double pack) method, though in combat situations there must be a compromise between agility and energy cost, which probably accounts for the popularity of backpacking as a means of load carriage (Charteris and Scott, 1996). Thus backpacking was the method selected for the present investigation.

EFFORTS TO REDUCE THE LOAD

There have been many attempts to unburden the soldier by providing him only the items necessary for combat. A decrease in load would result in lower energy costs, could reduce injuries and is highly likely to improve performance of tasks following the load carriage. As early as 1869 Parkes fully realised the importance of clothing and footwear in connection with personal equipment and load carriage. He also noted the significance of foot hygiene, rest, sleep, food, training, climate and terrain in the relationship to the rate of marching and the distance covered.

In an effort to improve the condition of the foot soldier with respect to load carriage, Renbourn (1954) summarised the principles that were prescribed after various discussions throughout the 18th Century:

- the weight of the load should be distributed over a wide area;
- the weight of the backpack should be balanced by the weight of pouches in front;
- all loads should lie as close to the body as possible as this is convenient and should be near to the centre of mass;
- the total load to be carried should be about 20 to 21 kg.

In 1962 and 1964 the U.S. Army Infantry Combat Development Agency reinforced the weight recommendations, suggesting an 18 kg load for a conditioned fighting soldier and 25 kg for a soldier on the march. The American Army Development and Employment Agency (1986) and the U.S. Army Infantry School (1987) designated the load carried by the soldier as the "combat load", which could be divided into two distinct categories. The "fighting load", carried when enemy contact is expected or stealth necessary, and consisting of soldier's clothing, load bearing equipment, helmet, weapon(s), rations, bayonet and ammunition, with a recommendation that the total load be 22 kg. The "approach load", carried on more prolonged operations, and comprising the combat load plus a pack, sleeping roll, extra clothing, rations and extra ammunition, with a recommended mass of 33 kg.

Lothian (1922), in an historical review, has shown the conflict between "essentials" of a load and the necessities of the soldier's mobility. In the history of all armies there are numerous examples of overburdened soldiers discarding excess or uncomfortable equipment to survive, and other examples of situations in which they have collapsed, too exhausted to fight or to consolidate gains already made. Although there have been great technical advances in the present century, the principles used today in load carriage were already well known long before the end of the 19th Century. Despite the numerous international recommendations, SANDF infantry are required to carry a backpack ranging from 30 to 60 kg and to march with these for extended periods of time. This no doubt results in personal discomfort, and impacts negatively on post-march performance, thus some sort of intervention is necessary.

LOAD CARRIAGE FACTORS

Understanding the factors that influence load carrying ability may best be accomplished by a multi-factorial analysis, since load carriage involves biomechanical, physiological, psycho-physical and other factors. The present investigation assessed the morphological, physiological and concomitant perceptual responses to load carriage during prolonged marching. This multi-dimensional approach assists in addressing the problem of human variability; for while the platoon marches as one unit, it must be noted that each unit consists of 10 to 100 individuals, all with their own personal physical and mental profile.

Charteris **et al.** (1976) recommended that any analysis of human movement must be studied as an ecological phenomenon of organism-environment interaction. Four foundational propositions serve as the cornerstone of their "Centre-M: Man-in-motion" model. The most immediate consideration is physical: human movement must initially be comprehended in a spatial dimension with respect to time. The biological perspective considers the dynamic two-way interaction between organism and environment. The psycho-social dimension accounts for the intellectual poverty of a purely bio-physical analysis by admitting humaness into human movement analysis. Finally, an holistic, interdisciplinary approach is deemed essential in the study of human movement. This model forms the basis of the present study. Consequently in this review the morphological aspects of load carriage are discussed, followed by the physiological and then the psycho-social dimensions, and an attempt is made to weave these perspectives together for conceptual understanding of load carriage in the SANDF.

MORPHOLOGICAL CONSIDERATIONS

Anthropometry provides information about the morphology of the human body. Anthropometry utilises among other things, data to appraise human size, shape, proportion, composition, maturation and gross function as an attempt to better understand work capacity and performance related to activities. Kroemer and associates (1995) note that information about body size is needed when an object must fit the human body, such as tool handles to hold, protective equipment and clothing to wear, chairs to sit on and workstations in general. Such measurements are of critical importance to the SANDF because they should be used in the design of military equipment specifically for the indigenous user population. This is highly likely to result in more comfortable load carriage, less fatigue, and ultimately more efficient post-march combat performance.

Anthropometrical Indices

Numerous structural measurements may be taken on the human body. When considered singly, these basic anthropometric data only provide information about absolute size. However, such data may form the basis of special formulae, indices and equations yielding a considerable amount of information about body shape, form, proportion and composition, which in turn can be shown to have great functional relevance.

Stature and body mass are frequently used to obtain a stature-mass index or ratio. Although these contribute towards assessing the somatotype, without additional information they cannot be satisfactorily used to assess physique as a whole. Two indices used in the present study while trying to gain an insight into body proportion and composition were the Reciprocal Ponderal Index (RPI), a rough index of linearity of physique, and Body Mass Index (BMI), a rough index of ponderosity. The reciprocal ponderal index (RPI) is calculated by dividing stature (mm) by the cube root of mass ($\sqrt[3]{kg}$) and was used in the present investigation to give a general impression of leanness. The Body Mass Index (BMI) is calculated by dividing body mass (kg) by stature (m) squared and is a widely used indicator of stoutness where the ACSM guidelines (1986) recommend 20.0 to 24.9 $kg(m^2)^{-1}$ as a desirable range for adult men and women. The advantage of this method in estimating body composition is that it down-plays the effect of stature. However, simplistic over-reliance on the index is a limiting factor identified by several doctors at A Round Table discussion on body composition (1986): mass has very different effects depending upon whether it is composed of lean or fatty tissue.

Body Composition and Load

A significant factor in load carriage is that differential stresses are sustained under identical external loads, largely because of inter-individual differences in body composition. The human head, arms and trunk (HAT) in non-obese adults weighs about 74% of body mass. One of the effects of obesity, an increase in mass in the trunk-abdomen region, is to increase the percentage contribution of HAT to total body mass. This has implications for the position of the centre of mass relative to load-bearing joints, even before eccentric loads, such as backpacks are considered.

Miller and Blyth (1955) suggested that obesity limited the capacity for strenuous exertion by increasing the energy cost without a proportional increase in maximal capacity for oxygen uptake. Sum **et al.** (1994) studied obese male military recruits in the Singaporean Army. They sampled 12 with body mass index (BMI) between 25 and 30 kg.$(m^2)^{-1}$, 14 with BMI between 30 and 40 kg.$(m^2)^{-1}$ and 16 with BMI over 35 kg.$(m^2)^{-1}$. While it was not their purpose to relate levels of obesity to performance inefficiency it is clear that unnecessary loading, in the form of adipose tissue that must be carried in addition to military equipment, places additional burdens on the organs, collagenous and osseous tissue. This predisposes the overweight soldier to fatigue, stress fractures and mechanical inefficiency, at a level in excess of the stressors borne by non-obese counterparts.

Relative Load

Lothian (1922) recognised that as the load to be carried has a definite relationship to the subject's strength, which is normally a function of his mass, it was evident that more attention be paid to the mass of the subject. Wyndham **et al.** (1971) showed that under carefully controlled experimental conditions body mass was the most important determinant of oxygen consumption in walking both on a level road and a treadmill.

Correcting for lean body mass (LBM) permits comparisons of strength between persons markedly different in body size (Perrin, 1993). The literature shows that LBM (total mass minus fat) is highly correlated with maximal oxygen consumption (Buskirk and Taylor, 1957; McInnis and Balady, 1999) and is a positive factor in load carriage ability.

Conversely, excess body fat is "dead mass" in performance of work and degrades the performance of physical tasks involving movement of the body and the carrying of an external load; hence the utility of expressing $\dot{V}O_2$max on a body mass basis as an expression of aerobic capacity. Kennedy (1963) suggested that the larger soldier may be able to carry a heavier load by virtue of having greater bone and muscle mass. However, Berger (1982) stated that although those with a heavy body mass tend to have more absolute strength, they often have less relative strength than do those with lighter body mass.

Haisman (1988) reported that the idea of correlating the maximum load to body mass had been established as early as 1923, when Cathcart and his co-workers recommended that under laboratory conditions the maximum load for maintenance of efficiency and health should be 40% of body mass. Those with greater body mass can thus carry heavier loads, but the constituent proportions of body mass, whether muscle or fat would be important. Furthermore, Haisman (1988) advised that the design of load carriage equipment must take into account the range of dimensions in key anthropometric variables in the population to be fitted, especially back length and waist circumference.

Stature and Speed of Walking

Although certain investigators have proposed that stature is a poor indicator of locomotor energy cost (Wyndham **et al.**, 1971), there is considerable evidence to suggest that the same absolute locomotor speed taxes short and tall subjects differently. Shorter subjects expend more energy per kilogram body mass per unit of speed for a given locomotor mode than their taller counterparts (Miller and Blyth, 1955; Charteris, 1982; Charteris **et al.**, 1982).

The lower oxygen consumption associated with the locomotion of subjects of a greater stature can therefore be attributed to the related gait pattern or combination of step length and frequency. Since those with longer lower limbs tend to move with greater step lengths and a lower cadence, it may be inferred that at any prescribed speed, taller subjects take fewer steps per unit distance by virtue of a greater length of stride, and as a consequence tend to expend energy at lower rates.

One means of factoring out the differences in locomotor energetics due to morphological variation is via the use of relative speed equations. Relative speed is broadly defined as that speed expressed with respect to some linear measure of size, and as such is used to effectively "normalise" human locomotion (Grieve, 1968). Traditionally, relative speed is most readily expressed as that fraction of stature covered over-ground during locomotion per second. This expression of relative speed is based upon the premise that the same raw speed ($m.s^{-1}$) will tax short and tall subjects differently (Miller and Blyth, 1955; Charteris, 1982; Charteris **et al.**, 1982).

Walking speeds have been classified and quantitative definitions given to each group in terms of the relative speed (Charteris, 1982; Charteris **et al.**, 1982). The following is a list of these relative speed classifications:

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

Relative Speed (stature.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

Based on data from many empirical studies "preferred speed" of adult males is described as 0.85 stature per second, where "preferred speed" is that freely chosen by the individual.

Age and Load Carrying

Several investigators (Åstrand, 1956; Åstrand, 1958; Berger, 1982; McArdle **et al.**, 1996) have reported that as a child grows physically, the force capacity of the muscles rapidly increases, with maximum strength being attained between 20-30 years. The increase in muscle mass is positively related to force capacity and after physical maturation an increase in muscle force is only provided by overload training. Unless training is maintained, muscles follow a general downward trend characteristic of other organ systems with advancing age and begin to diminish in force capacity (Berger, 1982). In the present study the age range was limited between 17-27 years.

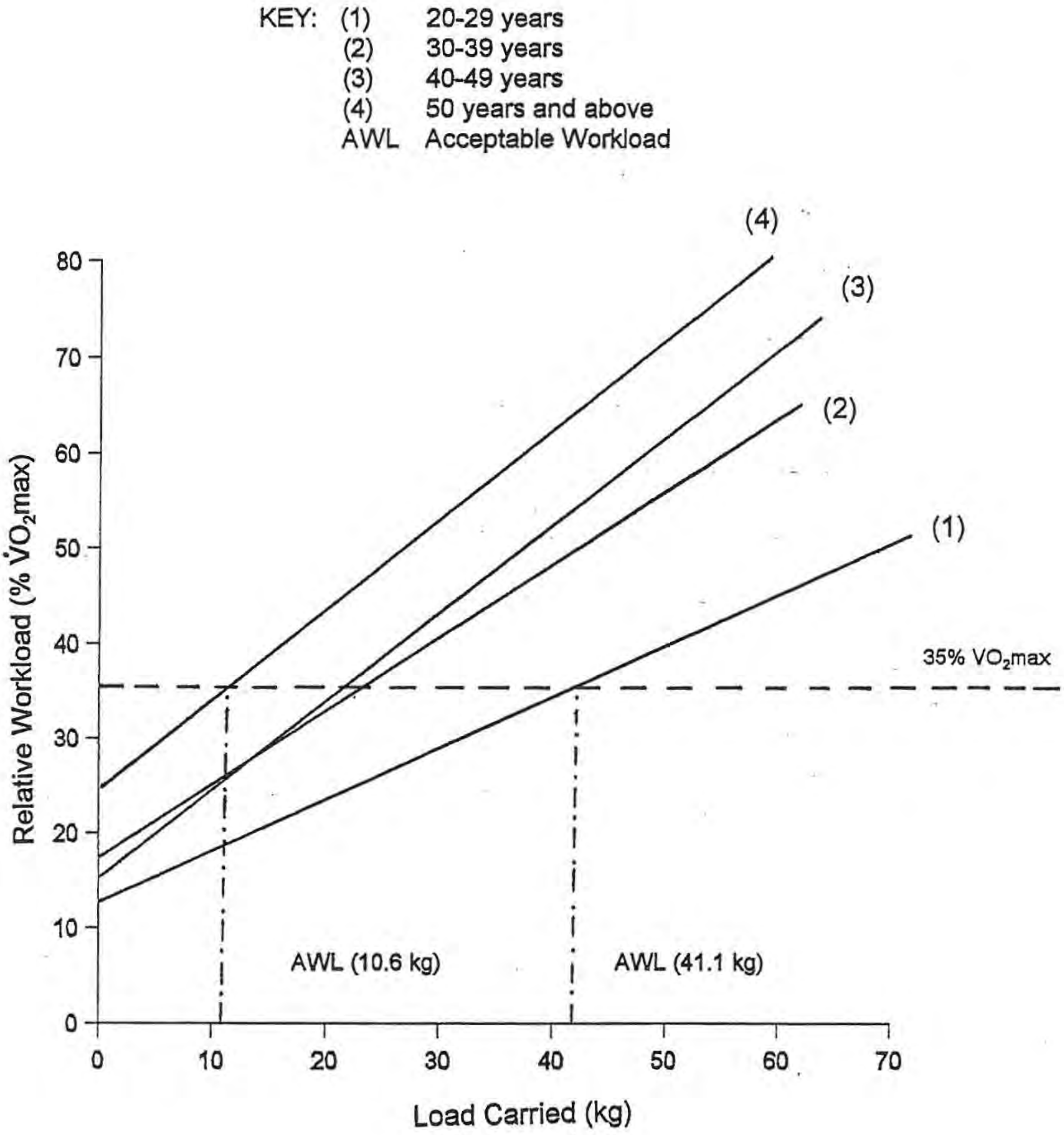


FIGURE 1 : Relation between percentage of maximal oxygen consumption and the load transported by the porters of different age groups (Adapted from Samata **et al.**, 1987).

Haisman (1988) reported a decline in maximal heart rate with increasing age. Furthermore, $\dot{V}O_2$max declines as the percent body fat increases with age. Previous researchers had recognised that obvious differences are brought about mainly by variations in the economy of muscular movement and in the amount of surplus activity (Passmore and Durnin, 1955). They found the young were spendthrift of movement whereas with an increase with age unnecessary physical activity diminished. Samanta **et al.** (1987) found that the maximum permissible load carried on the head (as defined by the load at 35% $\dot{V}O_2$max) by groups of Indian porters ranging in age from 20 to 50 years, decreased from 41 kg for the youngest group to 11 kg for the oldest group. Their data are represented in Figure 1.

Sex-Based Factors in Load Carrying

From 1948 to 1969, approximately 1% to 2% of the U.S. armed forces was composed of females, where they served in health care and clerical positions (Westphal **et al.**, 1996). However, the number of females involved in active duty is now increasing. Most studies investigating the military have involved only male soldiers, and this information has subsequently been extrapolated to females, often without the appropriate rationale. However, due to differences in anthropometry, body composition and $\dot{V}O_2$ between males and females (Vogel **et al.**, 1986) it may be that females respond to load carriage in a different manner to males. With the increasing involvement of females, it is important to investigate them in order to formulate more specific guidelines. However, as there is very little information on the South African soldier, and with the female numbers being low, the present study focussed exclusively on male troops.

PHYSIOLOGICAL DETERMINANTS

Cardiorespiratory Responses

While heart rate is certainly one of the most commonly measured physiological parameters, it is at the same time one of the most sensitive responses and as such it is very difficult to isolate and identify the major cause behind the excitation or inhibition of the heart rate response. Load carriage seems to impose an extra cardiovascular stress relative to the metabolic demands of the task (Gordon **et al.**, 1983). Since, during steady state sub-maximal exercise, heart rate is linearly related to the rate of oxygen consumption and hence, energy expenditure, Vuori (1998) suggested that monitoring of heart rate could provide useful information about the level and pattern of physical activity and the associated energy costs. Therefore, heart rate was constantly monitored throughout data collection in the present study. However, Kilbom (1995) reported that heart rate increases during both static and dynamic exercise, during heat exposure and as an effect of psychological stress. Hence heart rate is acknowledged as an unspecified cardiovascular strain response, and interpretation must always be made against a background knowledge of circumstances.

Brouha (1967) suggested that the average heart rate over an eight hour industrial work shift should not exceed 110 bt.min^{-1} since cumulative fatigue is likely to ensue. This can be applied to the foot-soldier, who is expected to perform efficiently after carrying heavy loads on extended marches.

Although the basic mechanical control of respiration has been well established, the physiological control is not yet completely elucidated. It is clear that the rate and depth of respiration must be controlled so as to maintain homeostasis in the face of varying metabolic demands. de Vries (1980) cites six important factors which may affect the chemo-sensitive cells of the respiratory centre in the brain. There seems little doubt that the control of respiratory activity is brought about by the combination of these six factors, which are level of carbon dioxide and subsequent pH changes, oxygen levels, proprioceptive reflexes from joints and muscles, temperature, cerebral factors, and the Hering Breuer reflex; however, the complexity of the ratio and interaction of these factors is not yet fully understood (de Vries, 1980, McArdle **et al.**, 1996). Berger (1982) predicted a sharp rise in ventilation with work, and also proposed that at the end of work, ventilation would decline progressively, depending on the severity of work. It should be evident that any demand, such as load carriage while on a 12 km march under military conditions, will upset the homeostatic state of the individual and in an attempt to regain equilibrium there will be a cardiorespiratory adjustment.

Metabolic Cost of Work

In a standing position load carrying does not influence oxygen uptake, heart rate or minute ventilation (Borghols **et al.**, 1978; Pimental and Pandolf, 1979). However, when the loaded subject begins to walk, energy expenditure increases as a function of load, terrain, temperature, speed and gradient. In most studies the main goal has been to determine the energy expenditure of marching taking into account various influencing factors. In order to make comparison between individuals it is useful to express the metabolic cost as a percentage of maximum cost. Such physiological calculations help determine the most "physiologically efficient" conditions with respect to load carriage.

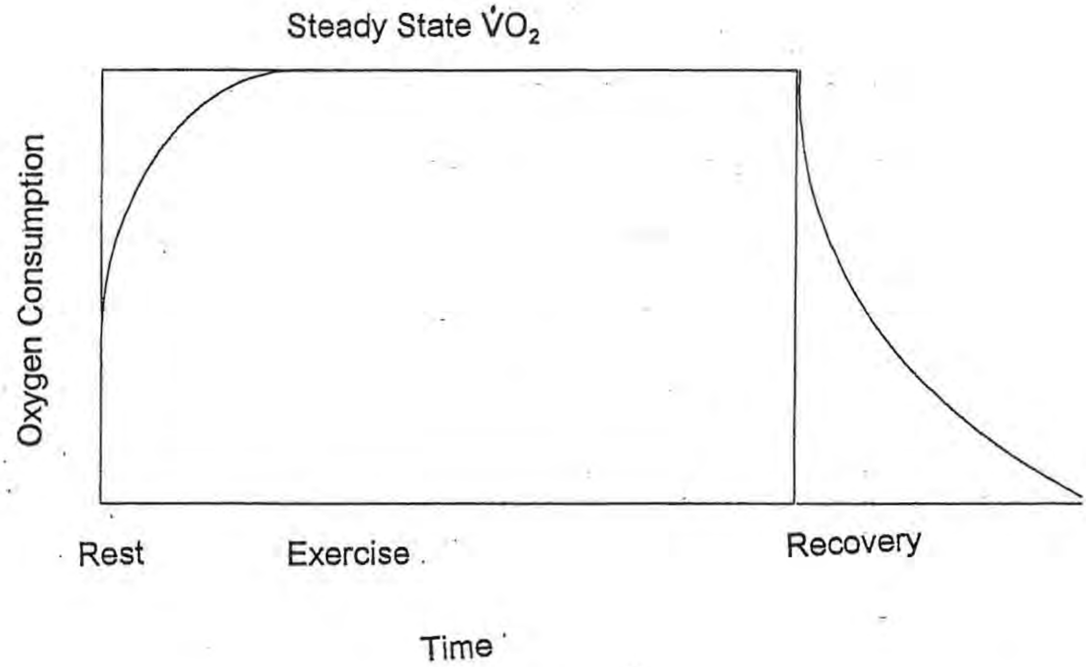


FIGURE 2 : Oxygen consumption during and in recovery from light to moderate steady state exercise (Adapted from McArdle **et al.**, 1996).

The estimation 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 response to any physical demands placed in the system, it is recognised that oxygen consumption rises rapidly during the first few minutes of exercise 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" as is represented in Figure 2. Many believe that once this steady state is achieved, an individual can go on almost indefinitely. Although this could be true for oxygen consumption, factors such as motivation, fluid loss, muscle contractility and fuel reserves come into play. Most researchers propose that steady state is reached below 50% to 60% $\dot{V}O_2$max, after which oxygen consumption continues to increase (Casaburi **et al.**, 1987; Epstein **et al.**, 1988; McArdle **et al.**, 1996).

Pierrynowski **et al.** (1981) point out that with a linear relationship between energy expenditure and loads carried the calculation of an optimal load would imply an ideal load of zero. According to these investigators the perplexity surrounding optimal load can be attributed to variations in experimental design, presentation of data and the initial assumption whether the curve is linear or not. Although it was argued by Soule **et al.** (1978) and Charteris **et al.** (1989) that the energy cost of moving body mass plus an external load increases concomitantly with increments in load, it has been hypothesised that high loads must have a curvilinear relationship with energy expenditure as reported by Maloiy **et al.** (1986).

Another factor which needs to be considered is the duration of the march carrying the load. It was argued by Patton **et al.** (1991) that the phenomenon of "physiological drift" is an important factor in prolonged load carriage. Although steady state may be retained even for a couple of hours, prolonged load carriage eventually results in a reduction in mechanical efficiency. Reductions in mechanical efficiency at sub-maximal levels result in an increased $\dot{V}O_2$, due to increased core temperature and minute ventilation, as well as a change in substrate utilisation. According to these authors, walking speed should be maintained between 3.96 $km.h^{-1}$ (1.1 $m.s^{-1}$) and 4.86 $km.h^{-1}$

($1.35 m.s^{-1}$) in order to stop physiological drift from occurring while carrying loads in the range of 31.5 kg to 49.4 kg.

Workloads

Saha and associates defined acceptable workload as " the level of physical activity that can be sustained for an eight hour work shift whilst remaining in a physiological steady state and without fatigue or discomfort " (Saha **et al.**, 1979; p 1068). In the same year Myles and Saunders stated that self selected work rates of men working hard would be an energy cost of 400 to 450 $kcal.h^{-1}$ (approximately 40% to 50% $\dot{V}O_2max$) regardless of the load being carried. Work above this would be characterised by significant anaerobic metabolism and lactic acid production which is likely to result in poor mental and/or physical performance (Wyndham **et al.**, 1962; Casaburi **et al.**, 1987; Epstein **et al.**, 1988). However, Saha **et al.** (1979) argued that for an eight hour shift a reasonable workload should not exceed 35% $\dot{V}O_2max$. An acceptable workload is difficult to set because of the complex human-environment (machine) interaction. The appropriate workload will vary from individual-to-individual, and from situation-to-situation, and is based on identification of factors such as worker capabilities, task demands and general work ambience.

Equation for Predicting Energy Cost

Equations derived from extensive research allows the prediction of energy expenditure from various variables, and such predictions can provide valuable information as to the physical severity of load carriage tasks and the potential for ensuing fatigue. Cathcart and co-workers (1920) studied the rate of marching and energy expenditure to determine the optimal rate of marching and represented the relation between energy cost per unit of time and speed as a parabola:

$$y = ax^2 + bx + c$$

where y = energy cost per unit time
x = distance per unit time

This implies the cost of work is at first great then decreases to an optimal value, thereafter increasing again. Since Cathcart's work there have been many attempts to develop an equation for predicting the energy expenditure of walking (Bobbert, 1960; Goldman and Iampietro, 1962; Givoni and Goldman, 1971; Pandolf **et al.**, 1977). It has been established that the energy expenditure per kilogram of load carried, is equal to the energy expenditure per kg of body mass for loads up to at least 30 kg (Goldman and Iampietro, 1962; Soule and Goldman, 1969).

The prediction equation developed by Givoni and Goldman (1971) claims to be relevant for both males and females for any speed above 0.69 $m.s^{-1}$ (2.5 $km.h^{-1}$) and is depicted by the following :

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

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, %

The authors maintain that the equation is valid for all conditions in which the product of load carried and velocity is no larger than the numerical value of 100. A product that exceeds this value will result in an under-prediction of energy expenditure.

Pandolf **et al.** (1977) revised this equation and included a factor for the energy cost of standing. While Norman (1979) showed this same curvilinear relationship, Gupta (1955) and Gordon **et al.** (1983) showed the relationship to be more linear. Pimental and Pandolf (1979) and Pimental **et al.** (1982) tested the formula of Pandolf and co-workers (1977) using slopes of 0% to 10% and loads of 0 to 40 kg for slow walking (0.61 $m.s^{-1}$, 2.2 $km.h^{-1}$). The predictions were higher than actual data, but at faster speeds (1.10 $m.s^{-1}$, 4 $km.h^{-1}$) the formula was accurate. In addition to this, Cymerman **et al.** (1981) demonstrated that the Pandolf **et al.** (1977) equation was usable at altitudes of 4300 m up to a metabolic rate of 730 W. Pierrynowski **et al.** (1981) found that predictions diverged from observed values as load carried increased up to 34 kg. These reports suggest that prediction equations have limitations and appear to be situation specific.

Unfortunately, some of the prediction equations (Givoni and Goldman, 1971; Pandolf **et al.**, 1977) estimate the energy cost during relatively short term (< 30 min) steady state exercise, and do not consider the possibility that the energy cost of exercise may increase over time. In military operations, soldiers are frequently required to traverse considerable distances, usually with some sort of load. It is thus important to know the metabolic demands in order to estimate the ability to accomplish a given marching distance, predict the internal heat burden and evaluate water and caloric requirements.

Heat and Body Temperature

The rate of rise of body temperature in the early stages of exercise and the steady state level which is eventually reached are both proportional to the metabolic rate. Relative to the factors which might affect $\dot{V}O_2$, Saltin and Stenberg (1964) noted that a slight increase in $\dot{V}O_2$ occurred along with an increased body temperature. Furthermore, Berger (1982) stated that an increase in body temperature results in respiratory stimulation. It would appear that any rise in temperature of fluids bathing the respiratory and cardiovascular regions in the brain stem makes the regions more sensitive to chemical stimuli. Consequently, their response to stimuli may be more exaggerated at higher temperatures. The body's ability to lower the acidity of fluids may also be lower as a result of higher temperatures. This situation is further complicated when the activity of $H+$ ions is enhanced, tending to increase the acidity of the cerebrospinal fluid, and possibly hindering performance as homeostasis is offset.

In extreme high ambient temperatures (or when conduction, convection and radiation are inadequate to dissipate a large metabolic heat load), the only means for heat-loss is by sweat evaporation. In fact, McArdle **et al.** (1996) suggest that the rate of sweating increases directly with the ambient temperature. As sweat evaporates, a cooling effect occurs and consequently, the cooled skin seems to cool the blood that has been shunted from the interior to the surface of skin. In addition, a Ha **et al.**(1998) report that the temperature on the surface of the skin also changes according to a change in environmental conditions. The present project attempted to investigate these influences by monitoring skin temperatures throughout the prolonged march at two different muscle groups, namely *erector spinae* and *pectoralis major*.

Circadian Rhythms

Another important factor to consider when investigating the variability of individual's responses is the possible effect of time of day. According to Conroy and Mills (1970) it is well established that there are characteristic circadian (24 h) rhythms in most physiological functions in humans. Nearly 15 years later, Shephard (1984) reported that biorhythms provide an internal clock that enables the co-ordination of rapid physiological processes and the precise timing of external events. He also noted that arousal is maximal in the afternoon, with associated improvements in pattern recognition, reaction speed and muscle force, while perceived effort falls, fatigue is lessened and all-out effort is better tolerated. In an endeavour to minimise the influence of circadian rhythms, subjects in the present investigation were tested at the same time of day for both data collection periods.

PSYCHO-PHYSICAL DETERMINANTS OF LOAD CARRYING ABILITY

Balogun **et al.** (1986) suggested it was important to consider the subjective feelings of the individual carrying a load since an ergonomic device should not only be metabolically efficient, but must be subjectively acceptable to the user. The present investigation used Borg's (1970) RPE scale and Corlett and Bishop's (1976) Body Discomfort scale to ascertain the soldier's perception of the physical demands of extended marching with a load.

Ratings of Perceived Exertion

Aminoff **et al.** (1998) found that additional important questions in work physiology were how individuals perceive the amount of work they performed. They found the subjective measures shown by the Borg scale gave a cross comparison to the physical measures and allowed the investigator to explore how a person performing the task felt. Gunnar Borg (1970) wrote that " as man reacts to the world as he perceives it and not as it really is, it is important to know more about the relation between objective and subjective measurements....". The Rating of Perceived Exertion (RPE) scale was constructed on the knowledge that heart rate speeds up linearly in relation to a progressive increase in work load on a bicycle ergometer (Borg, 1970).

The RPE consists of a 15-point numerical scale ranging from 6 (minimal exertion) to 20 (maximal exertion), where every second number has a verbal anchor. Accurate ratings may be influenced by the fact that verbal anchors are predominantly English and therefore the associated scale cannot be regarded as universal. Translation into other languages becomes difficult as terminology and concepts vary so much and the reliability of the use of the scale is very dependent on a clear understanding of the concepts of a personalised rating. The diverse cultural backgrounds and multitude of languages in the South African National Defence Force presents yet another problem. Therefore the scale has been adjusted with the addition of diagrams (Scott, 1986) as shown in Figure 3.

UNIVERSAL RPE SCALE

NUMERICAL	*VERBAL*	*DIAGRAM*
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		

FIGURE 3: The proposed universal RPE scale (Scott, 1986).

Early studies (Borg, 1962; Borg 1970; Pandolf 1978) showed a linear relationship between RPE and heart rate during cycling and treadmill locomotion. However, it is increasingly apparent that perception of exertion is affected by a complex interaction of many influences and a person's response would be the result of integrating signals from the peripheral working muscles and joints, central cardiovascular and respiratory functions and the central nervous system, to elicit a gestalt rating.

Ekblom and Goldbarg (1971) suggested a two-factor model to help explain the variation in RPE during different types of physical work. These involved a "local" factor, that is, feelings of strain in the working muscles, and a "central" factor; feelings primarily involving the cardiopulmonary systems. They hypothesised that when a particular factor became pronounced, it would dominate the overall perception of exertion. While Kay and Shephard (1969) imply that the "central" factor may be more prominent during treadmill work, Ekblom and Goldbarg (1971) and Pandolf and Noble (1973) indicate that the "local" factor appears to dominate the perception of exercise during bicycle work. As a result of the multi-dimensional nature of the RPE scale, it is critical that researchers provide subjects with specific instructions about the use of these scales. (Refer to Appendix B for RPE instructions to subject). In this investigation a "local" rating from the working muscles and joints of the lower limb and a "central" or cardiopulmonary rating were measured.

Robertson (1982) proposed that although "central" factors played a role, "local" factors such as force and rate of muscular contractions, and joint sensations dominate RPE. He suggested that when the level of exertion was below 50% $\dot{V}O_2$max, the relative contribution of ventilation to RPE was limited, and the contribution of $\dot{V}O_2$ was proportional to the percentage of $\dot{V}O_2$max employed to accomplish the task. However, Goslin and Rorke (1986) found that with loaded conditions, perceptions did not increase proportionately with $\dot{V}O_2$ as load carried increased, rather RPE climbed up more rapidly than central responses. The relative contributions of "central" and "local" input vary considerably depending upon the intensity, modality and duration of exercise, environmental conditions and subject characteristics. With the carrying of loads there are a complex array of influences primarily outside the realm of cardiac and respiratory factors.

Thus when evaluating load carriage systems, one should measure metabolic, cardiorespiratory, perceptual and biomechanical responses to determine if any subtle differences may exist that cannot be detected through metabolic and cardiorespiratory data alone.

Body Discomfort Scales

Corlett and Bishop (1976) produced the Body Discomfort scale in an attempt to provide a quantitative measure of the effects of posture which could be useful to specify limits and rest requirements. With this method the term "discomfort" is used (Corlett and Bishop, 1976), and it makes use of a perceived discomfort scale in conjunction with a body map diagram, represented in Figure 4. In order to identify the site(s) of discomfort, a body map dividing the body into 27 segments was used. Once subjects have identified the site(s) of discomfort, they are able to rate the intensity of the discomfort at each identified site.

Legg **et al.** (1997) examined subjective, perceptual methods of carrying two different leisure backpacks of similar, but not identical, design in more detail. They used other subjective methods, namely the visual analogue scale(VAS) of perceived discomfort and modified Corlett and Bishop (1976) regional discomfort scale. They established that perceptual responses did not distinguish between load carriage modes. However, short questions revealed that the backpack with the frame was the easiest to "don and doff". Thus, question techniques such as the subjective assessment of comfort or preferences and some biomechanical factors will be more sensitive, useful and appropriate for comparing load carriage systems, especially when differences between the systems are small.

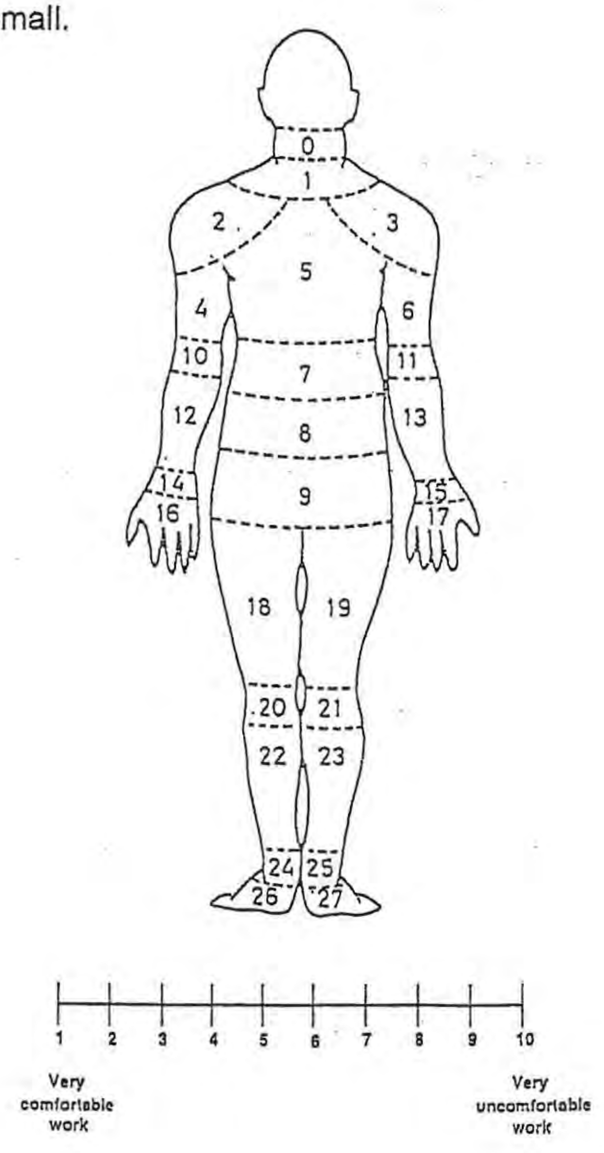


FIGURE 4 : The body map and discomfort scale used for evaluating body part discomfort (Adapted from Corlett and Bishop, 1976).

OTHER FACTORS INFLUENCING LOAD CARRIAGE

In principle, an optimum method of load carriage should induce stability, bring the centre of gravity of the load as close as possible to that of the body and make use of the large mass muscles (Legg **et al.**, 1992). Gordon **et al.** (1983) proposed that substantial differences in the dynamics and perceived exertion could be expected when field testing the relation between added load carriage and metabolic responses. They proposed that variability of velocity, the uneven terrain, distribution of pack loads and environmental conditions would all have effects on this relation.

Subject-Related Factors

Clothing

Acknowledging that clothes are essential as a means of protection against cold in winter, as well as against the damaging rays of the sun in summer, Duggan (1988) studied the effects of various military clothing ensembles on the energy cost of bench-stepping. He stated that not only clothing weight, but also clothing comfort negatively influenced the results.

The effect of temperature on a nude human body differs from that on a clothed body. As the human body is constantly generating heat, this heat is trapped between the skin and the first layer of clothes and the heat-loss process is slowed down. The effects of wearing multi-layer armoured vests were investigated in hot-wet and hot-dry climates by Haisman and Goldman (1974). They concluded that with impermeable garments such as body armour, the amount of air movement under the garment associated with the movement of the wearer is important in the elimination of heat.

Consolazio **et al.** (1963) reported that clothing may affect the heat production due to the weight and/or restrictive effects. The "extra" load, added to the external backpack load, will result in increased energy cost and a greater proportion of $\dot{V}O_2$max will be utilised, resulting in reduced time to the onset of fatigue. Furthermore, the higher metabolic heat production which will accompany the increased energy expenditure could exacerbate the problems of heat dissipation from clothing, thereby augmenting the risk of heat stress. In addition, the soldier would experience increased subjective discomfort which is also likely to lead to fatigue and poor post-march performance. To show the effect of clothing, the weights of clothing and personal equipment carried by a British infantryman are summarised in Table II.

The lightest load, comprising basic clothing, weapon, ammunition, digging tool and equipment (26.4 kg) is referred to as Assault Dress (B). The addition of food and warm clothing (3.7 kg) to sustain him for a period of 24 h produces the next heaviest load (C). Finally, the inclusion of spare clothing, rations, rucksack and sleeping bag, results in the Marching Order which has a total mass of 40.3 kg. It is of interest that Pierrynowski **et al.** (1981) found the optimum load to be 7 kg when the defined load included the entire body mass. This is equivalent to A (Dress) and implies that a clothed soldier is already carrying the optimum load.

TABLE II : Mass of clothing and personal equipment carried by a British infantryman (Adapted from Haisman, 1988).

			Mass (kg)	**Total Mass (kg)**
A	Dress	Clothing, boots and helmet	7	7
B	Assault Dress	As in A, weapon, ammunition, digging tool and equipment	19.4	26.4
C	Combat Order	As in A and B, food and warm clothing	3.7	30.1
D	Marching Order	As in A, B and C, spare clothing, rations, rucksack and sleeping bag	10.2	40.3

Clothing does play an important role in the thermo-regulation process, especially during physical activity. The different types of clothing material also have an influence and should be further investigated. The basic uniform and boots (3 kg in total) were included in the calculations determining loads to be carried by the subjects involved in the present investigation.

Speed of walking

Reynolds **et al.** (1990) showed that in the field soldiers may be required to carry loads equivalent to body mass while marching at high speeds. These authors note that the debilitation of the soldiers through fatigue and injury has deleterious consequences for training, combat readiness and final mission effectiveness. They also noted that when troops were required to increase the marching speed from 3.96 km.h^{-1} to 5.76 km.h^{-1} (1.1 m.s^{-1} to 1.6 m.s^{-1}) there was a 65% increase in the injury rate.

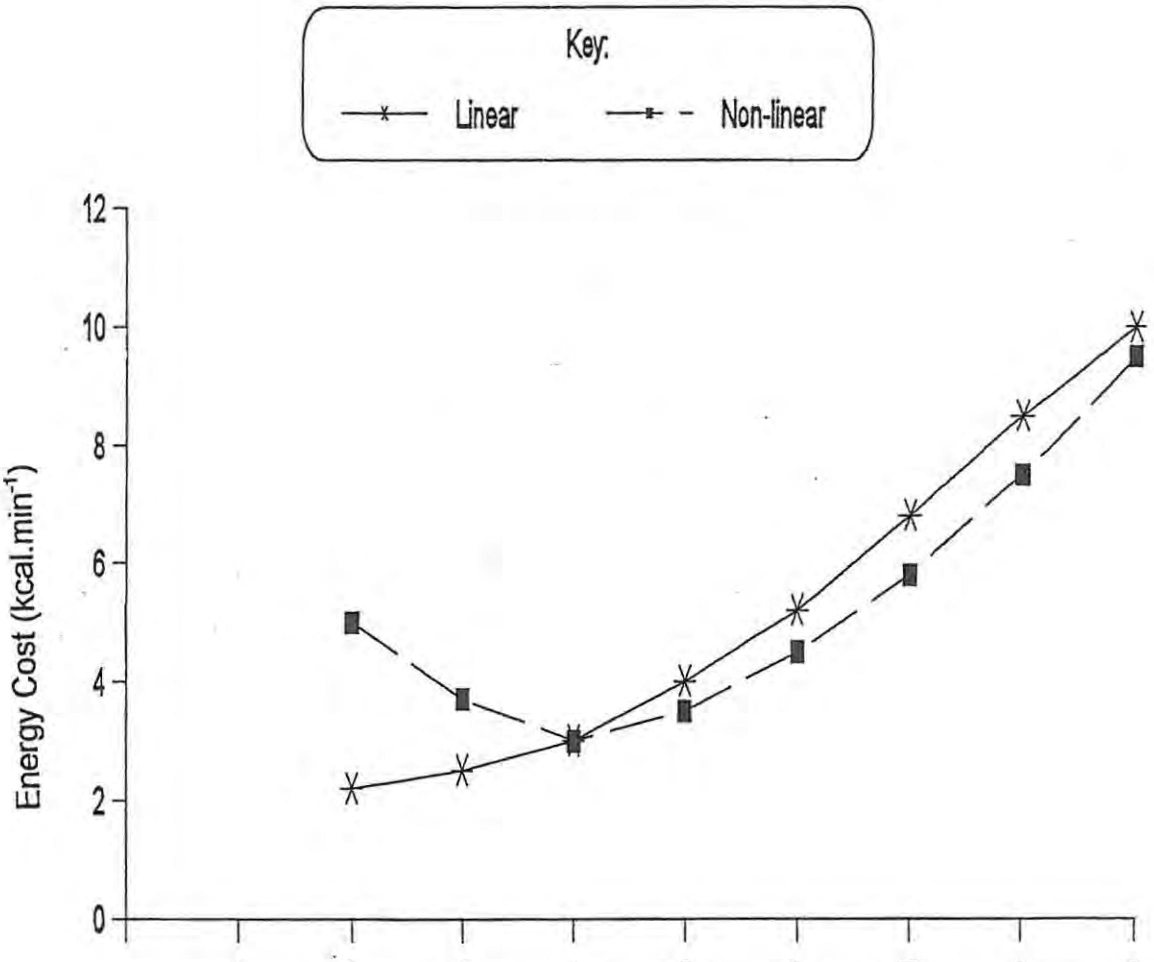


FIGURE 5 : Proposed linear and non-linear relationships between speed and energy expenditure (Adapted from McArdle **et al.**, 1996 and Bunc and Dlouha, 1997).

Although platoons do have a recognised speed for specific army requirements, there is a lack of consensus in the literature surrounding what speed is the most effective walking pace. As far back as 1920, Cathcart and associates conducted a study on optimal marching rate with respect to energy expenditure. These authors found that energy cost was initially high at slow speeds, decreasing to an optimal, thereafter increasing again as speed increased. Similar conclusions of an initially non-linear curve were drawn by later researchers such as Soule **et al.** (1978) and Bunc and Dlouha (1997). They attributed the non-linearity to the fact that minimum metabolic cost of walking is achieved at a speed of 4 $km.h^{-1}$ (1.11 $m.s^{-1}$). At speeds below or above this the energy cost of walking becomes higher as is evident in Figure 5. Several other authors (Hughes and Goldman, 1970; Givoni and Goldman, 1971; McArdle **et al.**, 1996) disagree with this theory and contend that there is a progressive linear relationship between walking speed and energy cost.

An important factor identified by Zarrugh and Radcliffe (1978) was that self-pacing resulted in a lower energy cost than forced pacing, and this pace will be influenced by the load. When allowed to adopt their own step rate for a given speed, these authors found soldiers unconsciously selected a unique step rate requiring the least energy. Walking at the same speed, but with any imposed step rate resulted in an increased energy expenditure. Self-selected velocity is reported to decrease in a linear manner with increased load (Hughes and Goldman, 1970; Knapik **et al.**, 1993).

Clearly there is disparity as to the exact relationship between energy expenditure and walking velocity. The pace in the present study was set by the Army personnel at the recommended pace for "Patrol Marching", that is 4 $km.h^{-1}$ (1.11 $m.s^{-1}$).

Biomechanical Factors

Gordon **et al.** (1983) found that although the mechanics of load carriage probably did not change as load increased, the mode of walking under added load certainly differed from that of added gradient. This imposed greater stress on muscle groups not accustomed to the required work during walking, as the addition of a load forced individuals to lean forward, in order to bring the centre of gravity back over the base of support. This tendency to lean forward was most obvious at heavier loads (Gordon **et al.**, 1983). They suggested that excessive forward flexion would be resisted by eccentric contracture of the hamstrings and semispinalis.

In a study on the walking patterns of men and women during load carriage, Martin and Nelson (1986), found a decrease in stride length and swing rate while stride rate increased with an increased load. Stride length is one factor known to affect $\dot{V}O_2$ during running where variations from an optimum length result in increasingly greater energy demands (Daniels, 1985).

Environmental Considerations

Terrain and Gradient

Marching soldiers are continually exposed to changing terrain and gradients. Passmore and Durnin (1955), in their review of energy expenditure state that the type of surface will have a slight effect on the energy cost of walking. As early as 1966 Strydom **et al.**, in a study of 11 young men, found that the metabolic cost of walking at 4.8 km.h^{-1} (1.33 m.s^{-1}) with loads of about 23 kg was 80% greater on loose sand than on a hard surface. Soule and Goldman (1972) investigated a variety of terrain including smooth and dirt roads, light and heavy brush, as well as swamp and sand, and compared results with the control conditions of walking on a treadmill to show how the energy cost increased with the severity of terrain.

TABLE III : Energy costs for a 70 kg man walking with no load, at a speed of 5.76 km.h^{-1} (1.6 m.s^{-1}) for various level terrains (Adapted from Pandolf **et al.**, 1977).

Terrain	**Tarmac Road**	**Dirt Road**	**Light Brush**	**Heavy Brush**	**Loose Sand**
Energy Cost (W)	374	401	428	508	669

Table III shows the effects of different terrain at a standard speed for no load. It is clear that walking on loose sand is almost 80% more costly than walking on a tarmac road. Furthermore, Wyndham **et al.** (1971) assert that close attention must be paid to the nature of the footwear. They suggest that a heavy boot or a slippery sole, both common in the military situation, may alter the energy demands of marching. Kirk and Schneider (1992) suggested that regardless of type of pack worn, a small increase in the slope of the terrain (with individuals walking at a constant speed) will result in significant increase in energy cost and perception of exertion.

TABLE IV : Energy costs (W) for a 70 kg man walking at a speed of 4.82km.h^{-1} (1.33 m.s^{-1}) for loads of 0, 20 kg and 40 kg at various uphill gradients (Adapted from Pandolf **et al.**, 1977).

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

* outside the physiological range for young, healthy men

Wanta **et al.** (1993) and Knapik **et al.** (1996) speculate that downhill walking energy cost is approximately U-shaped: it initially decreases, then begins to increase. This energy expenditure increase over time is important because individuals carrying the load may become more easily fatigues if energy cost does increase. Figure 6 shows the essential metabolic features of slope-walking for speeds of 2.93 km.h^{-1} (0.81 m.s^{-1}), 4.39 km.h^{-1} (1.22 m.s^{-1}) and 5.86 km.h^{-1} (1.63 m.s^{-1}), and at grades from +4° to -10° (+7% to -18%). The rapid rise in metabolic cost with increased gradient is evident, as gradient is evident, as well as the more modest decrease in energy cost at grades in the range 0° to -4° (0% to -7%).

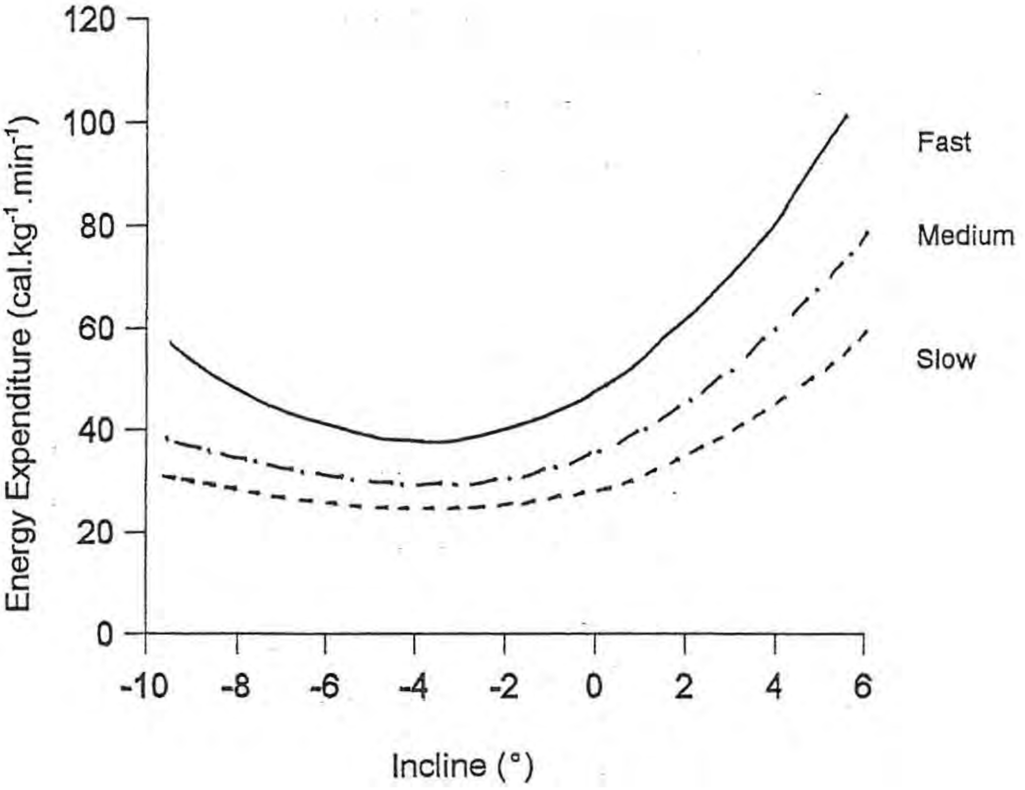


FIGURE 6 : Effect of grade on energy expenditure of young adult male during walking at three speeds (Adapted from Anmon **et al.**, 1981).

The texture and slope of the gradient are both influential in the analysis of energy cost of walking and thus the nature of the terrain must always be taken into account in anticipating the metabolic cost of walking.

Climate

The climate imposes heavy demands on the physical and mental capabilities of the troops deployed and often severe weather conditions must be endured for long periods. Kamon and Belding (1971) found no difference in the metabolic costs of carrying loads up to 20 kg in the hands in hot climates (35° and 45°) compared with those in temperate climate, but heart rate was found to increase by 7-10 beats for each 10° C in air temperature.

However, Snook and Ciriello (1974) showed that load carrying ability was reduced by 11% in a hot environment (27°C) with significantly higher rectal temperatures and heart rate. Bailey (1982) noted that the actual level of heat necessary to degrade performance varied from situation to situation, and person to person. It is however generally accepted that high temperatures will influence human performance negatively. Physiological functions such as core temperature, skin temperature, sweat rate and loss are directly affected by the thermal conditions and will in turn influence the performance. An interesting concept proposed by Parsons (1993) was that hot ambient environments would reduce arousal levels which may cause performance to degrade. This is a relevant factor to consider with South African soldiers who are often faced with hot, humid conditions.

In cold climates, the energy cost of walking at standard speeds with loads is increased compared with that predicted for temperate ambient conditions, but this is possibly not because of reduced air temperature **per se** (Haisman, 1977). Rather, it has been shown that the energy cost of walking in multi-layer, cold-weather clothing is increased by up to 20% over the same task, wearing shorts with the weight of multi-layer clothing carried on the belt. Thus, should higher levels of energy expenditure be found in cold climates, the extra energy expenditure is more than likely to be attributable to the weight, hobbling and restrictive effects of multi-layer clothing than to the effects of the cold itself.

FATIGUE

Johnson **et al.** (1995) report that successful accomplishment of a particular objective often demands that soldiers complete a road march as rapidly as possible with minimal fatigue and discomfort. Heavy loads can lead to body soreness, aches, pains, fatigue and interfere with the accomplishment of mission. Loads are heavy because they include special equipment items to complete the military mission, including communications gear, weapons, ammunition, food, water and body armour.

Gupta (1955) and Legg and Mahanty (1986) have suggested that a limiting factor in load carriage is fatigue of local muscle groups. Dalen **et al.** (1976) interviewed Swedish conscripts after a 20-26 km march on which they carried a 15 kg pack. Problems with the legs and feet were most commonly reported as limiting factors (42%) and general fatigue (11%). They suggested that local fatigue of back and shoulders was more important than the energy cost in limiting load carriage. This is supported by Legg **et al.** (1997) who reported that localised muscular discomfort with loads is more likely to have an ischaemic or anaerobic lactic origin relating to muscular fatigue, rather than to be associated with limitations in aerobic muscular process. During heavy dynamic work or during static exercise, blood circulation can not keep up with the demands on O_2 supply and the removal of CO_2 leading to the accumulation of lactic acid, decreased pH, a perception of fatigue and reduced endurance.

Knapik **et al.** (1996) reported that very strenuous walks (maximal speed with loads of 34 kg to 61 kg over 20 km distances) can lead to post walk decrements in marksmanship and grenade throwing distance. A decrease in marksmanship presumably due to small movement of rifle resulting from fatigue of the upper body muscle groups, fatigue-induced tremors, or elevated heart rate or respiration.

Haisman (1988) revealed that one can not expect individuals to work all day at work level equivalent to more than 50% of his $\dot{V}O_2$max without becoming fatigued. Earlier, Åstrand (1967) showed that working at 50% of maximal output could produce objective and subjective indications of fatigue, whereas the spontaneously chosen work load in building work corresponds with about 40% of an individual's $\dot{V}O_2$max. It is recommended that adjusting work intensity during prolonged work to an individuals $\dot{V}O_2$max should minimise muscle fatigue and damage.

LABORATORY vs. *IN SITU* INVESTIGATIONS

There appears to be a considerable amount of controversy in terms of the validity and reliability of laboratory and field studies investigating energy cost while marching. It is thus necessary to examine the advantages and disadvantages of these two modes of study in order to determine their utility.

Field studies tend to be rare occurrences in view of their high costs and associated organisational difficulties. These difficulties arise when scientists attempt to gain access to the real situation. **In situ** investigations cannot be as rigorously controlled as the laboratory environment particularly with reference to social and environmental factors. There is also the possibility of contamination of results due to external distractions which are part of all environments, yet specific to each situation. However, Oborne (1987) has argued that **in situ** studies have greater validity in terms of relating back directly to the actual situation.

The alternative to **in situ** investigations is laboratory simulations, but this seems to be overshadowed by a different set of problems. The artificial nature of the testing ambience and the inevitable shorter duration are highly likely to present significantly different results than would occur under natural field conditions. A simulated march may bias performance in a negative manner as the subject may perceive the required task as being trivial and irrelevant. Laboratory studies generally comprise a relatively small subject pool and therefore do not facilitate adequate inter-individual comparisons. While these studies allow for standardisation of local physical conditions, as well as providing stringent control over stimuli presented to the subjects, Oborne (1987) finds this extremely "sterile" environment to unsatisfactorily account for social influences and realities.

The present investigation opted for the **in situ** option for investigating the effect of extended marching on load carrying efficiency. With rigorous control on speed of marching and load carried (set at sub-maximal levels); there is a need to establish baseline measures of what happens in the natural ambience of a controlled march. As such, there is a need to conduct both rigorous laboratory experiments, as well as field testing which together acknowledge the network causality of factors underlying the soldiers responses.

CONCLUSION

The focus of military ergonomics is to optimise personal well-being, while at the same time enhancing combat-readiness and efficiency in cost effective ways. The "network causality" of load determinants make it very difficult to offer a definite assumption of what the optimum load carrying conditions should be. An awareness of all these factors has been addressed in an holistic, integrated way while investigating the load carriage problem in the SANDF.

It is evident that load carriage in military, industrial and other civilian areas will involve a compromise between the person's capabilities and requirements of the task, which may in some circumstances have important implications for health and safety.

CHAPTER III

METHODOLOGY

INTRODUCTION

Load carriage is one of the most common human activities, often combining two of the basic movement patterns described by Charteris **et al.** (1976), that is, bipedal locomotion and manipulative capabilities. While manual load carriage has pre-historic roots, modern technological advances have not been able to fully liberate humans from this physically demanding activity.

Load carrying is a major component of army activities. During military engagement soldiers are required to carry extremely heavy backpacks and march long distances, after which they are expected to perform critical military tasks with efficiency. The universal norm has been that all military personnel be required to carry similar absolute loads regardless of age or morphology. However, individual soldiers have unique physical and mental characteristics, so the effect of load mass or method of carrying a load varies appreciably from individual to individual, and even within the same individual depending on terrain, climate, physical conditioning and experience (Renbourn, 1954).

Balogun **et al.** (1986) argued that although physiological measures provide significant information concerning the physical strain experienced by the individual, it is also important to consider the subjective feelings of those carrying the loads, since a device should not only be metabolically efficient, but must also be subjectively acceptable to the user. Consequently, this study investigated the deterioration in physical and perceptual responses over the duration of an extended march, and proposed an alternative of equalising the strain being experienced by carrying a load which is relative to the individual's body mass.

PILOT STUDY

Prior to this study, several preliminary investigations were conducted, both in the laboratory and in the field, in order to establish the suitability of equipment and the rating scales to be used. As all equipment selected is internationally accepted as valid and reliable, the pilot studies were required to establish a logical order of testing, familiarity of equipment and the establishment of the overall protocol.

EQUIPMENT AND SPECIFIC EQUIPMENT PROTOCOL

ANTHROPOMETRIC MEASUREMENTS

Prior to the actual data collection, a set of personal information was recorded for each subject. This included age (years) of the subject, military experience (years) and the following anthropometric measures that were ascertained using the appropriate equipment.

Body mass - Toledo Scale

A previously calibrated TOLEDO electronic scale was used which measured body mass to the nearest 0.01 kg. Subjects were required to stand still with equal distribution of mass while the readings were manually recorded onto a data sheet. Each subject was weighed before and immediately after the march, under the following conditions:

- minimal clothing: shorts and vest
- full army uniform
- full army uniform with load (inclusive of helmet and rifle)

Stature - Tape Measure

A tape measure was mounted on the wall and was used to measure the distance from the vertex in the mid-sagittal plane to the floor. This measurement was made with the subject standing barefoot in the military position at attention, head erect, looking straight ahead so that his visual axis was parallel to the surface of the floor. Arms hung freely by the sides of the trunk with palms facing the thighs. The tape value was manually recorded to the closest 1.0 mm.

Body composition - Bioelectrical Impedance Analysis

Graves **et al.** (1989) and van Loan (1990) reported that Bioelectrical Impedance Analysis (BIA) was already 30 years old in 1937 when first used to detect changes in thyroid function. Since the early 1970's BIA has been applied to estimate body composition, as in the present investigation.

The basic idea underlying most methods of determining body composition is that there are two chemically distinct compartments; fat and non-fat. The fat component is anhydrous and has a uniform density of 0.9 $g.cc^{-1}$. In contrast, the non-fat component, which has a relatively uniform in density (1.1 g.cc^{-1}), has a water component of 73% and contains almost all the bodily electrolytes (Wagner and Heyward, 1999).

Electrical conductance provides an indirect method of determining fat-free and fat content. In biological material the application of a constant low-level alternating current produces an impedance to a current depending on the frequency (van Loan, 1990). Bodily tissues, being largely fluid and electrolytes, act as electrical conductors. Impedance is related to conductor length, cross sectional area and signal frequency. If the signal frequency and conductor configuration are kept constant then impedance is related to the resistivity to the flow of current. The conductivity is far greater in the fat-free mass and resistivity is less, since resistivity is the inverse of conductivity.

The subjects were required to be barefoot, lying supine on a non-conductive surface with arms and legs abducted at an angle of 30° to 45° from the trunk in preparation for the testing. The BI unit consists of four electrodes placed on hands and feet. An AC sine-wave signal generator with a current at 800 A and frequency at 50 kHz supplies the excitation current (Wagner and Heyward, 1999). All electrodes were placed on the right side on the long axis of the central ray of the hand and foot. Care was taken to ensure that the sensor (black) and current (red) electrodes were at least 55 mm apart: closer together may result in an interference between electrodes and artificially increase the resistance readings. Positioning of the electrodes is described below and is represented in Figure 7:

Hand electrodes - Sensing electrode (SE) (black) on mid-dorsum of wrist on a line bisecting the ulnar styloid. Current electrode (CE) (red) on mid-dorsum of hand, midway between proximal meta carpal-phalangeal joint and SE.

Foot electrodes - SE on mid-dorsum of ankle on a line bisecting the medial malleolus. CE on mid-dorsum of foot, midway between proximal metatarsal phalangeal joint and SE.

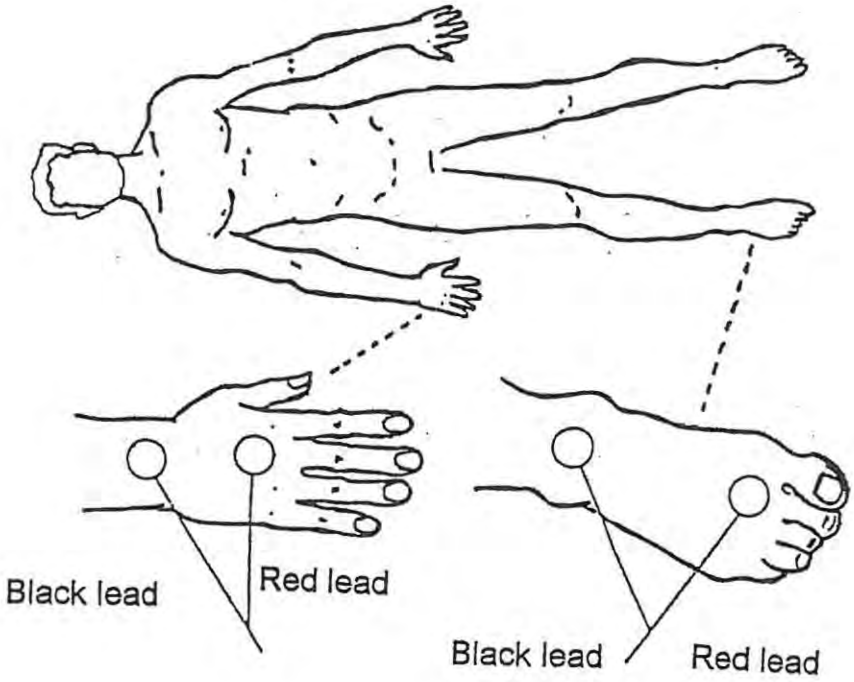


FIGURE 7 : Positioning of the electrodes for the BIA.

Estimates of fat mass (F), lean body mass (LBM), basal metabolic rate (BMR) and body mass index (BMI) were relevant in the present study. The data from the BIA were read and manually recorded for each subject prior to the marches with various loads. The body composition of the ten subjects selected for detail physiological assessment was also estimated at the end of the marches.

FIGURE 8 : Bioelectrical Impedance Analysis administration.

PHYSIOLOGICAL PARAMETERS

Cardiac Frequency - Polar Heart Monitor

Heart rate is a useful indicator of the intensity of physical activity because of its known, predictable and reproducible relationships, within certain limits, to energy expenditure and cardiac strain (Leger and Thivierge, 1988; McArdle **et al.**, 1996, Aminoff and associates, 1998). Relatively recently (Leger and Thivierge, 1988; Godsen **et al.**, 1991; Laukkanen and Virtanen, 1998) ambulatory light-weight radiotelemetric devices have been introduced, allowing virtually instantaneous on-line monitoring of heart rate. Supporting the use of these heart rate monitors, Vuori (1998) claimed that ambulatory heart rate monitoring allowed objective, reliable and feasible assessment of cardiovascular loading. It is also relatively easy to use for both experimental subjects and research personnel, and is non-obtrusive and socially acceptable in a wide variety of conditions.

The present investigation used the Polar Heart Rate Monitor to assess cardiovascular performance. Two models, **viz.** Polar Accurex Plus and Polar Sports Tester, which have similar operation procedures, were used. This equipment utilises the electrical activity of the heart to measure and store heart rate data. It has three components: the watch, and electrode strap and a transmitter. The heart watch serves as a display unit, allows the various functions to be programmed and stores the collected data. The subjects wore the monitors on their wrists to ensure these remained within the range of the transmitter.

FIGURE 9 : Polar Heart Rate Monitor display unit.

The electrode strap is an elasticised strap which holds the transmitter. For use, the strap is placed around the mid-chest at the level of the inferior border of the pectoralis major muscles, as evident in Figure 10. The transmitter is fixed to the electrode strap and the red mark on the transmitter must always be in the centre of the chest. One must ensure that good contact is made between transmitter and skin; the conductive electrode strips may be moistened with water or an electro-conducting gel to improve contact.

FIGURE 10 : Subject wearing the transmitter belt used with the wireless Polar Heart Rate Monitor.

The subjects' heart rates were allowed to settle after the watch and transmitters were positioned correctly and "reference" heart rates were recorded. "Reference" as opposed to resting heart rate were used for baseline measures since variations in emotional state significantly affect cardiovascular responses, and make it difficult to obtain true resting values for heart rate (McArdle **et al.**, 1996). Immediately prior to the testing conditions "anticipatory" heart rates were recorded. McArdle **et al.** (1996) report that the elevation in heart rate preceding participation in a demanding activity is probably the result of both an increase in sympathetic discharge and a reduction of vagal tone.

The heart watch was programmed to record heart rate every 15 s during the march. The data stored were manually recorded every 15 min onto the data sheet (See Appendix B). However, the heart rates of the 10 subjects undergoing detailed assessments were recorded throughout the three-and-a-half hour data collection period. The data stored on the heart watch were downloaded onto a computer and relevant printouts obtained (Refer to Appendix C).

Metamax

The Metamax is a portable ergospirometry system whose mobility, low weight, stable sensors, ease of operation and integrated telemetry show its superiority over other conventional stationary methods. The system provides all the data needed for a complete functional analysis of the lungs, heart, circulation and metabolic activity under stress. Coetsee (1998/99) has validated the Cortex Metamax and found it to be suitable for measurement of steady state activity, where its portability make it an invaluable apparatus for true field studies.

The Metamax uses a Triple-V volume transducer for measurement of ventilation volumes, a Zirconium sensor to analyse O_2 and an infra-red sensor for CO_2 (Coetsee, 1998/99). The base unit contains the complete electronics for measuring and processing of physiological responses during a given period. The main parts of the processing unit consist of several microprocessors. In addition, several sensors and mechanical components are controlled by these microprocessors. Connections are at the front of the Metamax base unit and allow for linkage of the various components as seen in Figure 11.

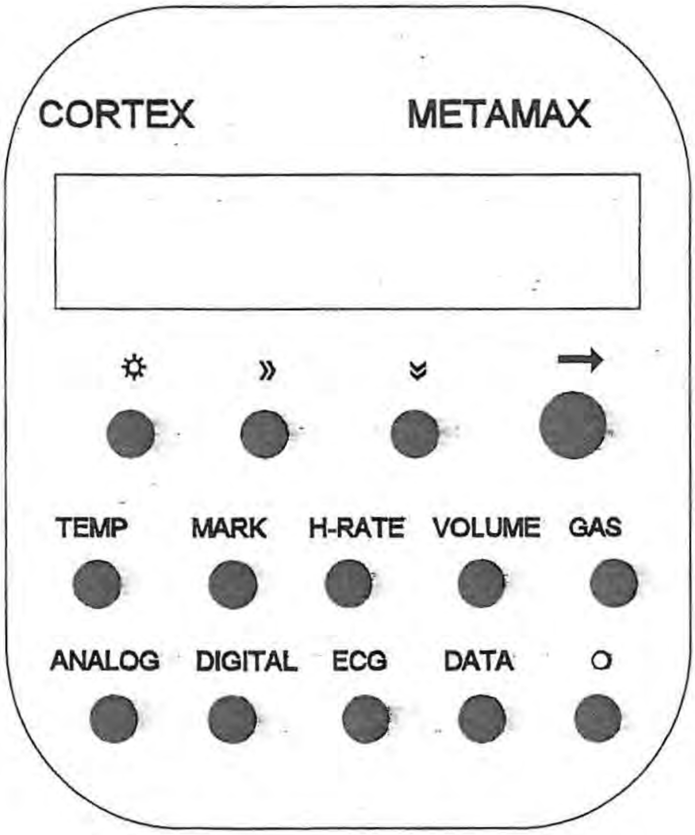


FIGURE 11: Schematic representation of Metamax base unit showing various connections.

Accessory sensors connect to the base unit as follows:

TEMP is the connection for the environmental temperature sensor. It is essential that the sensor not be placed near the body or in direct sunlight as this might lead to incorrect ambient temperature measurement. MARK is the connection for the event marker. Pressing the button results in a marker being recorded at that particular time and enables one to distinguish events during the actual data collection. H-RATE is for the Polar cardiac frequency receiver which must be placed close to the subject's heart. It contains the transmitter which records the electrical activity from the electrode strap which is worn around the subject's chest.

VOLUME is where the volume transducer connects to the Metamax base unit. The volume transducer fits into the gap on the face mask. The clear expiring gas tube has been linked to the Nafion tube (used to guarantee a constant humidity during the assessment) which has a bent outlet connecting to the volume transducer. The other end connects to GAS at the Metamax base unit. Since the Metamax was used in field, the transparent wind-shield was installed, so as to minimise the influence of headwind.

It was deemed necessary to assess the body's various thermo-regulatory mechanisms, especially when marching for extended periods. The temperature on the surface of the human skin changes according to changes in the environment and various stresses experienced by the individual. The present investigation used the Metamax to monitor skin temperature at two locations during the various marches. Both anterior and posterior surfaces of the trunk were selected to assess the effect of the backpack on the thermo-regulatory system. Temperature electrodes were placed on the *erector spinae* and *pectoralis major* and secured with surgical tape. These were then connected to the Temperature Sensor Box (connected to ANALOG at the Metamax base unit) which was placed above the Metamax base unit.

FIGURE 12 : Mask and head cap assembly.

The face-mask with head cap assembly is used together with the Triple-V volume transducer for the defined exchange of the expiratory gas with the base unit. The face-mask is a single piece moulded of translucent silicone rubber which is durable, resilient, comfortable to facial skin and designed with a sealing flange for added reliability and comfort. Various sizes (large, medium and small) were available to ensure a tight fit and to control all expiratory exchange through for analysis. The face-mask was held in place on the face comfortably and snugly with a polyester net head-cap assembly which incorporates stretch Velcro straps with locking-type clips, as illustrated in Figure 12.

It was essential to calibrate the Metamax volume transducer and gas sensors to ensure accurate gas analysis. With reference to calibration of the volume transducer, a three litre default pump was used. The volume transducer was connected to the syringe (ensuring the gas output is closed) and the junction cable connected to the VOLUME socket on the Metamax base unit. The calibration process was initiated from the main unit and involved full-excursion pumping six times steadily. The Metamax performs six volume measurements and compares the average with the nominal value. Then it calculates the correction factor which should be between 0.8 and 1.2.

FIGURE 13 : Equipment needed for Metamax calibration.

With regard to the gas sensors, two different gas mixtures (O_2 and CO_2 at different concentrations) are needed to perform the calibration. The gas analysis tube was connected to GAS at the base unit and the other end suspended in ambient air. This formed the basis of Measurement 1, where measurements were automatically terminated when three values were within scope of the allowed deviation. Measurement 2 was a mixture (CO_2 4.9%; O_2 16.10% and balance nitrogen). A small amount of this gas was collected in a rubber bladder and the outlet was connected to the gas tube inlet of the Metamax. Again, measurements were taken and automatically terminated when three values were within the scope of the allowed deviation. The Metamax volume transducer and gas sensors were calibrated prior to the start of each morning data collection session in this particular study.

The energetic data captured during the final stages of each hour included measures of breathing frequency (f_b), tidal volume ($\dot{V}_T$), minute ventilation ($\dot{V}_E$), oxygen consumption ($\dot{V}O_2$), carbon dioxide production ($\dot{V}CO_2$), respiratory exchange ratio (R) and skin temperatures (T°). Energy expenditures (kcal.min^{-1} and kJ.min^{-1}) and power output (W) were derived from $\dot{V}O_2$. The data stored in Metamax base unit were downloaded onto a computer and suitable print-outs obtained (Refer to Appendix C for formulae applied and example of Metamax report).

PSYCHO-PHYSICAL PARAMETERS

RPE Scale

Borg (1970) suggested that fatigue is a subjective state with both physiological and psychological components, and furthermore that a positively accelerating relationship exists between physical workload and perceived exertion. He believed that ratings of perceived exertion offer a great deal towards the understanding of human physical performance and thus developed his now well used psycho-physical scale. This rating of perceived exertion (RPE) consists of a 15-point scale, ranging from 6 (minimal exertion) to 20 (maximal exertion). Although Borg claimed in 1970 that his scale was universal, a modified RPE scale proposed by Scott (1986) was used to account for the semi-literate, non-English-speaking South African military personnel who were the subjects of this study.

The conceptual basis and use of the RPE was carefully explained to all subjects prior to the testing sessions (See Appendix B). As military personnel are required to carry diverse loads over considerable distances, differential ratings for "local" and "central" responses could help identify whether respondents were in poor cardiovascular condition or whether the strain was more localised and associated with poor muscular strength and/or endurance. Thus two measurements of perceptual responses were essential in the present investigation. A "local" RPE based on feelings of strain in the muscles and/or joints of the lower limbs, and a "central" RPE reflecting feelings of strain in the cardiovascular system were recorded. Subjects were required to give ratings of perceived exertion every 15 min during the two 12 km marches. Ratings were verbally verified by the researcher before being manually recorded on individual data sheets (See Appendix B).

Body Discomfort Scale

In order to determine the exact location of discomfort or pain experienced by the military personnel, a rating of perceived discomfort was recorded, using a body map diagram in conjunction with a discomfort scale (Corlett and Bishop, 1976). The body map is divided into 27 segments so the subjects are able to visually identify the site(s) of body discomfort experienced. Subjects were asked to point to the site(s) of current discomfort on the body map and were then required to rate discomfort intensity at each identified site. Ratings were given on a 10-point scale where 1 refers to "very comfortable work" and 10 refers to an experience of "extreme discomfort". Body discomfort ratings were administered at the completion of each hour, so that 3 sets of measurements were recorded per march per soldier.

The perception of exertion during physical activity reflects a personalised response to the physical demands of the task, thus assisting in the understanding of the individual's perception of the external demands, plus the general capacity of the individual. The two subjective responses collected were quantifiably measured on valid rating scales of perceived exertion and discomfort, and were included to aid in obtaining an overall assessment of the physical demands experienced by the individual and the exact location of the physical strain.

SUBJECTS

The initial sample comprised of 60 volunteer foot-soldiers from the Oudtshoorn Infantry School. All were part of the B Company Platoon and were about to complete the three-month "Area Protection Training Course". As age and sex are factors in physiological and perceptual responses, an attempt was made to limit the effect of these variables by restricting the sample to male subjects between 17 and 27 years.

All subjects were cleared for participation after a full medical examination (administered by Army Medical Personnel). The subjects received oral and written information about the test procedures and possible risks involved in participating (Appendix A). The test protocol had been approved by the Ethics Committee of Rhodes University and a written informed consent (Appendix A) was obtained from the Colonel on behalf of the subjects.

Ten subjects were randomly selected from the above sample for detailed physiological assessment using the Metamax. Henceforth this group is referred to as the **Metabolic** study group (M) where n=10, and **General** study group (G) will relate to the entire group where n=60. The basic physiological responses of the remaining 50 subjects were measured via heart rate monitors. The perceptual responses of all 60 were evaluated by the Rating of Perceived Exertion scale and Body Discomfort scale.

As all subjects were resident at the same army base it was accepted that they followed a similar daily routine and hence no special dietary restrictions were placed upon the subjects while participating in the study. All soldiers wore the same clothing for the duration of the investigation. This consisted of standard undergarments, camouflage trousers, long-sleeved shirt, and military boots as seen in Figure 14:

FIGURE 14 : Basic military uniform worn by all soldiers during the test.

SUBJECT CHARACTERISTICS

During the six days of data collection several subjects were, for various reasons, unable to fulfil the requirements. The final number of subjects was 43. The mean age of the **General** group was 21.42 (±2.20) years, the youngest being 19 years and the oldest 27 years. The **Metabolic** study group, depicted in Figure 15, were 21.20 (±2.57) years and were morphologically similar to the general squad. A summary of the relevant subject data is presented in Table V.

TABLE V : Demographic data relative to the **General** group vs. the **Metabolic** study group.

	General Study Group **(n=43)**	**Metabolic Study Group** **(n=10)**	**M/G (%)**
Age (years)	21.42 (2.20)	21.20 (2.57)	98.99
Stature (mm)	1750 (76)	1741 (88)	99.48
Mass (kg)	74.45 (9.56)	73.35 (15.39)	98.52
RPI ($mm.^3\sqrt{kg^{-1}}$)	422.65 (18.49)	419.44 (27.40)	99.24
BMI $kg.(m^2)^{-1}$	23.45 (2.76)	23.52 (3.99)	100.29
Body Fat (%)	12.41 (3.580	15.62 (3.45)	125.87
BMR ($kJ.day^{-1}$)	8113.09 (904.65)	7928.20 (1321.14)	97.72
BSA (m^2)	1.87	1.88	100.53

(Figures in ( ) = standard deviation; RPI - Reciprocol Ponderal Index; BMI - Body Mass Index; BMR - Basal Metabolic Rate; BSA - Body Surface Area; M/G - Metabolic group as percentage of General group)

FIGURE 15 : Profile of subjects from **Metabolic** study group.

There was only one slight morphological difference (% fat) between the **General** study group and the **Metabolic** study group, an indication that the selected ten were reasonably representative of the overall squad. The present **General** group measured 1750 (±76) mm 74.45 (±9.56) kg and are thus similar to Behnke's (1974) reference man of a similar age group. His theoretical model was based on the average physical dimensions obtained from detailed measurements of thousands of individuals from large-scale anthropometric surveys. Behnke's (1974) reference male was 1740 mm and 70 kg. BMI, averaging 23.5 $kg.(m^2)^{-1}$ for both groups, were within the ACSM (1986) recommended 20 $kg.(m^2)^{-1}$ to 25 $kg.(m^2)^{-1}$ range for young male adults.

STATURE AND SPEED OF WALKING

Although certain investigators have proposed that stature is a poor indicator of locomotor energy cost (Wyndham **et al.**, 1971), there is considerable evidence to suggest that the same absolute locomotor speed taxes short and tall subjects differently. It has been reported that shorter subjects expend more energy per kilogram body mass per unit of speed for a given locomotor mode than their taller counterparts (Miller and Blyth, 1955; Charteris, 1982; Charteris **et al.**, 1982).

The lower oxygen consumption associated with the locomotion of taller subjects can therefore be attributed to the related gait pattern, which is affected by the combination of step length and frequency. Since those with longer lower limbs tend to move with greater step lengths and a lower cadence, it may be inferred that at any prescribed speed, taller subjects take fewer steps per unit distance by virtue of a greater length of stride, and as a consequence tend to expend energy at lower rates.

Based on data from many empirical studies "preferred speed", that is, that freely chosen by the individual, is described as 0.85 stature per second. In the present study, given the stature 1750 mm, the mean stature-normalised speed of walking at 4 km.h^{-1} was 0.64 stature per second. This would be categorised as *slow medium* according to relative speed classifications by Charteris (1982) and Charteris and associates (1982). Furthermore, all subjects could be said to have walked between 70% and 83% of their natural preferred walking speeds. In short, the selected pace of the march did not contribute much to the intensity of walking.

EXPERIMENTAL CONDITIONS

Two experimental marching conditions were the basis of the present investigation, and every effort was made to keep both conditions, except the load carried, as similar as possible. The method of load carriage was standardised as it significantly influences energy expenditure. Backpacking was selected as it provides greater versality and is a relatively low energy cost method. The load carried was varied from one condition to the other. Condition 1 involved an **Absolute** load of 40.5 kg, while Condition 2 was a **Relative** load in which subjects carried 37% of their own body mass. Uniform mass (including clothing and boots) was 3 kg in both conditions.

CONDITION 1 (Absolute Load):

Uniform and boots		3.00 kg	
	Ergotech Battle Jacket		1.76 kg
	2 x water bottles		5.12 kg
	4 x grenades		1.68 kg
	4 x magazine clips		1.12 kg
Full Ergotech Battle Jacket		9.68 kg	
	Ergotech Backpack		5.40 kg
	Sleeping bag		2.24 kg
	2 x water bottles		5.12 kg
	Sand		8.99 kg
Loaded Ergotech Backpack		21.75 kg	
	Battle helmet		1.24 kg
	Rifle,strap and magazine clip		4.83 kg
Extras		6.07 kg	

Full Marching Order with **Absolute** load - 40.5 kg

METAMAX SUBJECTS:

Metamax with cover, battery and Temperature Sensor Box 3.10 kg

The **Absolute** load for the Metamax subjects was similar to the arrangement for the other soldiers. The Metamax was packed securely into the backpack and the mass of the loaded Ergotech backpack was adjusted by adding 5.89 kg of sand (instead of the 8.99 kg as for other subjects).

FIGURE 16 : Metamax packed into the backpack.

CONDITION 2 (Relative Load):

For the **Relative** load conditions, adjustments were made to each subject's backpack load to ensure a load of 37% of body mass. The backpacks were packed in such a way that mass distributions were similarly orientated between conditions and from subject to subject. The aim was to demonstrate that the effect of normalising for body mass is to reduce to nominal levels the disproportionate strain taken by lighter, more gracile army personnel. The **Relative** load of 37% of body mass was selected for several reasons:

a) Traditionally, loads over 40% of body mass have long been regarded as beyond optimal limits.

b) To replicate, as closely as was feasible the energy cost (under field conditions) that is assumed normal for an industrial worker over an 8 hour shift, that is, about 40 to 50% of maximal output.

c) Given that the literature is clear that up to 25% of body mass can be carried on the back in a well-designed backpack with minimal change in energy expenditure, the need exists to demonstrate, that beyond this energetic "free ride" level, further loads, even of modest proportions, begin to show increasing levels of absolute strain responses (Charteris **et al.**, 1989).

In the present study a relative load of 37% of body mass was selected as the lowest relative mass that would meet the above criteria. The results of the **Absolute** load study and **Relative** load study stand alone, and comparisons, while justifiable, must be made with appropriate caution, because it was not logistically possible under prevailing field conditions to ensure that exactly the same overall load per platoon was moved over 12 km in both **Absolute** and **Relative** load conditions.

METAMAX SUBJECTS:

The backpack loads were the same as in the **Absolute** condition while the battle jackets were adjusted to the individual. It was important not to change the mass of the backpack because backpacks were interchanged between the two Metamax subjects during the data collection.

The order of presentation of conditions was randomised as seen in Table VI. The two experimental sessions were separated by a 72-hour period to allow for full recovery and were scheduled at the same hour of the day to control for the influence of circadian rhythms. In the interim the soldiers continued with their training which consisted of active involvement in urban patrol, crowd control, road blocks and drilling.

TABLE VI: Summary of schedule.

	MONDAY	**TUESDAY**	**WEDNESDAY**	**THURSDAY**	**FRIDAY**	**SATURDAY**
AM 08:00-11:30	Group 1 Absolute load	Group 3 Relative load	Group 5 Absolute load	Group 1 Relative load	Group 3 Absolute load	Group 5 Relative load
PM 14:00-17:30	Group 2 Relative load	Group 4 Absolute load	Group 6 Relative load	Group 2 Absolute load	Group 4 Relative load	Group 6 Absolute load

EXPERIMENTAL PROTOCOL

The testing was scheduled over a period of one week and conducted at the Infantry School in Oudtshoorn in conjunction with the Research and Development Wing of the School and Ergotech (APPENDIX A for detail testing schedule). Ergotech was responsible for the measurement of general environmental conditions prior to and during each data collection period.

All military personnel were medically examined (administered by Army Medical Personnel) to ensure they were suitable subjects for the present study. Prior to the actual experiment the background and application of the RPE and Body Discomfort scales were thoroughly explained to all subjects. It was critical to standardise the instructions given to each group as this could possibly have influenced the reliability of the perceptual ratings. A detailed summary of the verbal instructions given is included in Appendix B.

The subjects were divided into six cohorts and ten soldiers were randomly selected for detailed physiological assessment. The latter subjects were tested for mask size and were required to wear a mask prior to data collection to become familiar with the gear.

The General Test Protocol summarising the daily routine during data collection can be found in Appendix B. Prior to the actual testing sessions, the Metamax volume transducer and gas sensors were calibrated. In addition, the various leads were appropriately connected in preparation for use.

Basic demographic data including age, military experience, stature, mass (with minimal clothing, full army uniform, full army uniform with load) were collected when the troops arrived. Bioelectrical Impedance Analysis was conducted on all subjects prior to marching, and immediately after the session for those assessed with the Metamax. The soldiers were instrumented with heart rate monitors and were encouraged to relax in an attempt to record "reference" heart rates.

The skin temperature electrodes were securely positioned on both Metamax subjects. Subject 1 carried the backpack with the Metamax first and his electrodes were connected to the Temperature Sensor Box. Subject 2 secured his leads safely in his pocket. The size of the face mask was confirmed and the subjects wore them loosely around the neck, ready for data collection during the march.

Each group was required to march a 12 km course in three hours with a 15 min rest period after the first and second hours. They formed two lines of five, with the Metamax subjects always forming the last couple. The pace 4 km.h^{-1} (1.11 m.s^{-1}) was selected by the Army as the required pace for "Patrol March", which is generally through bush under conditions in which soldiers are expected to observe the surroundings and be ready for combat. Each group was accompanied by a "Platoon Leader" who controlled the pace of the march. Cadence was checked at regular intervals with a stopwatch and response counter in an attempt to approximate 112 steps.min^{-1}. Water was available **ad libitum**. In compliance with Army convention and to facilitate the military sponsor's clear interpretation of the findings of this study, all references to marching speed in the Chapters that follow are expressed in km.h^{-1} rather than in SI units (m.s^{-1}).

FIGURE 17 : Typical formation maintained during the field test.

During the actual march, RPE and HR were manually recorded for all subjects at 15 min intervals. Body Discomfort site and intensity were assessed at the end of each hour.

FIGURE 18 : Heart rate responses and psycho-physical data logging.

Half an hour into each hour, the Metamax was switched on to allow the 15 min necessary for sensors to reach their specific working temperatures. Related research (McArdle **et al.**, 1996) suggests that an exercise duration in excess of about 3 to 4 min is sufficient to allow even unconditioned subjects to attain a steady state if the exercise is aerobic in nature, thus ensuring that any data capture is not coincidental with the metabolic adjustment of the subject as he adapts to the activity. The present investigation assessed the cumulative effect of marching with two loads over a 12 km route, and thus it was decided to capture 5 min of energetic data per Metamax subject near the completion of each hour. Fifteen minutes prior to the end of each hour, the mask was fitted and Metamax data collection was initiated on Subject 1.

FIGURE 19 : Metamax data collection initiated on Subject 1

Five minutes later data collection was terminated and both soldiers stopped marching. The skin temperature cords of Subject 1 were disconnected from the Temperature Sensor Box and the volume transducer was removed from his mask. Meanwhile, Subject 2 unloaded his backpack, put on his mask and removed the skin temperature cords from his pocket. The two subjects changed backpacks so that Subject 2 carried the Metamax to the end of the hour. The skin temperature cords, as well as the volume transducer were connected and taping secured the cords. Every effort was made to execute the changeover as quickly as possible. As soon as the soldiers resumed marching, 5 min Metamax data logging was initiated on Subject 2.

FIGURE 20 : Metamax changeover.

During the mandatory 15 min rest period the soldiers were allowed to unload and rest. In this period, the Metamax battery was changed and the backpacks of the two Metamax subjects were changed so that Subject 1 carried the spirometer-loaded backpack.

At the end of the three and a half hours of data collection the troops were transported back to the base. "Recovery" heart rates were recorded and heart rate and Metamax data were downloaded to storage discs. After each session the equipment was cleaned and prepared for the next field test.

FIGURE 21 : Rest break during the route-march.

GENERAL FACTORS

THE COURSE AND TERRAIN

Subjects were required to march a 12 km route which was identified at the Infantry School in Oudtshoorn (Refer to Appendix B). The mapping and measuring of the route was commissioned by Ergotech in conjunction with the Army's Research and Development Wing at the School.

Markings every 100 m assisted in the controlling of the recruits' marching pace. A field ambulance and a vehicle with drinking water followed the troops over the course. Assistants were positioned along the course for the purpose of verification of passage, assistance to soldiers, if required, and data collection.

The 12 km route (Appendix B) was subdivided into three 4 km sections, and although undulating over short distances, was not physically taxing. The terrain was essentially flat at 350 m above sea level for the first 4 km, of which the initial 2.5 km was tarmac. There was an average 0.27% positive gradient, that is less than 11 m vertical rise over that distance. This section was deliberately selected in order to establish a "steady state" of physiological and perceptual responses. The next section traversed several rolling hills with rough underfoot texture; the average uphill slope was 2.4%. This second 4 km section constituted the most taxing of the three 4 km segments. Although the third 4 km segment was marked by the steepest gradient of 510 m above sea level, this was at the start of the section and was of short duration (1.5 km). It was followed by modest downhill slope averaging 1.6% negative gradient over the final 2.5 km. This served as a recovery phase where most subjects' physiological and perceptual responses returned to baseline values.

AMBIENT CONDITIONS

Ambient conditions were measured throughout the week of testing. Several parameters were monitored, of which detailed results can be found in Appendix C. A summary of the ambient conditions can be found in Table VII. It is evident that wind chill effective temperatures recorded on the morning of day 5 (5.6°C to 13.2°C) and afternoon session (8.9°C to 13.6°C) were significantly lower than the other 5 days of testing. This was due to snowfall in the surrounding mountains the night before. There were no significant differences between the other days of testing; wind chill effective temperatures were within a reasonable range of acceptance, with maximum ranging from 18.1°C to 25.0°C, and the minimum range from 11.7°C to 20.9°C .

However, there was considerable variability in both the wind speed and humidity factors. The morning of day 6 had the lowest maximum wind speeds of 0.9 $m.s^{-1}$ and this was significantly lower than those recorded on other days. The average maximum wind speeds recorded for the morning of Day 3 (1.80 $m.s^{-1}$) were also significantly lower than the wind speeds recorded throughout the data collection process.

With respect to humidity, the minimum morning percentages were within reasonable range (23% - 33%) with no significant differences being established. With reference to maximum humidity measured in the morning sessions, day 3 and day 5 (45% and 48% respectively) had significantly lower recordings than the other days. All the afternoon sessions were slightly less humid than their respective mornings, however, there was a significant drop-off of approximately 20% on days 2, 3 and 6.

It should be noted that the variability in all ambient conditions is likely to have had some effect on the soldiers' responses and therefore would have influenced the results. This is acknowledged as one of the problems when collecting **in situ** data. However, these conditions provide an indication of the reality of the situation. Soldiers are expected to march long distances with external loads, and still produce effective and efficient post-march combat performance, no matter how harsh the environmental conditions.

TABLE VII : Summary of ambient conditions.

		Outside Temperature (°C)	**Wind Speed ($m.s^{-1}$)**	**Wind Chill Effective Temperature (°C)**	**Humidity (%)**
MONDAY	AM Max	21.8	4.5	20.2	69
	Min	17.4	1.3	14.8	33
	PM Max	20.2	3.6	19.3	57
	Min	18.4	1.3	16.7	43
TUESDAY	AM Max	21.6	4.0	20.1	60
	Min	15.0	0.4	15.0	30
	PM Max	22.4	3.1	21.9	39
	Min	19.0	1.3	19.0	33
WEDNESDAY	AM Max	21.9	1.8	21.9	45
	Min	15.4	0.4	15.4	28
	PM Max	25.3	2.2	25.0	36
	Min	20.9	0.9	20.9	19
THURSDAY	AM Max	22.4	4.0	21.0	56
	Min	15.1	0.4	15.1	23
	PM Max	23.3	4.5	21.7	53
	Min	15.8	1.8	14.9	20
FRIDAY	AM Max	13.8	4.9	13.2	48
	Min	9.1	1.8	5.6	33
	PM Max	14.9	5.4	13.6	48
	Min	12.9	0.9	8.9	29
SATURDAY	AM Max	18.1	0.9	18.1	57
	Min	11.7	0.0	11.7	26
	PM Max	20.9	2.2	20.9	35
	Min	18.8	0.4	18.4	21

(AM : 08:00 - 11:30; PM : 14:00 - 17:30; Max - maximum; Min - minimum)

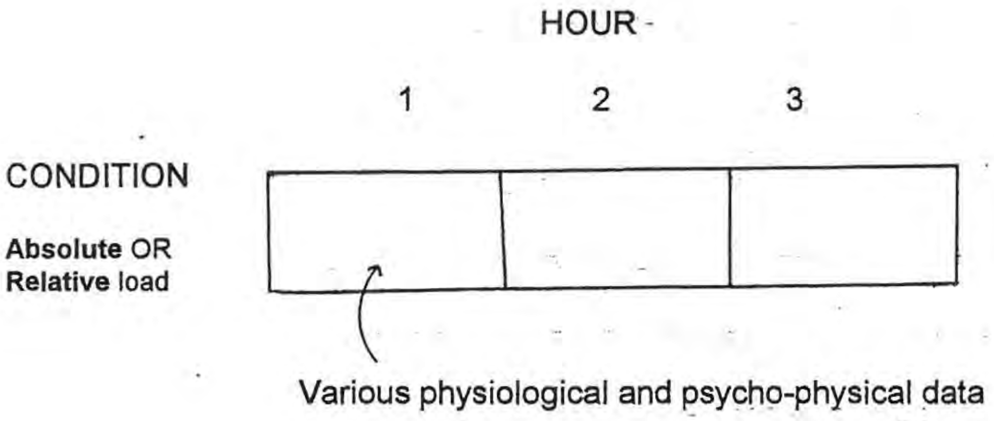
STATISTICAL ANALYSIS

The Statgraphics (Version 6.1) package was used in order to statistically analyse the data. As a first step basic descriptive statistics relative to the variables assessed were gathered, providing general information concerning the sample (See Appendix C for example of relevant print-out).

EXPERIMENTAL DESIGN

This investigation involved a study of the cumulative effect of a 12 km march. Several physiological and psycho-physical measures were taken on the same subject during each march enabling the researcher to study the effect of march duration on the various parameters investigated. One-way ANOVAs were calculated to determine whether there were differences during the three hours of marching.

Tests of normality of data and homogeneity of variance showed that parametric statistics were appropriate. Accordingly, parametric ANOVAs were computed for the assessment of cardiovascular and psycho-physical responses of the **General** group to load carriage over a 12 km route **in situ**. However, the small sample size (n=10) and non-normality of the detailed physiological data collected on the **Metabolic** study group meant that the non-parametric equivalent, the Kruskall-Wallis Test, was more appropriate. Finally, Pearson's correlations (r) was obtained to examine if there was a relationship between heart rate responses and corresponding RPE.



CONFIDENCE LEVEL

The 0.05 level of probability was employed throughout the statistical treatment of the data of the present study for testing the significance of differences and the relationship within the data. Therefore, any conclusions based on the results of these analyses must bear in mind that there were still five chances out of one hundred 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, where the probability of committing a Type II error is lower at the 0.05 level than at a higher level of probability. Thus, the larger the sample population the lower the chance of failing to reject a false hypothesis. However, the logistics of organising appropriate subjects, and the temporal demands of data collection kept the subject numbers relatively low in the present investigation.

Hence, in relation to Type I and II errors, considering the inherent variability of parameters under investigation, and the limitations related to subject availability, the choice of 0.05 level of confidence was considered a reasonable and acceptable level.

CHAPTER IV

RESULTS AND DISCUSSION

INTRODUCTION

The purpose of the present study was to form a basis for the feasible determination of optimum infantry loads consistent with post-march combat-readiness of the South African National Defence Force.

Each human tends to respond to any given stimulus according to unique, personal constraints enforced by factors such as genetic endowment, morphological structure and psycho-social background. It follows that differences in body shape and size may exert a significant influence upon a soldiers response to load carriage in a military situation. Consequently, a thorough understanding of load carriage in the SANDF must necessarily include examination of those differences in morphology that may partially account for variations inherent in the responses typical of a soldier.

A field march under two conditions was investigated and the loads carried for each were selected by Army personnel of the Base where data were collected. The **Absolute** load (inclusive of clothing) comprised of 40.5 kg, identified as an "average" load, and was carried for 12 km marching at a speed of 4 km.h^{-1}. The **Relative** load was selected as equivalent to 37% of body mass, which was within the generally suggested load of between 33% (a third of body mass) and 40% of body mass. This relativised load was carried by the same subjects over the same course, at the same marching speed.

Relativisation of the external load to a morphological characteristic such as body mass is an effective means of minimising the inter-individual variability that exists regarding the energetics of load carriage. The above conditions constituted sub-maximal exertion levels, the aim being to establish baseline information relevant to the present SANDF foot-soldier.

The present investigation focussed on the changes in soldiers' responses to two loads carried over three consecutively-run one-hour marches. Physiological and perceptual data collected in the first hour were compared to responses from the second and third hours of physical exertion. Although an integrated interdisciplinary approach to the understanding of load carriage in the SANDF was a critical objective of this project, for convenience and clarity of presentation of the data, the results of the physiological and psycho-physical domains were critically analysed in isolation and are initially presented separately. The results are integrated and discussed more fully in the final *Integrated Discussion*.

PHYSIOLOGICAL VARIABLES

CARDIAC RESPONSES OF THE GENERAL GROUP

Cardiac responses prior to, during and after the experiments were recorded on all 43 subjects. "Reference" heart rates were recorded as baseline measures since variations in emotional state and anticipation of the pending activity are known to significantly affect cardiovascular responses, thus making it difficult to obtain true resting values for heart rate (McArdle **et al.**, 1996). The mean "reference" heart rates for this sample were the same during both testing conditions, 73.93 (±7.28) bt.min^{-1} under **Absolute** loading and 73.21 (±8.11) bt.min^{-1} under **Relative** loading conditions.

Immediately prior to the testing conditions "anticipatory" heart rates were recorded. It is evident from Figure 22 that the "anticipatory" heart rates recorded before the soldiers commenced marching were significantly higher than the reference heart rates, supporting McArdle **et al.** (1996) who reported that there would be an elevation in heart rate preceding participation in a demanding activity. This was probably the result of both an increase in sympathetic discharge and a reduction in vagal tone as the soldiers were likely to have experienced some apprehension as they prepared for the march where data were collected. "Anticipatory" heart rates prior to Condition 1, where soldiers marched 12 km with an **Absolute** load of 40.5 kg, were nominally higher than those recorded prior to the start of Condition 2, which had the same soldiers marching the same route with a **Relative** load of 37% body mass. Thus there soldiers appeared to have experienced more trepidation with the expectation of a heavier absolute load.

"Recovery" heart rates were recorded at the completion of the 12 km march. It is evident from Figure 22 that "recovery" heart rates returned to "reference" heart rate values under both **Absolute** and **Relative** conditions. The mean "recovery" heart rates after Condition 2 were nominally lower than those recorded after Condition 1, suggesting that Condition 2, where the subjects carried 37% of their body mass, was less physically stressful to the soldiers. Further evidence of the limited physical demands of the march in general was provided by the rapid reduction of heart rates after the hill march and over the steady decline of the terrain towards the end of the 12 km march.

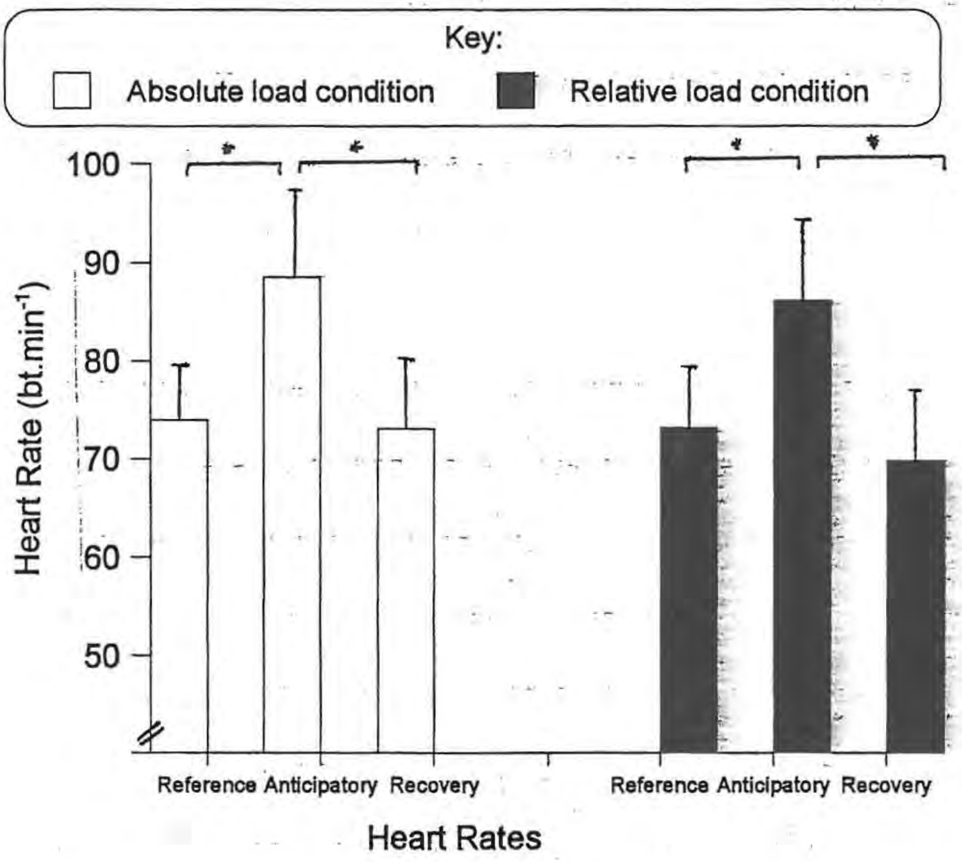


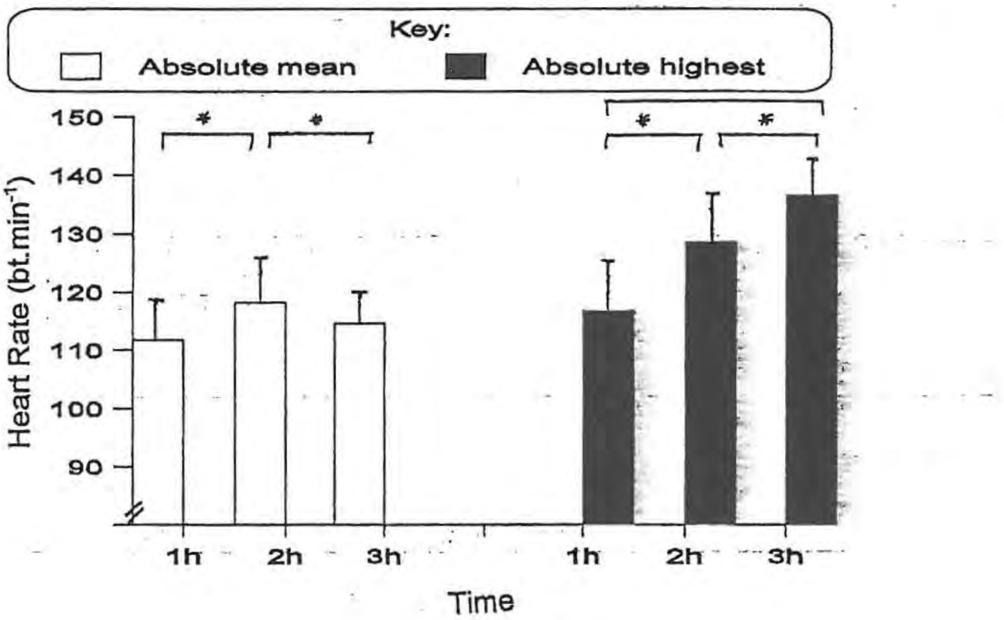
FIGURE 22 : Heart rate data of the **General** study group, recorded prior to and after march under the **Absolute** and **Relative** load conditions.

(* denotes significant difference at $p<0.05$)

Significantly higher "working" heart rates were registered briefly during the second hour where the uphill terrain appeared to be most taxing section of the march. During this spell "working" heart rates reached 70% of maximal under **Absolute**, and 65% of maximal under **Relative** loads. This is a typical biological response to increments in work intensity, and is the result of the workload related stress placed upon the myocardium as it strives to deliver sufficient amounts of oxygen saturated blood to the active musculature (Åstrand and Rodahl, 1977; McArdle **et al.**, 1996). The highest heart rates of 138 bt.min^{-1} and 123 bt.min^{-1}, under Conditions 1 and 2 respectively, were recorded in association with the steepest gradient at 1.5 km into the last 4 km segment. The overall pattern of "working" heart rates was 50% to 60% of age-predicted maximal rates during both conditions and there appeared to be a limited cumulative effect over the three-and-a-half-hours.

Brouha (1967) suggested that mean heart rates over an 8 h industrial work shift should not exceed 110 bt.min^{-1} since cumulative fatigue is likely to ensue. Mean "working" heart rates, presented in Figure 23, indicate that the subjects were not severely physically taxed and that the loads imposed a sub-maximal demand on them. "Working" heart rates recorded during the march with a load of 37% of body mass followed the same trend as heart rate responses under **Absolute** loading conditions, but at lower values. This lends further credence to the assumptions previously made that less robust subjects are more severely taxed at any given absolute load than their heavier counterparts. This energetic advantage accorded to the heavier subjects prevailed despite the fact that there were no significant differences reported in the "reference" heart rate between Condition 1 and Condition 2. In other words, despite a relative parity with respect to the level of physical conditioning, the lighter soldiers tended to be more severely taxed than were their heavier counterparts when the load was expressed in absolute terms.

(a) Absolute Loading Condition.



(b) Relative Loading Condition.

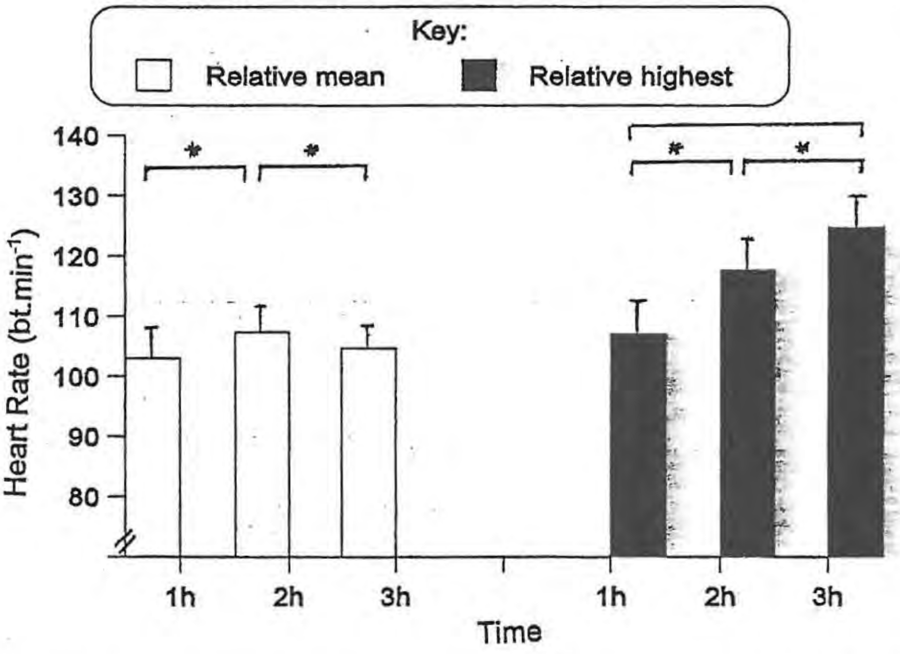


FIGURE 23 : "Working" heart rates of **General** study group collected during each hour for (a) **Absolute** and (b) **Relative** loading.

(* denotes significant difference at $p<0.05$)

An important finding was that the variability of "working" heart rates was substantially reduced by approximately four points when a subject was carrying loads relative to his own body mass. This gives an indication that individuals were differentially more taxed when required to carry the same load of 40.5 kg; while heart rate responses were less diverse when carrying a load relative to the individual's body mass.

RESPONSES OF THE METABOLIC STUDY GROUP

Ten soldiers were randomly selected from B Company for detailed physiological assessment using the Metamax, a portable ergospirometer with associated cardiac, respiratory, metabolic and thermo-regulatory technology. These subjects comprise the **Metabolic** study group and the following physiological data relates to this specific group. Heart rate responses have been presented and discussed in conjunction with the **General** study group since these data were recorded on all 43 subjects. The detailed ventilatory and energetic information was collected for 5 min, near the completion of each hour, and are therefore taken as representative of the cumulative effect of the hour's march.

Changes in Subject Characteristics

The **Metabolic** study group (n=10) were subjected to Bioelectrical Impedance Analysis pre- and post-marching conditions in an attempt to assess the changes in body composition after a 12 km march. The group began the marches at an average 15.62% body fat and ended at 13.91% body fat, representing a nominal reduction in fat content as a result of participation in a three-and-a-half-hour march. At low-moderate power as a result of participation in a three-and-a-half-hour march. At low-moderate power output levels involving sub-maximal aerobic exertions over protracted periods it is fat that is preferentially metabolised as an energy source. Little can be said, however, in this regard, because the subjects were healthy, young adults (Refer to Table V) sufficiently seasoned to be able to handle 12 km marches under relatively light loading with water provision **ad libitum**, and walking at a relatively slow pace with substantial rest breaks at the completion of the first and second hours. Such levels of exertion were insufficiently taxing to elicit significant energetic effects.

Ventilatory Responses

An increase in physical demands affects oxygen consumption and carbon dioxide production where an increase in ventilation is needed to maintain the proper alveolar gas concentrations to allow for the increased exchange of oxygen and carbon dioxide (Åstrand and Rodahl, 1977; Berger, 1982; McArdle **et al.**, 1996).

While breathing, oxygen continuously moves from the external air into the blood via the alveoli, while carbon dioxide constantly moves from the blood into the alveoli and is expired. Several investigators (Åstrand and Rodahl, 1977; Berger, 1982; Kilbom, 1995; Tortora and Anagnostakos, 1990; McArdle **et al.**, 1996) have established that this breathing cycle is repeated approximately 12 times each minute in resting adults.

During the **Absolute** load condition, the mean breathing frequency (f_b) for the first and third hours was 32 br.min^{-1}. This is approximately three times greater than the rate of breathing reported at rest. In addition, during the uphill conditions of the second hour, a 13% increase was recorded. This increment is characteristic of any increase in work intensity, as greater volumes of air need to be inspired in order to furnish the individual the increased demand of oxygen required to "fuel" the exercising muscles. The highest f_b of 42 (±4.79) br.min^{-1} during **Absolute** loading was recorded in association with the steepest hill in the third hour.

With respect to the **Relative** loading, the breathing frequency responses recorded during the first hour were lower than those measured in the second hour. There was an increase in mean f_b during the second and third hours of data collection. This is a typical response to increased work intensity, since the respiratory centre increases both the depth and rate of breathing in an attempt to cope with the increased demand for oxygen by the working muscles (McArdle **et al.**, 1996). A maximum 34 (±5.29) br.min^{-1} was recorded in association with the peak in positive gradient near the start of the third 4 km, that is, at the same time at which responses peaked in the **Absolute** 40.5 kg load condition. However, there was almost a 50% reduction in variability, an indication that relativised load carriage tends to stress the soldiers in a more uniform manner.

Table VIII shows the mean breathing frequency recorded from the **Metabolic** study group while marching 12 km at 4 km.h^{-1} with two different loads. In order to show the inter-individual variability of responses the coefficients of variations are also presented with the mean and standard deviation. As an indication of the differences in variability between the conditions, the reduction in variability of responses are also included.

TABLE VIII : Comparison of mean breathing frequency during three hour march under the **Absolute** and **Relative** loading conditions.

HOUR	BREATHING FREQUENCY (f_b) (br.min^{-1})		Reduction in variability of responses (%)
	Absolute Load	**Relative Load**	
First	31.70 (3.69) [11.63] *	27.01 (2.65) [9.83]	28.18
Second	36.36 (5.98) [16.44]	29.71 (3.19) [10.74]	46.66
Third	32.00 (4.39) [13.72]	28.31 (3.04) [10.74]	30.75
Overall	33.42	28.34	35.20

(Figures in ( ) = standard deviation; [ ] = coefficient of variation ; * denotes significant difference at $p< 0.05$)

It is evident from Table VIII that responses during the **Relative** load conditions mirrored those of the **Absolute** load condition but, because the demands were less, the trends occurred at an average of 14% reduction in breathing frequency. There was a tendency for inter-individual variability of responses to decrease by 35.20% when loads were normalised for body mass of the carrier. This reiterates the tendency of the lighter subjects to be more severely taxed than were their heavier counterparts when the load was expressed in absolute terms.

Åstrand and Rodahl (1977) define tidal volume ($\dot{V}_T$) as the amount of air moved into and out of the lungs with each normal breath. Furthermore, the same authors suggest that the tidal volume for a young male adult at rest is almost 0.50 L. Table IX depicts the mean $\dot{V}_T$ for the ten soldiers subjected to detailed physiological assessment while marching with two different loads.

TABLE IX : Comparison of mean tidal volume during 12 km march under **Absolute** and **Relative** loading.

HOUR	**TIDAL VOLUME ($\dot{V}_T$) (L)**			**Reduction in variability of responses (%)**
	Absolute Load	**Relative Load**		
First	1.68 (0.34) [20.24]	1.09 (0.24) [22.02]	*	29.41
Second	1.62 (0.36) [22.22]	1.41 (0.27) [19.15]	*	25.00
Third	1.36 (0.32) [23.53]	1.07 (0.16) [14.95]		50.00
Overall	1.55	1.19		34.80

(Figures in ( ) = standard deviation; [ ] = coefficient of variation ; * denotes significant difference at $p < 0.05$)

The tidal volumes recorded while the subjects marched with the 40.5 kg load progressively decreased with time. The highest $\dot{V}_T$ was 2.11 (±0.70) L under **Absolute** loading and this correlated to the undulating terrain in the second hour of data collection. The 1.36 (±0.32) L measured in the third hour was the lowest mean tidal volume recorded over the three hours of physical exertion. This suggests that, despite the steepest hill at the start of this 4 km section, the soldiers experienced little or no physical strain when marching over the final open plain.

During the **Relative** loading condition, the responses from the second hour were significantly higher than those from the first or third hours of marching. This is possibly because the infantrymen experienced most physical demands with the uneven terrain. The $\dot{V}_T$ peaked at 1.97 (±0.99) L in the second hour of testing, and was the result of the increased workload demands as the soldiers progressed over the strenuous rolling hills.

The mean 12 km tidal volume response was about 21% lower under **Relative** loading. In addition, the variability of responses was almost 35% less when taken over **Relative** rather than **Absolute** loading. This observation further supports the presumption previously made that smaller, less robust subjects are more severely taxed than their taller, heavier counterparts when carrying absolute loads.

The minute volume ($\dot{V}_E$) is the product of the rate of breathing and depth of breathing (McArdle **et al.**, 1996). Accordingly, increments in the $\dot{V}_E$ may be facilitated by either an increase in frequency or depth of ventilation (or both). Table X represents the mean minute volumes for the **Metabolic** study group when marching with two different loads. When marching with the **Absolute** load the mean $\dot{V}_E$ recorded during the second hour was significantly higher than those measured in the first or third hours of data collection. This was due to the increased breathing frequency and depth of breathing, brought about in response to the strenuous physical exertion associated with the demand of the uneven terrain. Since the soldiers experienced moderately intense conditions, breathing frequency and depth of breathing contributed equally to the workload imposed increase in ventilatory volume.

TABLE X : Comparison of mean minute ventilation over three hour march under the **Absolute** and **Relative** load conditions.

HOUR	**MINUTE VENTILATION ($\dot{V}_E$) (L.min^{-1})**		**Reduction in variability of responses (%)**
	Absolute Load	**Relative Load**	
First	39.14 (4.59) [11.73]	33.66 (3.87) [11.41]	15.69
	*	*	
Second	46.83 (8.55) [18.26]	39.51 (5.88) [14.88]	31.23
	*	*	
Third	40.40 (5.87) [14.52]	32.86 (4.87) [14.82]	17.04
Overall	42.12	35.34	21.32

(Figures in ( ) = standard deviation; [ ] = coefficient of variation ; * denotes significant difference at $p < 0.05$)

It might be postulated that, had very intense physical demands, requiring anaerobic metabolism, been included in this research, the depth of breathing would ultimately have plateaued, requiring the frequency of breathing alone to increase in order to facilitate the increment in ventilatory volume. The terrain was fairly flat during the first and third hours of testing, except for the steepest hill at the start of the third hour. This might account for the absence of a significant difference between ventilatory responses during the first and the final 4 km where 39.14 (±4.59) $L.min^{-1}$ and 40.40 (±5.87) $L.min^{-1}$ were recorded respectively.

With reference to the **Relative** loading, 39.51 (±5.88) $L.min^{-1}$ recorded in the second section was significantly higher than 33.66 (±3.87) $L.min^{-1}$ and 32.86 (±4.87) $L.min^{-1}$ registered during the first and final 4 km respectively. Again, these observations are probably due to the increased demands of the rough, challenging uphill terrain.

During the **Relative** load condition, ventilatory responses mirrored those of the **Absolute** load condition but, because the demand was less the trends occurred at a substantially reduced level. There was a 17% reduction in minute ventilation: an average of 35.34 $L.min^{-1}$ air moved under the **Relative** load condition versus an average of 42.12 $L.min^{-1}$ under the **Absolute** condition. In addition, matching loads relative to the carrier's own body mass had the effect of causing a 23.3% decrease in inter individual variability of response.

The data presented in Table XI demonstrate the mean highest $\dot{V}_E$ recorded during a three hour march under the two conditions. The present results indicated that the soldiers experienced similar strain during the first and third hours of physical exertion. The peak responses for the first and third hour were 46.78 (±6.06) $L.min^{-1}$ and 46.30 (±5.94) $L.min^{-1}$ when marching with the 40.5 kg load, while 37.42 (±4.85) $L.min^{-1}$ and 38.28 (±4.77) $L.min^{-1}$ with a load of 37% of body mass. For both load conditions there was approximately 10.00 $L.min^{-1}$ increase in the second hour. These significantly higher ventilatory responses were due to the terrain, where the soldiers were challenged by the undulating conditions of this section which also included two sections with marked increases in gradient.

TABLE XI : Comparison of highest minute ventilation over three hour march under the **Absolute** and **Relative** load conditions.

HOUR	MINUTE VENTILATION ($\dot{V}_E$) (L.min^{-1})		Reduction in variability of responses (%)
	Absolute Load	**Relative Load**	
First	46.78 (6.06) [12.95]	37.42 (4.85) [12.96]	19.97
	*	*	
Second	57.98 (7.38) [12.73]	48.90 (4.60) [9.41]	37.67
	*	*	
Third	46.30 (5.94) [12.83]	38.28 (4.77) [12.46]	19.70
Overall	50.35	41.53	25.78

(Figures in ( ) = standard deviation; [ ] = coefficient of variation ; * denotes significant difference at $p < 0.05$)

Oxygen Consumption Responses

Oxygen consumption ($\dot{V}O_2$) data were collected on ten subjects while marching under two conditions in which the load was varied. It is widely accepted that body mass is the single most important determinant of locomotor energy cost, and that there exists a linear relationship between the mass of the subject and the energy required to move at a given rate (Miller and Blyth, 1955; Wyndham **et al.**, 1971). Thus at any given locomotor speed, heavier subjects consume oxygen at a higher rate than do their smaller counterparts. An effective means of reducing this mass-specific variability in locomotion oxygen cost is to express the energy expenditure in units relative to body mass ($m\ell.kg^{-1}.min^{-1}$). This relativisation of locomotor $\dot{V}O_2$ effectively reduced the inter-individual variability in energy expenditure reported at any given work intensity (Åstrand and Rodahl, 1977; McArdle **et al.**, 1996).

TABLE XII : Oxygen consumption during the 12 km march.

HOUR	OXYGEN CONSUMPTION ($\dot{V}O_2$) ($m\ell.kg^{-1}.min^{-1}$) Absolute Load	OXYGEN CONSUMPTION ($\dot{V}O_2$) ($m\ell.kg^{-1}.min^{-1}$) Relative Load	Reduction in variability of responses (%)
First	25.11 (2.58) [10.28]	19.95 (2.44) [12.23]	5.43
Second	27.60 (3.66) [13.26]	23.14 (2.90) [12.53]	20.77
Third	22.72 (3.19) [14.04]	18.00 (2.18) [12.11]	31.67
Overall	25.14	20.36	19.29

(Figures in ( ) = standard deviation; [ ] = coefficient of variation ; * denotes significant difference at $p < 0.05$)

Statistical analyses revealed significant differences ($p<0.05$) in oxygen consumption between the first and third hours, and the second and third hours under the **Absolute** load carriage condition. During **Relative** load carriage, $\dot{V}O_2$ responses from the second hour were statistically higher than during the first and third hours of marching. In other words, the foot-soldiers tended to be more severely taxed by the challenging, uphill terrain, and were consequently seen to consume oxygen at higher rates.

A tendency for the oxygen consumption to increase with gradient was evident from responses during the second hour of marching. In both **Absolute** and **Relative** loading conditions the highest $\dot{V}O_2$ of 33.35 (±4.83) $m\ell.kg^{-1}.min^{-1}$ and 31.71 (±4.56) $m\ell.kg^{-1}.min^{-1}$ respectively, were recorded during the second hour in response to the steady uphill limb over this 4 km segment. However, the steady downhill or level gradient over the last 20% of the course resulted in a 22% decrease in $\dot{V}O_2$ responses under Condition 1 and a 28% decrease with subjects carrying a **Relative** load of 37% body mass.

It is customary to determine the intensity of work in MET units, defined as a multiple of the resting metabolic rate. The MET is expressed in terms of oxygen consumption per unit of body mass; 1 MET being approximately 3.50 $m\ell.kg^{-1}.min^{-1}$.

TABLE XIII : MET equivalents for **Absolute** and **Relative** loading.

	MET Equivalent	
	Absolute Load	**Relative Load**
First Hour	7.17	5.70
Second Hour	7.89	6.61
Third Hour	6.49	5.15
Overall	7.18	5.82

The average output under the **Absolute** loading was 7.18 MET and under the load-relativised condition, 5.82 MET. According to a five-level classification system from McArdle **et al.** (1996) these values are categorised as "heavy" and "moderate" respectively. Thus the relativisation of loads to the carrier body mass appears to decrease the demands placed on the soldiers, particularly in the case of the light, less robust subjects.

All conditions involved sub-maximal tests conducted **in situ** at the Infantry School at Oudtshoorn, and although the maximal $\dot{V}O_2$ responses of these soldiers were not measured, the foot-soldiers were comparable in physical status to the miners of diverse ethnic groups studied by Wyndham and associates (1962). The $\dot{V}O_2$max of these miners was 49 mℓ.kg^{-1}.min^{-1}. This suggests that the MET outputs of the present study probably equate to 51.3% $\dot{V}O_2$max for the **Absolute** loading, and 41.6% of $\dot{V}O_2$max during the **Relative** load condition. These values fall within the acceptable sustained workload range of between 40-50% proposed by Myles and Saunders (1979). However, in the same year Saha and colleagues disagreed with the above suggested range and argued that for an 8 h shift a reasonable workload should not exceed 35% of $\dot{V}O_2$max, corresponding to 18 kJ.min^{-1} and heart rates of 110 bt.min^{-1}.

It seems evident that the loads and pace in the present study were not physically taxing for a 12 km route march, but cumulative fatigue effects may have been elicited had the distance been longer with rest breaks less in number and of shorter duration.

Carbon Dioxide Production

As with $\dot{V}O_2$, significant increases in $\dot{V}CO_2$ were revealed during the second 4 km phase of data collection for both **Absolute** and **Relative** loads. This observation is characteristic with an increased work intensity since there is an increase in metabolic activity as the body attempts to maintain physiological homeostasis under physically demanding situations. When marching over the final segment of the 12 km route with a **Relative** load, the $\dot{V}CO_2$ were significantly lower ($p<0.05$) than the previous two hours. This emphasises the extent of the recovery effect the open, flat terrain of this section had on physiological responses.

TABLE XIV : Carbon dioxide production during the 12 km march.

HOUR	**CARBON DIOXIDE PRODUCTION ($\dot{V}CO_2$) (mℓ.kg^{-1}.min^{-1})**					**Reduction in variability of responses (%)**
	Absolute Load		**Relative Load**			
First	22.39 (1.94) [8.66]		18.03 (1.31) [7.27]			32.47
Second	24.54 (3.00) [12.22]	*	20.73 (1.99) [9.60]	*	*	33.67
Third	20.54 (1.91) [9.29]		14.91 (1.71) [11.47]			10.47
Overall	22.49		17.89			25.54

(Figures in ( ) = standard deviation; [ ] = coefficient of variation ; * denotes significant difference at $p< 0.05$)

The response of $\dot{V}CO_2$ to increments in loads tends to be closely paralleled by other physiological variables. The $\dot{V}CO_2$ for example, increased with the increment in load from a percentage of body mass to an **Absolute** 40.5 kg. Again, this is a typical biological response to any increase in exercise intensity, in as much as that CO_2 is recognised as the metabolic end-product of cellular oxidation (Åstrand and Rodahl, 1977; McArdle **et al.**, 1996).

Respiratory Exchange Ratio

Respiratory exchange ratio (R) averages 0.82 under basal conditions for young male adults (Åstrand and Rodahl, 1977; Kilbom, 1995; McArdle **et al.**, 1996). Furthermore, the same authors suggest that there is no change in R during moderate work, but after one minute of severe exercise, the R may be as high as 1.50, because of over-breathing after exercise, and the buffering of lactic acid by sodium bicarbonate.

The R as reported throughout the **Absolute** and **Relative** loads were not significantly different. In other words, at any given hour of marching the ratio of carbon dioxide produced to oxygen consumed ($\dot{V}CO_2 \div \dot{V}O_2$) was approximately constant. Further, it is evident in Figure 24 that the R tended to remain relatively stable despite the cumulative effects of marching, but that it increased nominally during the **Relative** loading as compared to the **Absolute** loading condition. However, as reported in previous research investigating the energetics of human locomotion (Rorke, 1985; Candler, 1986; Goslin, 1987) the R at any given condition is highly variable and may be significantly influenced by factors such as the dynamic action of a pre-test meal and/or the subject's state of rest (both of which are difficult to control).

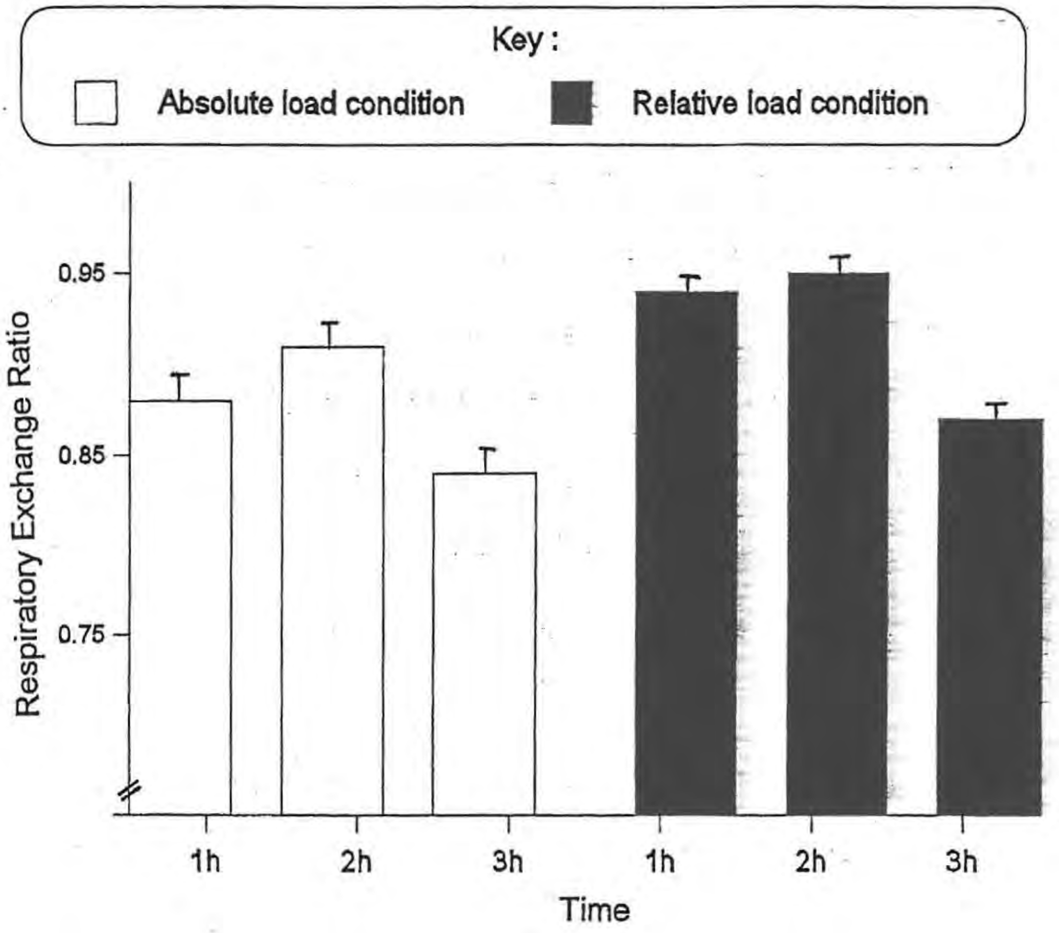


FIGURE 24 : Respiratory Exchange Ratio under **Absolute** and **Relative** loads.

Energy Expenditure

Customarily sub-maximal oxygen uptake is expressed in mℓ.kg^{-1}.min^{-1}, a rate of O_2 demand per unit mass of the mover. Similarly, the metabolic energy expenditure (EE) of load carriage is expressed here in terms relative to total load (body mass plus external load) moved since the subject expends energy to move himself as well as any extraneous loads being carried. All references to total load in the discussion that follows are expressed as "Σkg".

There exists a plethora of studies that classify work limits and recommend guidelines for acceptable workloads in varying task situations. For example, working within a 40% to 50% range of $\dot{V}O_2max$ (Myles and Saunders, 1979) is considered "normal" for an 8 h shift. However, these classifications and recommendations apply in a specific context and are subjective; what one researcher categorises as "heavy" work may be rated as "light" by another. Thus caution is advised when comparing data to previously developed guidelines.

TABLE XV : Mean metabolic energy cost of the route march, with SD in brackets.

	Mean Energy Cost	
	Absolute Load	**Relative Load**
kJ.min^{-1}	37.07 (0.98)	30.02 (0.62)
kJ.Σkg^{-1}.min^{-1}	0.33 (0.04)	0.29 (0.28)
kcal.min^{-1}	8.86 (0.37)	7.17 (0.28)
kcal.Σkg^{-1}.min^{-1}	0.08 (0.03)	0.07 (0.02)
W	618.28 (0.84)	500.35 (0.71)
W.Σkg^{-1}.min^{-1}	5.43 (0.29)	4.96 (0.35)

According to a five-level classification system used by McArdle **et al.** (1996) and relative to untrained subjects, the energy expended during the **Absolute** load condition would be classified as "heavy", whereas the values from the **Relative** loaded condition represent "moderate" work. These same authors listed energy requirements in household, recreational and sports activities. The data from the present study show that the cost of marching 12 km at 4 km.h^{-1} is approximately 3 to 5 times (**Absolute** and **Relative** load conditions respectively) greater than standing quietly.

Furthermore, McArdle **et al.** (1996) found walking across fields and hillsides at a normal pace to cost 0.08 kcal.kg^{-1}.min^{-1}. However, these represent values of unloaded subjects while the soldiers in the present investigation carried two different loads. It can be assumed that marching with loads would result in an increase in energy cost. Since the average energy costs for the soldiers marching under experimental conditions of the present study are the same as the value cited by McArdle **et al.** (1996), it appears that the soldiers experienced little or no physical strain.

Previous research has shown that work performed at less than 50% of maximal output (Åstrand and Rodahl, 1977) or energy expenditure of 500 W (Hughes and Goldman, 1970) could be sustained at a steady state over an 8 h period. The higher energy cost values with an **Absolute** load suggest that steady state would not be sustained. However, note should be taken that the present subjects were involved in a rest-broken 3.5 h session.

Under the **Absolute** load condition the heaviest subject, whose body mass was 98.40kg, carried a load of 41.15% of body mass, while the lightest subject (54.56 kg), under the same 40.5 kg load was carrying 74.23% of body mass. Clearly under **Absolute** loading conditions the load stress differential is considerably greater (1.86

times greater in the above case) for the lighter subject. Although these two subjects carried virtually the same load, the differential effects of this load are seen by the fact that the heavier subject was expending 0.27 kJ.Σkg^{-1}.min^{-1} while the lighter was expending 0.39 kJ.Σkg^{-1}.min^{-1}, a 44% increase.

Under the **Relative** loading the subjects each carried a load equivalent to 37% of body mass. In this case the lightest subject carried a load of 20.19 kg while the heaviest subject carried 36.41 kg, 1.80 times greater. With these loads, the heavier subject was expending 0.26 kJ.Σkg^{-1}.min^{-1} while the lighter was expending 0.34 kJ.Σkg^{-1}.min^{-1}, a 30% increase. It is of interest to note that the energy costs under the two conditions were similar for the heavier subject. He carried very similar loads: the **Absolute** load condition had him carrying 4.09 kg more than the **Relative** loaded condition. In contrast, relativising the load to body mass showed almost a 13% reduction in the physiological strain experienced. In this case, the soldier's load had been reduced by almost half of the load carried during the **Absolute** load condition. Figure 25 depicts the metabolic energy cost of the march under **Absolute** and **Relative** loading where both curves are on the same axis in an attempt to show the differences and/or similarities. The total load carried takes into account the carrier's body mass as well as the mass of the external load (40.5 kg and 37% of body mass for the two conditions respectively).

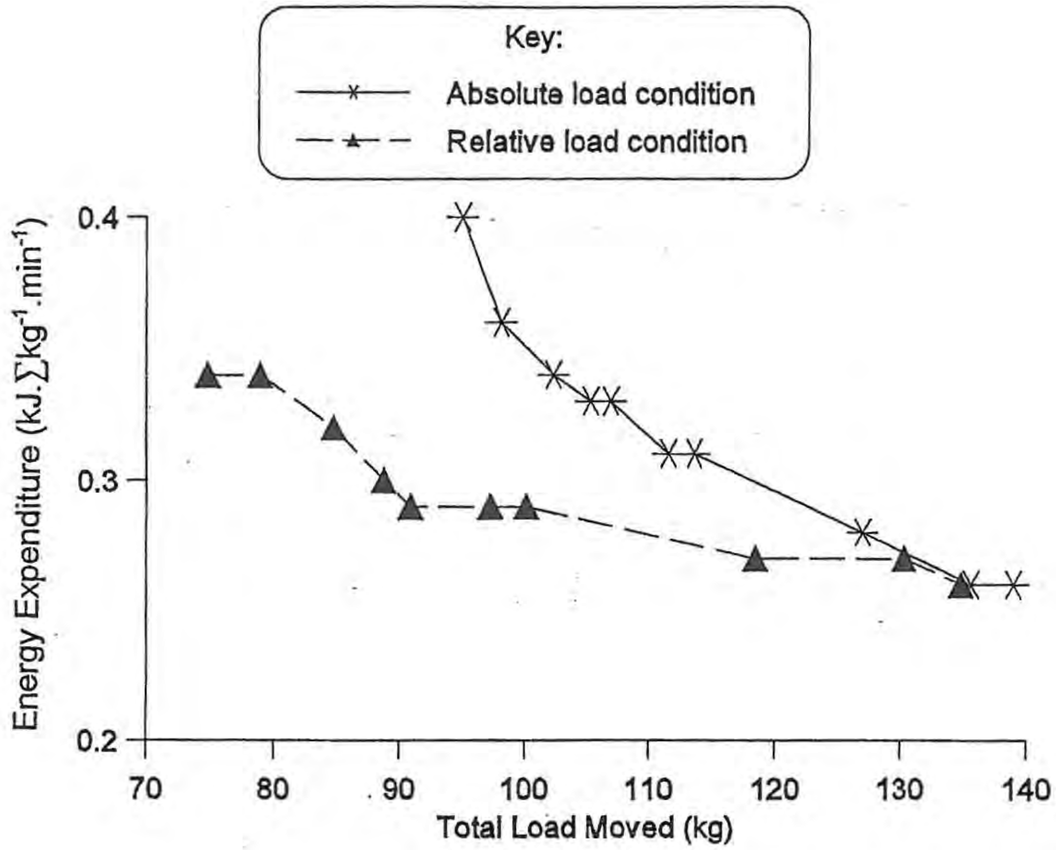


FIGURE 25 : Energy expenditure relative to body size during the **Absolute** and **Relative** loading conditions.

It is clear that, for the present data, the energy expenditure was higher at any **Absolute** load. In addition, the gradient for this curve was steeper; most probably due to the accentuated drop-off in energy cost of load carriage for the heavier individuals. The greater the total load mass (implying a more robust soldier), the lower the EE for both conditions. This was perhaps due to an increased efficiency of the soldier. However, at lower total loads (implying a more gracile morphology), there was an increased EE for both conditions. Furthermore, the differences between the conditions was greater when the total load moved was less than about 110 kg.

The reason for the higher energy costs of smaller carriers is seen in the comparison of stresses faced by the smallest and largest subjects under investigation. The smallest soldier was carrying nearly 75% of body mass and the largest carried almost 42% of body mass, even though they carried identical 40.5 kg loads. The effect of normalising the total external load carried to the body mass of the carrier is to even-out the metabolic energy expended by the platoon as a whole over the march, thereby ensuring that the lighter-weight soldier is not more physically taxed and therefore less combat-ready at the end of a gruelling forced march. Thus in the **Relative** condition all subjects carried 37% of personal body mass in an attempt to standardise the level of physical stress experienced by each individual within the group.

Skin Temperature Responses

In an attempt to assess the thermo-regulatory systems during three hour exertion under two different load conditions, skin temperature was monitored at two key locations. One was on the posterior aspect of the trunk, over the *erector spinae* and the other on the anterior of the trunk, over the *pectoralis major* region.

Skin temperatures measured at *erector spinae* while marching 12 km with the **Absolute** 40.5 kg load showed no difference over 3 h. Several investigators report an increase in body heat during exercise, since a large proportion of energy produced is converted to heat (Berger, 1982; Kilbom, 1995). However, a major part of this heat must be dissipated because human tissues have a limited range of temperature tolerance (Kilbom, 1995). The excess heat is carried in the blood to the body surface where the heat is transferred to the environment and results in the cooling of the body surface. This might account for the lower skin temperatures recorded after the third hour when compared to back temperatures collected during the first and second hours of data collection.

TABLE XVI : Comparison of skin temperatures during the three hour march.

HOUR	SKIN TEMPERATURE (°C)				Reduction in variability of responses (%)	
	Absolute Load		Relative Load		Back	Chest
	Back	Chest	Back	Chest		
First	36.31 (0.54) [1.49]	34.63 (1.36) [5.37]	35.46 (0.52) [1.46]	33.89 (1.59) [4.69]	3.70	14.52
Second	36.27 (0.60) [1.65]	34.46 (1.21) [3.51]	34.44 (3.54) [9.96]	33.80 (0.94) [2.78]	-490.00	22.31
Third	35.62 (0.69) [1.94]	32.76 (1.66) [5.07]	34.73 (0.92) [2.36]	31.70 (0.93) [2.94]	-33.31	43.98
Overall	36.07	33.95	34.88	33.13	-	26.94

(Figures in ( ) = standard deviation; [ ] = coefficient of variation ; ES - erector spinae and PM - pectoralis major ;
* denotes significant difference at $p< 0.05$)

Back temperature recorded with the **Relative** load showed no significant differences with time. These responses suggest that the physical or physiological strain experienced by the soldiers was not of sufficient magnitude to increase skin temperatures, and that they were able to maintain homeostasis without a notable increase in sweat production as a cooling mechanism. *Erector spinae* skin temperatures averaged 36.07°C under **Absolute** and 34.88°C under **Relative** loading, a nominal condition related reduction when loads were matched better to the individual subjects body mass.

The present results for *pectoralis major* skin temperatures revealed nominally lower values for the third hour, under both **Absolute** and **Relative** load conditions. Chest temperatures averaged 34°C under **Condition 1** and did not vary much from **Relative** loading. However, there was almost a 26% reduction in inter-subject variability of response when loads were relativised to 37% body mass.

Regardless of loading condition, however, back skin temperatures exceeded chest skin temperatures by virtue of less constrained air flow across the chest. Johnson **et al.** (1995) suggest that load served as a barrier to heat-loss by means of reduced evaporation of sweat in the region, thereby impairing thermo-regulation. The reduction approximated 5% regardless of conditions or stage in the march. Haisman and Goldman (1974) reported that the amount of air movement is reduced at the back because of the backpack, so heat elimination is reduced and thus skin temperatures increase.

PSYCHO-PHYSICAL VARIABLES

RPE OF THE GENERAL GROUP

It is believed that the demands of the situation are not the prime determinants of how an individual responds, but rather that the individual's perception of the event plays a key role. However, as a general rule, physiological parameters are more reliable and more readily and objectively measured. It is therefore necessary to include both physiological and perceptual responses, and a monistic view of humans requires regarding him as a psychosomatic unit (Borg, 1978); thus in order to fully understand the complexities of human reasoning and functioning, there is a need for an holistic approach.

There is no doubt that the same event or physical demands can be, and indeed are, perceived very differently by individuals in different situations. Strain experienced by an individual in any situation is a personal, subjective response which is dependent on how the individual perceives the stress imposed by the situation. Borg's (1970) Rating of Perceived Exertion scale was used in the present investigation in order to gain greater insight into perceptions of the physical demands of a 12 km route march with two different loads. RPE were recorded for the **General** group (n=43) every 15 min, when soldiers were required to rate "local" (lower limb) and "central" (cardiovascular) perceived exertion.

During **Absolute** loading, "local" ratings of perceived exertion showed an average increase from 10 (Very Light - Fairly Light) in the first hour, to 11 (Fairly Light) in the second and third hours of marching. The flat terrain encountered during the first hour of marching might account for the low ratings of perceived exertion in the lower limbs and there appeared to be little cumulative effect over the three hours, implying that the rest-to-work ratios implemented by the Army were, under these conditions, effective.

The highest RPE for the "local" rating of the lower limbs ranged from 11 to 17 (Very Hard), and were associated with the highest heart rates of 138 $bt.min^1$ recorded during ascent of the steepest hill at the start of the third hour. This range of responses may be due to the shortest soldier carrying 78% of body mass while the tallest carried 43% body mass, even though they carried identical 40.5 kg loads. Similar responses were evident for the "local" ratings during the steep uphill: the smallest soldier reported 17 (Very Hard), compared to 12 (Fairly Light - Somewhat Hard) by the largest soldier. Although there was no significant cumulative effect, there was greater inter-individual variability in RPE for the final hour. The underlying assumption here is that the more gracile subjects were disadvantaged relative to their more robust counterparts under this load condition. Also, the present data suggest that significant increments in the intensity (due to the uneven terrain) were in fact consciously monitored by the soldiers and accurately reported in their psycho-physical estimations of effort.

Although the "central" ratings, associated with the perception of exertion of the cardiovascular system, followed the same patterns as those of the "local" lower limb ratings, it was evident that "central" responses during Condition 1 were lower than "local" ratings. Ratings incremented nominally from 9 (Very Light) to 10 (Very Light -

Fairly Light), indicating that the soldiers were in good cardiovascular condition and were not taxed by the demands of the march.

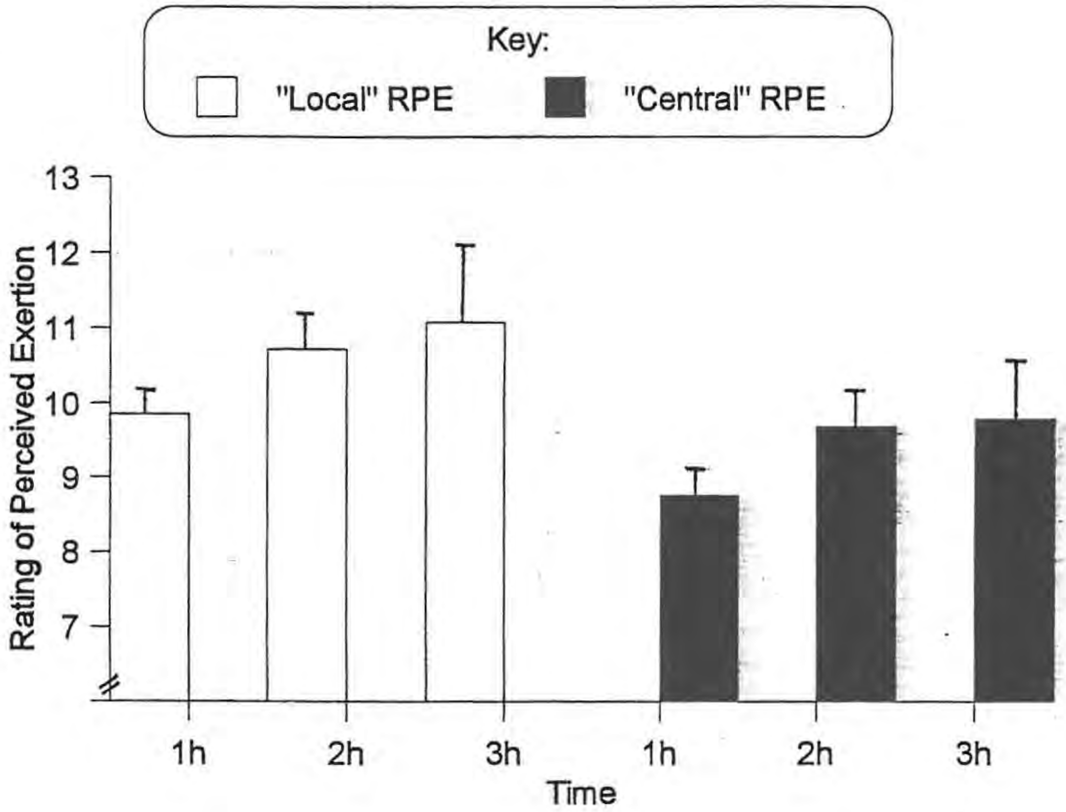


FIGURE 26 : "Local" and "central" Ratings of Perceived Exertion reported during 12 km march under the **Absolute** load of 40.5 kg.

The higher "local" RPE could be explained by Robertson's (1982) proposition that although central factors played a role, "local" factors such as force and rate of muscular contraction, and joint sensations dominate RPE. However, data were collected **in situ** while marching in groups of ten (maintaining a 2 x 5 formation) and, in the presence of others, individuals may have suppressed their subjective ratings of physical exertion, as they could have been concerned with how they looked relative to others. Furthermore, MacKinnon (1999) reported that mid-scale values of the RPE would most likely result in the greatest variability, as perceiving minimal and maximal efforts are more consistent when using an ordinal scale, such as Borg's.

There was little change in the "local" ratings of perceived exertion when soldiers marched with a **Relative** load of 37% of body mass. The mean rating over the three hours of marching was 9 (Very Light), illustrating that the subjects did not find the demands very severe. The perception of lower limb exertion during the challenging terrain at the beginning of the third hour ranged from 9 (Very Light) to 15 (Hard), and clearly show the perceived strain in the lower limbs with the increased work intensity.

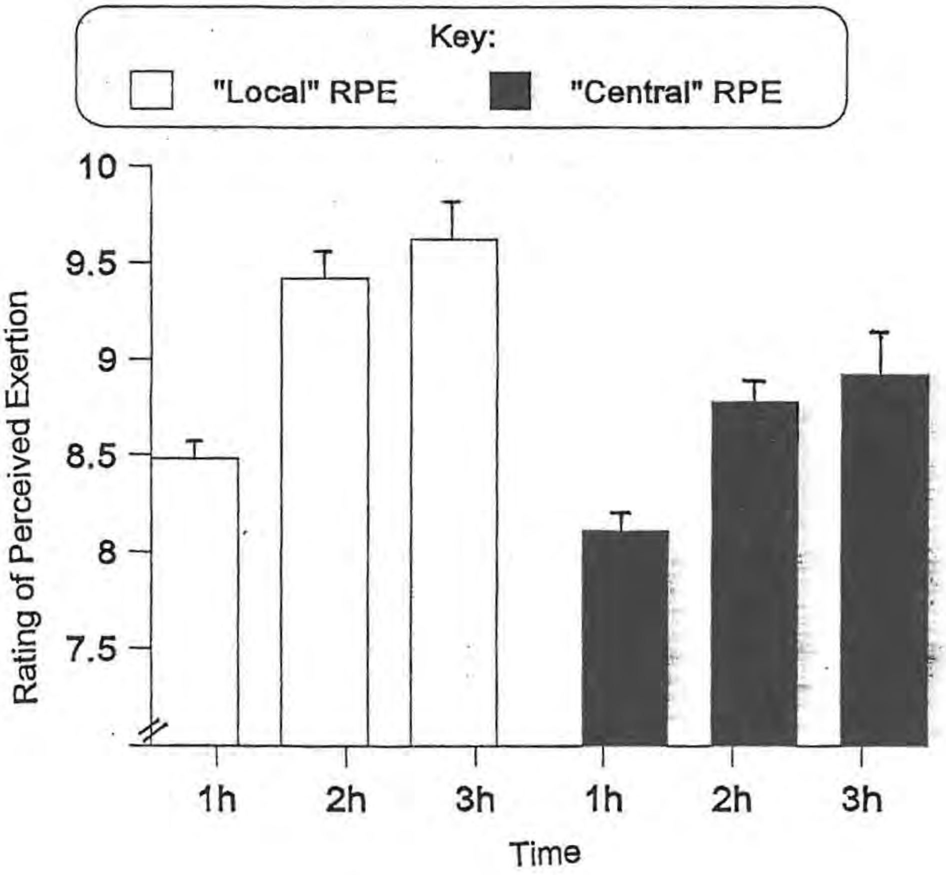


FIGURE 27 : "Local" and "central" Ratings of Perceived Exertion recorded on the12 km march under **Relative** loading.

The difference between the lightest and heaviest soldier's perception of effort was greatly reduced with the normalisation of loads. The heaviest soldier, now carrying 36.41 kg, perceived the uphill challenge as Fairly Light to Somewhat Hard (12) while the smallest soldier carried 20.19 kg and perceived "local" limb effort as Fairly Light (11). Thus relativising the load appears to standardise the level of stress experienced by the soldiers of varying size. It must, however, be cautioned that a nominally lighter "total platoon load" was moved in the **Relative** load condition. The author's contention, however, is that this was not a significant factor in observed differences between **Absolute** and **Relative** load responses.

As with the 40.5 kg load, there were insignificant increases, over the 3 h, in "central" RPE when marching with the **Relative** load. Overall, the soldiers perceived the cardiovascular demands of a 12 km march with a relative load to be Very Light. Furthermore, the variability of "central" ratings decreased, an indication that the soldiers' perceptions of the demands was similar.

"Local" ratings at any time for both **Absolute** and **Relative** loading were greater than "central" ratings of exertion. From these results it is concluded that the soldiers were in good cardiovascular condition and experienced marginally more strain in the legs. However, it might be argued that the perception of exertion during low intensity portion of the 12 km route march is mediated fairly equally by both "local" and "central" cues, while for the hill march, "local" lower limb cues tend to dominate the perception of effort. These findings are in agreement with views expressed by Ekblom and Goldbarg (1971), Pandolf and Noble(1973), and Robertson (1982) which propose that as the intensity of exercise increases, the sensory input from the "local" cues gradually become more influential. Thus, in this situation, as the gradient of the terrain became steeper, the sensations experienced in the working muscles and joints of the lower limbs tended to contribute more to the overall, cognitive perception of strain.

Despite considerable research on the topic, the mechanism(s) by which individuals perceive the intensity of exertion is not fully understood. Furthermore, there are particularly limited findings on RPE outside of a controlled, laboratory environment. It has been demonstrated that the physiological correlates of RPE are multi-dimensional and situationally specific. Multiple physiological indices only account for about 65% of the variance in RPE (Rejeski and Ribsl, 1980). Morgan (1973) contends that a portion of the unexplained variance mentioned might be dependent upon factors of a psychometric nature. It has also been reported (Rejeski and Ribisl, 1980; Rejeski, 1981) that factors such as perception, cognition, motivation and emotion play a part in ratings of perceived exertion. Despite this, an individual's cognitive appraisal and perception of the physical demands are important and must be assessed in an attempt to understand the functioning of this complex being.

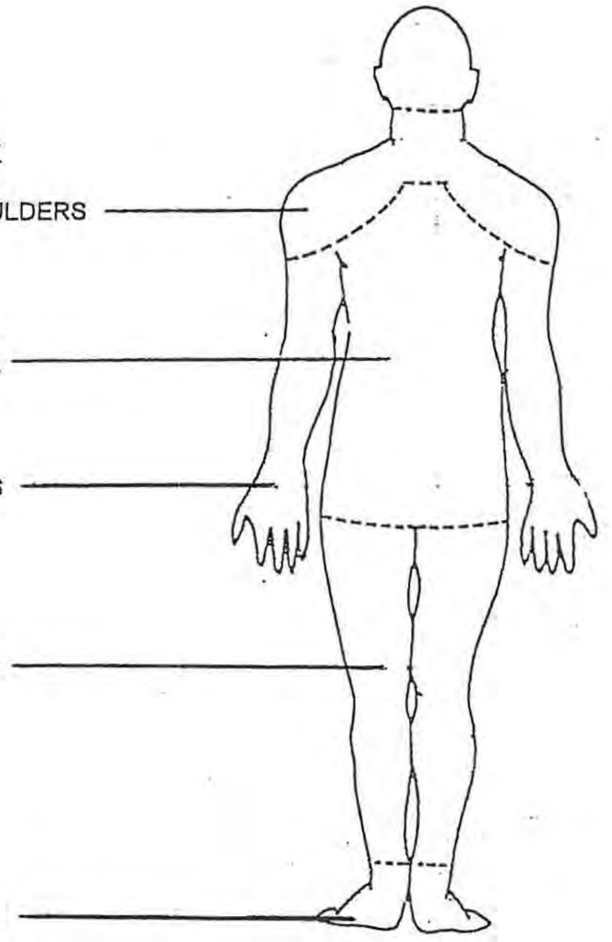
BODY DISCOMFORT OF THE GENERAL GROUP

A Body Discomfort scale adapted from Corlett and Bishop (Wilson and Corlett, 1990) was used in the present investigation to identify and rate areas of discomfort experienced by the infantrymen while marching 12 km with two different loads.

Individuals were asked to identify and rate the area(s) of discomfort during the rest breaks at the end of each hour.

From 27 available locations for identifying zones of discomfort on the body map, responses were collated into five broad regions as in Figures 28 and 29; neck and shoulders, back, arms, legs and feet. With reference to intensity of discomfort, there was extensive variability with no consistency either within or between subjects. Mean ratings tended to be moderate (from 4-6) over the three-and-a-half hours, very few ratings above 8 being recorded.

Holewijn (1990) argues that pressure on the skin underneath the shoulder straps is a cause of frequent complaints during marching, and hence a limiting factor for endurance capabilities. This pressure caused by the straps might account for the present findings in which the neck and shoulder regions represented over 60% of citings during the first hour of marching with an **Absolute** 40.5 kg load. Complaints of back (14%) and feet (17%) were very similar. During the second hour there was an almost 20% increase in the number of sites of discomfort reported. The substantial increase in the citing of the feet as the dominant region of discomfort may have been due to the undulating and challenging terrain encountered in the second 4 km. At the end of the route march, discomfort in the feet represented 50% of the citings reported in the third hour, while the neck and shoulder regions decreased to 27%. Figure 28 shows the areas of reported discomfort as a percentage of the total number of citings [illegible] under **Absolute** load condition.

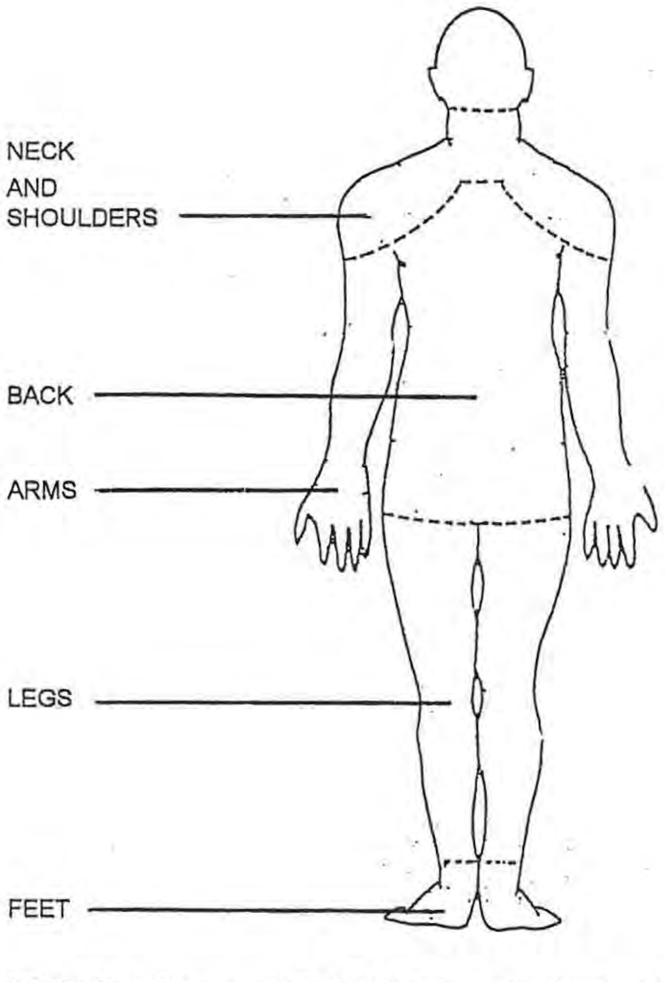


	FIRST HOUR	SECOND HOUR	THIRD HOUR
NECK AND SHOULDERS	61	47.6	27
BACK	14	10.7	10
ARMS	4.3	2.4	2.2
LEGS	2.9	9.5	10
FEET	17	29.8	50

NOTE: All regions, except for BACK, refer to anterior aspect.

FIGURE 28 : Representation of areas of discomfort (as % of total citings per hour) reported during the **Absolute** load condition.

When the soldiers marched with the **Absolute** load, there was a 22% increase in the number of citings from the first to the third hour of marching. The number of citings for the neck and shoulder regions were almost halved by the third hour, possibly because attention was focussed on other areas of discomfort. The reports of back discomfort decreased nominally from 14% to 11% while the pain in the arms was similar throughout the three hours. The carrying of the rifle while marching might account for the reports of discomfort in that region. Discomfort in the legs and feet increased from 3% to 10% and from 17% to 50% respectively. These are probably due to the cumulative effect of the uphill terrain. In addition, soldiers complained of the footwear that appeared to hinder "normal" gait patterns, thus leading to discomfort after marching on rough ground.



	FIRST HOUR	SECOND HOUR	THIRD HOUR
NECK AND SHOULDERS	71	36.8	28.4
BACK	12.5	8.8	5.9
ARMS	1.8	3.5	2.9
LEGS	3.6	12.3	4.5
FEET	8.9	38.6	58.2

NOTE: All regions, except for BACK, refer to anterior aspect.

FIGURE 29 : Representation of areas of discomfort (as % of total citings per hour) reported during the **Relative** load condition.

Once again, the discomfort reported during the **Relative** load condition followed a similar trend to the **Absolute** load findings; 70% of citings in the first hour represented the neck and shoulder regions, with 13% in the back. Legg and Mahanty (1985) reported that for backpacks, the majority of discomfort was in the neck and shoulder regions. However, the present data shows the area of discomfort shifting from the neck and shoulder regions in the first hour to the feet in the third hour. There was almost a 60% reduction in citing of the neck and shoulder region from the first hour to the end of the march. Furthermore, there was an 80% increase in the citing of the feet, reiterating the challenge of the uphill terrain in this segment of the route. With respect to carrying a **Relative** load, there was an increase of 16% in the number of areas of discomfort reported from the first to the final hours.

There was a 25% reduction in number of citings of discomfort when loads were relativised to the carriers' body mass. The areas of reported discomfort were similar for both **Absolute** and **Relative** loading. However, there was considerable variability in ratings of the discomfort. The smaller, more gracile soldiers appeared to be more taxed by the 40.5 kg load and therefore reported higher ratings of discomfort. Again, the underlying assumption here is that at any given absolute load a greater demand is placed upon the smaller soldiers. The results indicate that there was a steady increase in the discomfort experienced in the feet over the three hours under both conditions. In fact this was the one region in which there was no difference in discomfort ratings between the two march conditions.

In conclusion, there was a progressive, if modest increase in the number of citings and in the intensity of discomfort over the three hours. The shoulders and feet were the two regions in which most discomfort was experienced, with the shoulders being the worst area in the first hour and the feet being the worst by the end of the third hour of marching.

INTEGRATED DISCUSSION

Understanding the factors that influence load carriage ability may best be accomplished with a multi-factorial analysis since load carriage involves physiological, psychological, experiential and other factors. The literature indicates several approaches for facilitating load carriage, including decreasing the total load, modifying equipment, improving load distribution and specific techniques directed at injury reduction (Parkes, 1869; Lothian, 1922; Renbourn, 1954). Load reduction would result in lower energy costs, could reduce injuries and is highly likely to improve post march performance.

Several studies have suggested a strong link between heart rate and perceived exertion (Pandolf, 1978) under certain conditions. Correlations between RPE and heart rate in the present study were low (r=0.35 and r=0.29 for the **Absolute** and **Relative** loaded conditions respectively). This suggests that either heart rate or effort sense were perturbed. It is however, difficult to speculate on the interactive effects of the two measures, as correlation does not imply causality. Borg (1982) himself stated that the close relationship between heart rate and RPE was not intended to be taken too literally since the former is only one indicator of exercise strain. In addition, perceived exertion involves the integration of local peripheral signals, central cardiopulmonary signals and the central nervous system.

Borg (1970) maintained that exercise intensity expressed by means of heart rate could be predicted by utilising the formula: heart rate = RPE x 10. Figure 30 compares predicted heart rates (derived from the above formula) and actual heart rate responses collected. Since data were collected in the field while marching in groups of ten and in the presence of other individuals, soldiers may have suppressed their subjective ratings of physical exertion, as they could have been concerned with self-image. This would explain why predicted heart rates were approximately 20 beats lower than the actual heart rates.

It is evident that this formula cannot validly be applied to the results of the present research. The failure of the formula in respect of the present research further refutes the notion of causality between the two variables and indicates that sub-maximal RPE is probably not primarily mediated by heart rate. Several researchers have previously reached similar conclusions, and it has been noted that factors such as type of work (Pandolf, 1978), motivation, disease, drugs and heat (Rejeski, 1981) can affect the linearity of the relationship. It is important to note that data was collected **in situ**, where a wide spectrum of physiological and psycho-physical influences hinder the accurate prediction of the relationship. It is not possible to precisely partition these influences because each individual has a unique set of coefficients for factors contributing to efficient load carriage.

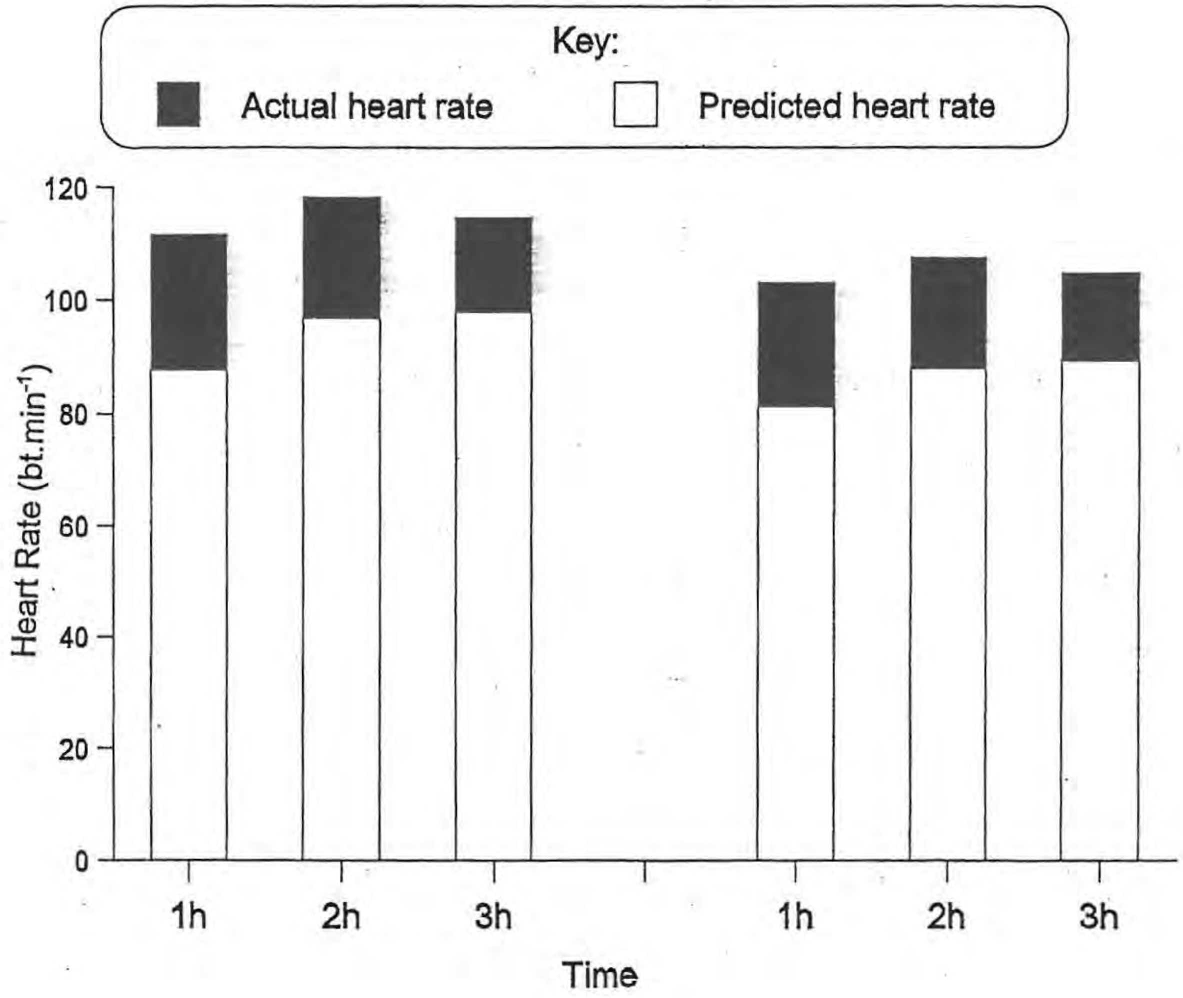


FIGURE 30 : Heart rate predictions from "central" RPE for **Absolute** and **Relative** conditions, as compared to actual heart rates.

In the following graphs, responses for each variable were calculated as a percentage of their maximum value and plotted over the 3 h period. Cardiorespiratory refers to the mean of heart rate, breathing frequency, tidal volume and minute ventilation; metabolic pertains to the mean of oxygen consumption, carbon dioxide production, respiratory exchange ratio and energy expenditure while perceptual represents "local" and "central" RPE.

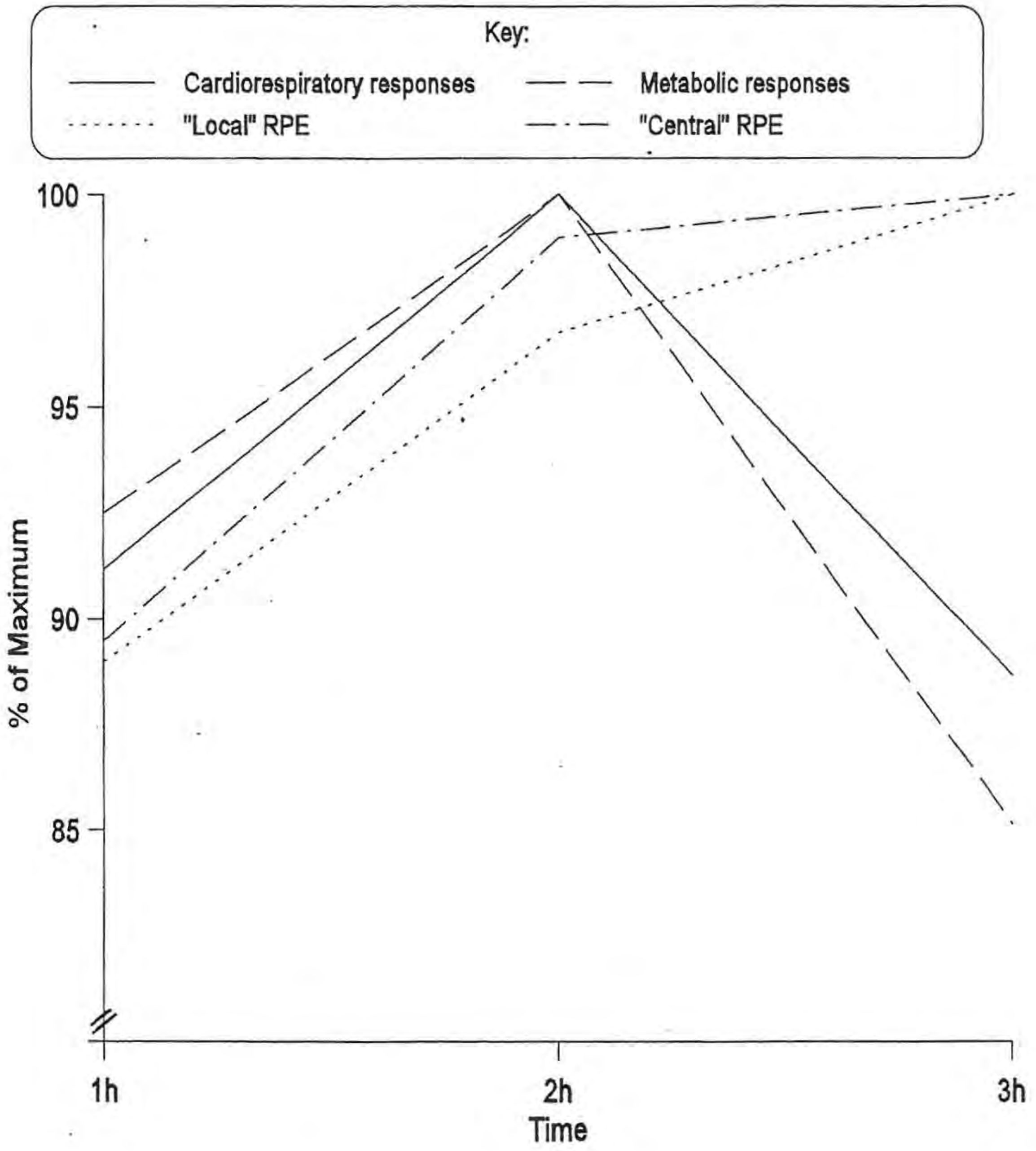


FIGURE 31 : Physiological and psycho-physical responses (as a percentage of their maxima) under the Absolute load condition.

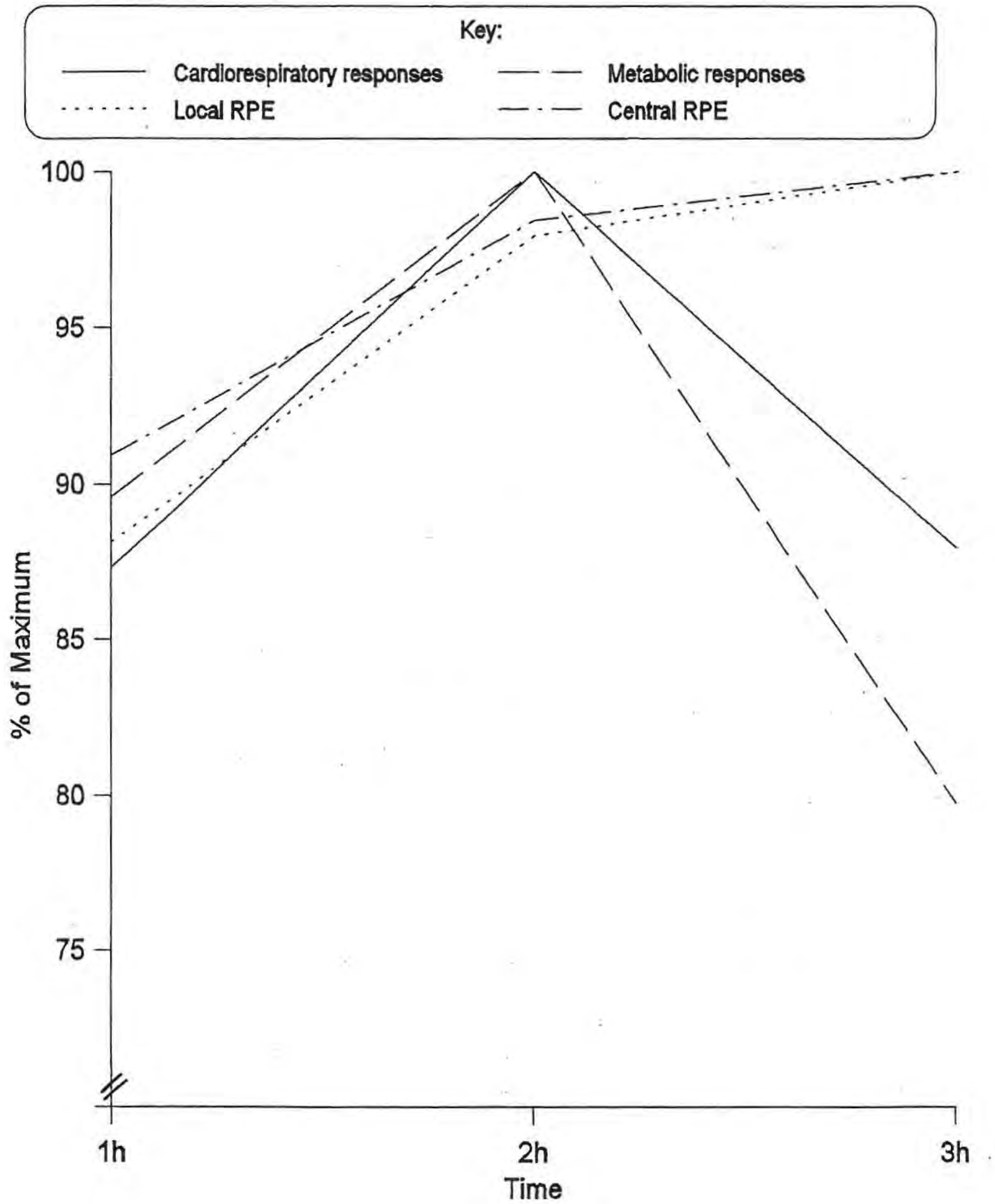


FIGURE 32 : Physiological and psycho-physical responses (as a percentage of their maxima) under the Relative load condition.

These data demonstrate that physiological responses peaked in the second hour (100% on diagrams) when soldiers were challenged by the undulating terrain encountered during this section of the march. These findings support Kirk and Schneider (1992) who suggested that a small increase in the slope of the terrain would result in significant increase in energy cost and perception of exertion. With reference to time-based differences in cardiorespiratory responses: the soldiers worked at a slightly higher percentage of maximum in the first hour compared to the final hour. The foot-soldiers may have been apprehensive at the beginning, and then settled down by the third hour. In addition, the flat, open terrain during the final stages of the experiment did not strain the soldiers at all. With the **Relative** load, soldiers worked at a similar percentage of maximum for the first and third hours. A closer look at the metabolic trends reveals that the foot-soldiers worked at about 10% lower than maximum in the initial hour, and this dropped a further 10% so that in the third hour, they were working at 20% lower than the maximum.

In contrast, the perceptual responses ("local" and "central" RPE) were at 20% lower than maximum in the first hour, and then gradually increased so that they represented about 97% of maximum in the second hour and then peaked in the final hour. Responses here were very close to maximum and there was a decrease in variance of ratings of perceived exertion.

This could be explained by Rejeski's proposition that when work is performed at sub-maximal level, there is an increased probability that psycho-physical factors served as

RPE (central) dropped to 91% of its **Absolute** condition value, thus reflecting very closely the nominal mass decrease under the **Relative** load condition. This suggests that RPE is a useful assessment tool even though under the conditions pertaining it was not as sensitive as the physiological measures.

The following quotation makes it clear that the multi-disciplinary nature of the issue of load-bearing efficiency in the SANDF demands the balanced holistic approach of a human kinetics and ergonomics specialist. This particular quote refers specifically to biomechanics and physiology, but can as easily be applied to physiology, anthropometry and psycho-physical domains of human action:

> A better understanding of the complex interactions involved in measuring mechanical power and efficiency might best be obtained using a multi-disciplinary approach. Biomechanists often devote a great deal of time and energy to precise collection and intricate manipulation of kinematic and kinetic data to yield a sophisticated model for the measure of mechanical power. Once the complicated mechanical measures are obtained, it is usually assumed that a simple measure of oxygen consumption is all that is necessary to delineate the associated metabolic energy expenditure. Physiologists, on the other hand argue the finer points of the energetics of metabolism and arrive at sophisticated models to account for the subtle interactions of aerobic and anaerobic metabolism under different conditions. Once these interactions are quantified, they typically assume that a simple mechanical measure, such as the external work done on a cycle ergometer, is all that is necessary to quantify the mechanical power generated. Both groups tend to under-estimate the complexity of the problem when it is approached from the other discipline. A concerted effort should be made by biomechanists and physiologists to work more closely together in order to more completely explore the fundamental relationships between movement and associated energy costs.

(Williams, 1985: pp 323-324)

CHAPTER V

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

INTRODUCTION

A comprehensive understanding of load carriage in the military has been a challenge to researchers for over a century. Studies by Parkes (1869) and Cathcart and co-workers in the 1920's are examples of early investigations, while Haisman (1970's) and Knapik and associates (1990's) have shown initiative in the field during the later stages of this century. Taking a multi-disciplinary, integrated approach, the present study sought to examine selected physiological and psycho-physical parameters related to load carriage involving a 12 km march under military conditions. Military constraints hampered, but did not entirely inhibit the secondary aim of the study which concerned the effectiveness of relativising loads in order to normalise responses for all soldiers, irrespective of morphological diversity.

It was hypothesised that, whether under **Absolute** or **Relative** loads, there would be a deterioration in performance, as inferred from higher physiological and perceptual responses, as the march progressed.

SUMMARY OF PROCEDURES

In an attempt to collect data under "natural" environmental conditions, the present investigation was conducted **in situ** at the Oudtshoorn Infantry School. Two experimental marching conditions were the basis of this study, and every effort was made to keep both conditions as similar as possible, except for the load carried. Condition 1 involved an **Absolute** load of 40.5 kg, while Condition 2 involved a **Relative** load in which subjects carried 37% of their own body mass. The order of presentation of conditions was randomised (separated by a 72-hour period to allow for full recovery) and scheduled at the same hour of the day to control for the influence of circadian rhythms and, as far as feasible, ambient environmental conditions.

Forty three healthy male soldiers (mean age 21.42 years, mean RPI 422.65, mean BMI 23.45, mean body fat 12.41%) participated. Subjects were organised into six groups. Two soldiers per group (Subject 1 and Subject 2) were randomly selected and measured extensively with regard to ventilatory and energetic aspects using a portable ergospirometry system (Metamax) which provided all the data needed for a complete functional analysis of lung, heart, circulatory and metabolic activity.

Basic demographic data including age, military experience, stature, mass and body composition were collected on the troops. Each group was required to march a 12 km course in three hours with a 15 min rest period after the first and second hours. The pace, 4 km.h^{-1}, was selected by the Army as the required pace for a "Patrol March", which is generally through bush under conditions in which soldiers are expected to observe the surroundings and be ready for combat. Each group was accompanied by a "Platoon Leader" who controlled the cadence at about 112 steps.min^{-1}. Water was available **ad libitum**.

During the actual march, heart rates and RPE were recorded for all subjects at 15 min intervals. Body Discomfort ratings (site and intensity) were assessed at the end of each hour. Fifteen minutes prior to the completion of each hour, the following Metamax data were consecutively collected on Subject 1 and Subject 2:

1) breathing frequency (f_b);
2) tidal volume (V_T);
3) minute ventilation (V_E);
4) oxygen consumption (VO_2);
5) volume of expired carbon dioxide (VCO_2);
6) respiratory exchange ratio (R); and
7) skin temperature responses (anterior and posterior of trunk) (T°).

Additionally, from VO_2 measures, the following energy expenditure (EE) properties were derived : $kJ.\sum kg^{-1}.min^{-1}$

$kcal.\sum kg^{-1}.min^{-1}$

power output (W)

Basic descriptive statistics relative to the variables assessed were computed, providing general information concerning the sample. One-way ANOVAs were calculated to determine whether there were time-based differences and interactions during the three hours of marching ($p<0.05$). Finally, the relationship between f_c and RPE was investigated by computing correlations.

SUMMARY OF RESULTS

Heart rate data indicate that the subjects were not severely physically taxed and that the loads imposed a sub-maximal demand on them. The overall pattern of "working" heart rates was 50% to 60% of age-predicted maximal rates during both conditions and there appeared to be a limited cumulative effect over the three-and-a-half hours. The peak heart rates were recorded in association with the steepest gradient,, which was encountered at 1.5 km into the last 4 km, although the highest mean heart rates were recorded during the second hour, due to the undulating terrain. An important finding was that the variability of "working" heart rates was substantially reduced when subjects carried loads relative to their own body mass; giving an indication that individuals were differentially more taxed when required to carry the same **Absolute** loads of 40.5 kg.

The ventilatory responses (f_b, $\dot{V}_T$, $\dot{V}_E$) reiterate the sub-maximal demands placed on the sample. Data from the first and third hours were similar, while the significantly higher responses in the second hour demonstrate the challenge of the undulating terrain encountered during this section of the march. Once again, maximum ventilatory responses were recorded in association with the positive gradient encountered near the start of the third 4 km stretch. All responses during the **Relative** load conditions mirrored those of the **Absolute** load condition but, because the demands were less, the trends occurred at a reduced level. Furthermore, the reduction in inter-individual variability indicates that relativised load carriage tends to stress the soldiers in a more uniform manner.

Under the **Absolute** load condition the heaviest subject carried 41% of body mass, while the lightest subject, under the same absolute load, was carrying 74% of body mass. The differential effects of this are seen by the fact that the heavier subject was expending 0.27 $kJ.\sum kg^{-1}.min^{-1}$ while the lightest was expending 0.39 $kJ.\sum kg^{-1}.min^{-1}$, a 44% increase. With respect to the **Relative** load, the heavier subject was expending 0.26 $kJ.\sum kg^{-1}.min^{-1}$ while the lighter was expending 0.34 $kJ.\sum kg^{-1}.min^{-1}$, a 30% increase.

The effect of normalising the total external load carried to the body mass of the carrier is to even-out the metabolic energy expended by the platoon as a whole over the march, thereby ensuring that the lighter-weight soldier is not more physically taxed and therefore less combat-ready at the end of a gruelling march. From the energy expenditures cited in the previous paragraph it is evident that the **Relative** load condition appeared to standardise the level of physical strain experienced by each individual within the group.

"Local" ratings of perceived exertion showed an average increase from 10 in the first hour to 11 in the second and third hours, with an increased perceived strain corresponding to the increase in the gradient of the terrain. However, there appeared to be very little cumulative effect over the 3 h, implying that the rest-to-work ratios implemented by the Army were, under these conditions, effective. Although the "central" RPE, reflective of perception of general systemic strain, followed the same pattern, it was evident that these were slightly lower than the ratings of "local" (musculo-skeletal) strain. This suggests that the cardiovascular systems of the soldiers experienced marginally less strain than the lower limbs. These data have important implications with respect to training methods in the SANDF. Inclusion of more lower limb strength and endurance training would only benefit these foot-soldiers, and ensure they are able to perform critical military tasks with efficiency, even after a route march with a reasonable load.

There was little difference in either "local" or "central" RPE under the **Relative** loaded condition, and the inter-individual variability of the ratings decreased, indicating that the group of foot-soldiers perceived the demands similarly when carrying loads relativised to their own body mass. The present data demonstrate the usefulness of perceptual assessment. It is not the physical demands of the situation that are the prime determinants of how an individual responds, but rather the individual's perception of those demands.

With reference to body discomfort ratings, there was a progressive, if modest, increase in the number of citings and in the intensity of discomfort experienced over the three hours. The shoulders and feet were the two regions in which most discomfort was experienced; the shoulders being cited as the worst area in the first hour and the feet being rated the worst after the third hour of marching.

A general synopsis of the results reveals that there was no cumulative physiological or psycho-physical effect over the 3 h marching period. Furthermore, the results of this research tend to augment further the assumption that human morphology considerably influences the energetics of load carriage. It has been demonstrated herein that relativising backpack loads based on the morphological make-up of the soldiers was successful in terms of reducing inter-individual variability inherent in the response to load carriage. In other words, the use of mass-normalised loads was effective in evening-out the strain responses of foot-soldiers of diverse morphology.

HYPOTHESES

<u>Hypothesis 1(a)</u>: The hypothesis of no time-based difference in physiological responses (f_c; f_b; $\dot{V}_T$; $\dot{V}_E$; $\dot{V}O_2$; EE; $\dot{V}CO_2$; R; T°) is rejected for all but T° which was constant throughout the 3 h march, under Full Marching Order with an **Absolute** load of 40.5 kg.

All variables except $\dot{V}O_2$ had similar responses in the first and third hours, with a significantly higher response in the second hour. This may be explained by the undulating terrain and the substantial uphill gradients encountered in the second hour. In respect of the skin temperature constancy, the sub-maximal demands of the march ensured that homeostasis was maintained via the appropriate thermo-regulatory systems.

<u>Hypothesis 1(b)</u>: There were no significant differences between the ratings of perceived exertion during the march, thus forcing a tentative retention of the null hypothesis. This suggests the soldiers perceived the physical stress to be stable and not very demanding.

Hypothesis 2(a): The hypothesis of no time-based difference in physiological responses (f_c; f_b; $\dot{V}_T$; $\dot{V}_E$; $\dot{V}O_2$; EE; $\dot{V}CO_2$; R; T°) is rejected for all but f_b and T° which were constant throughout the three hour march, under Full Marching Order with a **Relative** load of 37% of body mass. Once again, the uphill terrain encountered in the second hour challenged the soldiers leading to significantly higher responses being recorded in during this period.

Hypothesis 2(b): Both "local" and "central" RPE showed little time-based or terrain-based influence. Soldiers appeared to be equally taxed by the demands of the task and demonstrated very little variation in perception of effort. Thus, the null hypothesis is tentatively retained.

CONCLUSIONS

Cost effectiveness is naturally a military concern and improved military efficiency, in terms of combat-readiness, safety and general well-being of personnel is necessary in reducing costs. In 1986 Goslin and Rorke stated that when loaded subjects commenced marching, the energy expenditure will rise as a result of the load carried, terrain factors, the speed and gradient of the march plus temperature and/or humidity. It should be noted that with an increase in external physical demands, the risk of both chronic and acute injury will also increase. Knapik **et al.** (1996) observed that soldiers who are required to march with heavy loads may reduce their overall military efficiency due to general fatigue, physical strain and a decrease in motivational drive.

It is of interest to note that while the physiological responses (f_c; f_b; $\dot{V}_T$; $\dot{V}_E$; $\dot{V}O_2$; EE; $\dot{V}CO_2$) in the **Relative** load condition dropped to about 81% of **Absolute** load condition values, the total load moved under the **Relative** load condition was almost 90% of that under the **Absolute** load condition. Thus the benefit of relative loading is demonstrated and the results of the present study indicate the need for further work in the area of relativising loads carried. In addition, RPE (central) dropped to 91% of its **Absolute** condition value, thus reflecting very closely the nominal mass decrease under the **Relative** load condition. This suggests that RPE is a useful assessment tool, even though under the conditions pertaining it was not as sensitive as the metabolic measures. In this experiment, since data were collected in the field while marching in groups of ten, soldiers may have suppressed their subjective ratings of physical exertion, as they could have been concerned with how they looked relative to others.

The mean EE for these soldiers was about 0.08 kcal.$\sum$kg^{-1}.min^{-1} under both loaded conditions. Since these correspond to values cited during unloaded walking (McArdle **et al.**,1996), it appears that the soldiers experienced little or no physical strain. Previous research has shown that work performed at less that 50% $\dot{V}O_2$max (Åstrand and Rodahl, 1977) or 500 W (Hughes and Goldman, 1972) could be sustained at a steady state over an 8 h period. The present costs (51.3% $\dot{V}O_2$max, 618.3 W under **Absolute** and 41.6% $\dot{V}O_2$max, 500.4 W under **Relative** loading) suggest that the **Absolute** workload was too high and would not be sustained. However, these soldiers of diverse morphology were involved in a rest-broken 3.5 h session. Caution is advised when comparing data to listed recommendations because classifications and guidelines are subjective and situation specific.

It is contended that the results of this research show that the relativisation of loads carried is effective as a means of significantly reducing the inter-subject variability inherent in responses to load carrying in the military context. If loads are set at levels commensurate with individual capabilities to carry them without undue strain, unnecessary physical demands experienced by smaller, more gracile soldiers are reduced.

Aspects such as morphology of subjects, mass of load carried, gradient of terrain, walking speed, number and duration of rest breaks and ambient environmental conditions can influence load carriage significantly. However, it is not possible to precisely partition these influences into particular factors, because each individual has a unique set of coefficients for the factors contributing to efficient load carriage.

RECOMMENDATIONS

With reference to any future study pertaining to energetic and psycho-physical responses to load carriage under military conditions, the following recommendations merit careful consideration:

1) In order to compare absolute and relative loads directly, it is strongly recommended that future projects have the same total mass per platoon moved in both conditions.

For this, it would be necessary to determine the total mass moved in the **Absolute** load condition (in this case 405 kg equally divided amongst 10 carriers) and then to apportion this same total load in proportion to carrier body mass.

2) Another factor which merits consideration for future research is the influence of the environmental conditions. Definitive small-group analyses should be conducted under strictly-controlled laboratory conditions. From this it will be possible to determine optimal relative loads, for later **in situ** corroboration under operational conditions.

3) Further study is also required to clarify the optimum conditions for load carriage. A wide range of gradients, loads and speeds need to be investigated in an attempt to provide an acceptable range of combinations of the above factors that would improve combat-efficiency in the SANDF.

4) Important issues such as army diet; disease related cumulative fatigue effects; over-training and sleep deprivation need to be identified and more carefully investigated as these all relate to the caloric cost of work.

5) It is imperative that future studies examine the responses of females, as the number of females involved in active duty in armed forces world-wide is now increasing and specific guidelines need to be formulated.

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APPENDIX A : GENERAL INFORMATION

Equipment Check List

Detail Test Schedule

Letter to Subject

Consent Form

General Testing Protocol

Metamax Preparation

Metamax Changeover Protocol

EQUIPMENT CHECK LIST

ADMINISTRATION

Letter to subject
Consent form
General information data sheet
Subject data sheet
Instructions to subject for RPE
Instructions to subject for Body Discomfort

STATIONERY

Small scissors
Exam pads
Calculator
Duck tape
5 x Clipboards
Pens / Pencils / Eraser / Sharpener
Stapler / Prestik
Masking tape

COMPUTER EQUIPMENT

2 x Laptops with cables
Portable printer with paper
Multiple adapter
Storage discs

DATA COLLECTION EQUIPMENT

Toledo scale
Tape measure
LIPOCARE Bioelectrical Impedance Analysis - Electrode tapes
METAMAX - Silver bag
    - Manual
    - Gas cylinder

- 3 litre syringe
- Rubber bladder with clamp
- 6 x masks with head cap assembly

Heart rate monitors - 3 x POLAR ACCUREX PLUS
- 4 x POLAR SPORTS TESTER
- Batteries

4 x RPE scales
4 x Body discomfort scales

MEDICAL EQUIPMENT

Milton disinfectant - Bucket
- Cloths

Elastoplast
Micropore tape
Tissues
Cotton wool

MISCELLANEOUS

Precision screwdriver set of 6
Cacu - 5 in 1 measure
1 x 2m tape measure
1 x 5m tape measure
2 x response counters
3 x stopwatches
Drinks for assistants
Waste bags

DETAIL TEST SCHEDULE

DATE	TIME	ACTIVITY
31 October	pm	Arrival of Ergotech
1 November	15:00 - 18.30	Preparation for tests, packing and weighing of loads. Checking of all measuring equipment.
	18:30	Co-ordinated meeting.
2 November	06:45	All sections report for briefing on testing and selection of Metamax subjects.
	07:15 - 07:45	Section 1. Reports for fist session. Full Marching Order with "absolute" load (Condition1). Subjects instrumented.
	07:45 - 08:00	Final preparations for tests and all logging equipment started.
	08:00	Depart on route of 12 km at 4 km.h^{-1}.
	09:00 - 09:15	Rest break.
	09:15 - 10:15	Next 4 km.
	10:15 - 10:30	Rest break.
	10:30 - 11:30	Next 4 km.
	11:30	Stop logging equipment and remove measuring equipment, download data and check.
	12:00	Lunch
	13:00 - 13:45	Section 2. Reports for exercise. Full Marching Order with "absolute" load (Condition 2). Briefing and soldiers instrumented.
	13:45 - 14:00	Final preparations for testing and all logging equipment started.
	14:00	Depart on route of 12 km at 4 km.h^{-1}.

	15:00 - 15:15	Rest break.
	15:15 - 16:15	Next 4 km.
	16:15 - 16:30	Rest break.
	16:30 - 17:30	Next 4 km.
	17:30	Stop logging equipment and remove measuring equipment, download data and check.
	18:15	Debriefing and stop for the day.
3 November	07:00 - 11:30	Section 3 with Condition 2.
	13:00 - 17:30	Section 4 with Condition 1.
	18:15	Debriefing and stop for the day.
4 November	07:00 - 11:30	Section 5 with Condition 1.
	13:00 - 17:30	Section 6 with Condition 2.
	18:15	Debriefing and stop for the day.
5 November	07:00 - 11:30	Section 1 with Condition 2.
	13:00 - 17:30	Section 2 with Condition 1.
	18:15	Debriefing and stop for the day.
6 November	07:00 - 11:30	Section 3 with Condition 1.
	13:00 - 17:30	Section 4 with Condition 2.
	18:15	Debriefing and stop for the day.
7 November	07:00 - 11:30	Section 5 with Condition 2.
	13:00 - 17:30	Section 6 with Condition 1.
	18:15	Debriefing and stop data collection.

LETTER TO SUBJECT

Dear _______________

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

THE EFFECT OF LOAD CARRIAGE ON SELECTED METABOLIC AND PERCEPTUAL RESPONSES OF MILITARY PERSONNEL

I will be investigating load carriage efficiency in a holistic manner through the assessment of physical, physiological and concomitant perceptual parameters. This integrated approach is deemed essential, for while there has been a great deal of research on energy cost, there has been very little interest shown in the individual's perception of the physical demands. This approach also addresses the problem of human variability; for while a platoon marches as one unit, it must be acknowledged that this unit is comprised of individuals with their own mental and physical strengths and limitations, hence each individual is taxed differentially and yet expected to execute the military task (s) with precision.

While extensive research has been conducted on the USA and British troops very little has been done with the South African troops. This void in information, together with the dramatic change in the personnel within the army identifies an essential need for information relevant to the present SANDF. This research would establish basic standards and guidelines relative to the manual moving of military material, especially since combat efficiency (a key element in any army) is affected by numerous factors, load being identified as one of the most important.

Foremost you will be medically examined (administered by Army Medical Personnel) to ensure you are suitable subjects for the present study. Prior to the actual data collection the background and application of the RPE and Body Discomfort will be thoroughly explained to you.

Basic morphological measurements including sex, age, stature, mass and body composition (as inferred by percentage fat) will be collected. Two per group of ten will be randomly selected for Metamax data collection. If you are selected, you will be required to wear a mask prior to data collection to become familiar with the gear.

You will then be required to march the same route in Full Marching Order with two different loads, separated by a 72 hour period to allow for full recovery. These are marching with an ABSOLUTE load then a load RELATIVE TO BODY MASS (38%),. Metabolic and perceptual data will be collected at regular intervals throughout the march and at the same times every day to minimise the effects of diurnal factors. The Metamax - a portable ergospirometer (with associated cardiac, respiratory, metabolic and thermo-regulatory technology) will be used to log physiological data from the selected 10 during the march. The physiological responses of the other recruits will be inferred by heart rate monitoring (POLAR HEART WATCH). Psycho-physical rating scales such as the RPE and discomfort scales will provide a means of assessing perceptual responses of all subjects.

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

Once again, many thanks for your interest. Please do not hesitate to contact me should you have any further questions.

Yours sincerely

LEENA I RAMABHAI
(Human Kinetics and Ergonomics Masters student)

SUBJECT CONSENT FORM

I, COL H. GRYFFENBERG, ON BEHALF OF BCOMPANY having been fully informed of the research entitled :

THE EFFECT OF LOAD CARRIAGE ON SELECTED METABOLIC AND PERCEPTUAL RESPONSES TO LOAD CARRIAGE

do hereby give my consent to act as a subject in the above named research.

I am fully aware of the procedures involved as well as the potential risks and benefits attendant to my participation as explained to me verbally and in writing. In agreeing to participate in this research I waive any legal recourse against the researchers of Rhodes University, from any and all claims resulting from personal injuries sustained. 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) :

H. GRYFFENBERG		01/11/98
(Print name)	(Signed)	(Date)

PERSON ADMINISTERING INFORMED CONSENT :

LEENA I. RAMABHAI	Ramabhai	01/11/98
(Print name)	(Signed)	(Date)

WITNESS :

P.A. SCOTT.		01.11.98
(Print name)	(Signed)	(Date)

GENERAL TESTING PROTOCOL

Data collection procedure, per hour, during each march was as follows :

7.00 am	Section reports and soldiers instrumented
	Collect basic anthropometrical data
7.45 - 8.00	Final preparations and checking
8.00	Start data collection
8.15	RPE / HR from all subjects
8.30	RPE / HR from all subjects
8.45	RPE / HR from all subjects
8.45 - 8.50	5 min Metamax data collection on 1st subject
	Check cadence
8.50 - 8.53	Changeover backpacks
8.55 - 9.00	5 min Metamax data collection on 2nd subject
	Check cadence
9.00	RPE / HR / Body Discomfort on all subjects
9.00 - 9.15	Rest period - Change Metamax battery
	Change backpacks of 2 subjects

SAME PROTOCOL FOR THE NEXT TWO HOURS

11.30	End data collection
	Collect post-march data - Mass for all 10 soldiers
	- BIA for 2 Metamax subjects

EQUIPMENT REQUIRED

Clipboards with pens / pencils
Subject data sheets
RPE scale and Body discomfort scale
Response counters
Stopwatch
Waste bags
Water bottles

METAMAX PREPARATION

Gas and volume calibration

Connect battery to Metamax and switch on

Place HRM transmitter belt and watch on

Place skin temperature electrodes - front (right mid chest - Pectoralis major)
back (centre lower back - Erector spinae)

Place Metamax in army pack

Connect temperature sensor box to Metamax (analog)

Secure Metamax to army pack

Connect leads to Metamax - Ambient Temp
HR
Event marker

Connect gas analysis tube to volume transducer which connects to mask

Connect gas analysis and volume transducer tubes to Metamax

Lift pack and place on back of test subject and secure

Place mask on and check no air leakage

Add wind shield and loosen mask's bottom adjuster so comfortable around neck

Tape all tubes securely to back of pack

Connect skin temperature cords to temperature sensors box

Check HRM of Metamax forward and event marker over left shoulder

Mask on and secure firmly

METAMAX CHANGEOVER PROTOCOL

Equipment :

Scissors
Tissues
Micropore tape
Duck tape
Elasoplast

Protocol :

Tester 1	*Tester 2*
Stop data collection	Disconnect skin temperature
Remove volume transducer	Remove tapes
Assist in removal of backpack	Assist in removal of backpack
Assist in loading of backpack	Assist in loading of backpack
Volume transducer to new mask	Connect skin temp cords to box
Ensure HRM + marker (left shoulder)	Taping
Start data collection	Check straps and tighten mask

APPENDIX B : DATA COLLECTION

Instructions to Subject for RPE

Instructions to Subject for Body Discomfort

General Data Sheet

Subject Data Sheet

Route Used for Data Collection

INSTRUCTIONS TO SUBJECT FOR RPE

You are now going to take part in a work test. You will be marching with a backpack for 12 km at 4 $km.h^{-1}$ while we measure various physiological functions. We also want you to try and estimate how hard you feel the work is; that is, we want you to rate the degree of perceived exertion you feel. You will be asked to point to a number on the scale presented which corresponds to your rating of perceived exertion. The first will be a "local" muscular rating pertaining to feelings or sensations of strain in the lower limbs. The second rating involves sensations or feelings from the "central" cardiorespiratory system.

Try to estimate as honestly and as objectively as possible. Do not underestimate the degree of exertion you feel, but do not overestimate it either. Try to estimate it as accurately as possible. You will be requested to give ratings of perceived exertion every 15 minutes. When you are asked to rate your work, you should do so by giving the numerical value which indicates your evaluation of you "local" and "central" perceived exertion respectively at that moment. A rating of six (6) corresponds with feelings of exertion while standing quietly, whereas a rating of twenty (20) reflects maximal exertion.

INSTRUCTIONS TO SUBJECT FOR BODY DISCOMFORT

You are now going to take part in a work test. You will be marching with a backpack for 12 km at 4 km.h^{-1} while we measure various physiological and psychological functions. We want you to try and determine the exact location of discomfort or pain experienced during marching. You will be required to point to the site(s) of body discomfort on the body map which has been divided into segments and numbered from 0-27. You will also be asked to rate the intensity of discomfort at each identified site on a ten (10) point scale where one (1) refers to " very comfortable work" and ten (10) refers to an experience of "extreme discomfort".

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

GENERAL DATA SHEET

	MON		TUE		WED		THUR		FRI		SAT	
	AM	**PM**	**AM**	**PM**	**AM**	**PM**	**AM**	**PM**	**AM**	**PM**	**AM**	**PM**
GROUP	1	2	3	4	5	6	1	2	3	4	5	6
CONDITION	a	b	b	a	a	b	b	a	a	b	b	a
T (°C)												
HUMIDITY												
WIND SPEED												
COMMENTS												

WHERE a : Full Marching Order with **Absolute** load (40.5 kg)

b : Full Marching Order with **Relative** load (37% body mass)

SUBJECT DATA SHEET

GENERAL INFORMATION

Name : ______________________________

Code : __________

Group : (Tick the appropriate block) 1 2 3 4 5 6

Metamax Code : ________ Mask Size : (Tick the appropriate block) S M L

Date of Birth : ___/___/19___ (Day / Month / Year)

Sex : (Tick the appropriate block) Male Female

Military Experience : _____years

CONDITION 1 : FULL MARCHING ORDER

ANTHROPOMETRICAL DATA

Stature : _____mm

Mass :

	PRE (kg)	**POST (kg)**
Minimal Clothing		
Uniform		
Uniform & Load		

37 % of body mass : _______kg

$$\text{RPI} = \frac{\text{Stature}}{\sqrt[3]{\text{Mass}}} = \_\_\_\_\_\_\_\_ \text{mm.}\sqrt[3]{\text{kg}}^{-1}$$

Bioelectrical Impedance Analysis : Lipocare Code : _______

	PRE	**POST**
Fat Mass (kg)		
%		
Lean Mass (kg)		
%		
Total Body Mass (kg)		
Total Body Water (l)		
%		
Basal Metabolic Rate (kJ.day^{-1})		
Body Mass Index ($(\text{kg.m}^2)^{-1}$)		

FULL MARCHING ORDER

CODE : __________

PHYSIOLOGICAL AND PERCEPTUAL DATA

	HEART RATE (beat.min $^{-1}$)	RPE	
		Local	**Central**
Reference			
Anticipatory			
Marching 1i			
Marching 1ii			
Marching 1iii			
Marching 1iv			
Rest Period			
Marching 2i			
Marching 2ii			
Marching 2iii			
Marching 2iv			
Rest Period			
Marching 3i			
Marching 3ii			
Marching 3iii			
Marching 3iv			
Recovery			

TIME	**BODY DISCOMFORT** (A = Anterior ; P = Posterior)							
	L	R	L	R	L	R	L	R
1								
2								
3								

Comments :

....

....

....

CODE : __________

CONDITION 2 : RELATIVE TO BODY MASS 37 %

ANTHROPOMETRICAL DATA

Stature : _____mm

Mass :

	PRE (kg)	**POST (kg)**
Minimal Clothing		
Uniform		
Uniform & Load		

37 % of body mass : _______kg

$$\text{RPI} = \frac{\text{Stature}}{\sqrt[3]{\text{Mass}}} = \text{mm}.\sqrt[3]{\text{kg}}^{-1}$$

Bioelectrical Impedance Analysis : Lipocare Code : _______

	PRE	**POST**
Fat Mass (kg)		
%		
Lean Mass (kg)		
%		
Total Body Mass (kg)		
Total Body Water (l)		
%		
Basal Metabolic Rate (kJ.day $^{-1}$)		
Body Mass Index (kg.m²) $^{-1}$		

RELATIVE TO BODY MASS

CODE : __________

PHYSIOLOGICAL AND PERCEPTUAL DATA

	HEART RATE (beat.min $^{-1}$)	**RPE**	
		Local	**Central**
Reference			
Anticipatory			
Marching 1i			
Marching 1ii			
Marching 1iii			
Marching 1iv			
Rest Period			
Marching 2i			
Marching 2ii			
Marching 2iii			
Marching 2iv			
Rest Period			
Marching 3i			
Marching 3ii			
Marching 3iii			
Marching 3iv			
Recovery			

TIME	**BODY DISCOMFORT** (A = Anterior ; P = Posterior)							
	L	R	L	R	L	R	L	R
1								
2								
3								

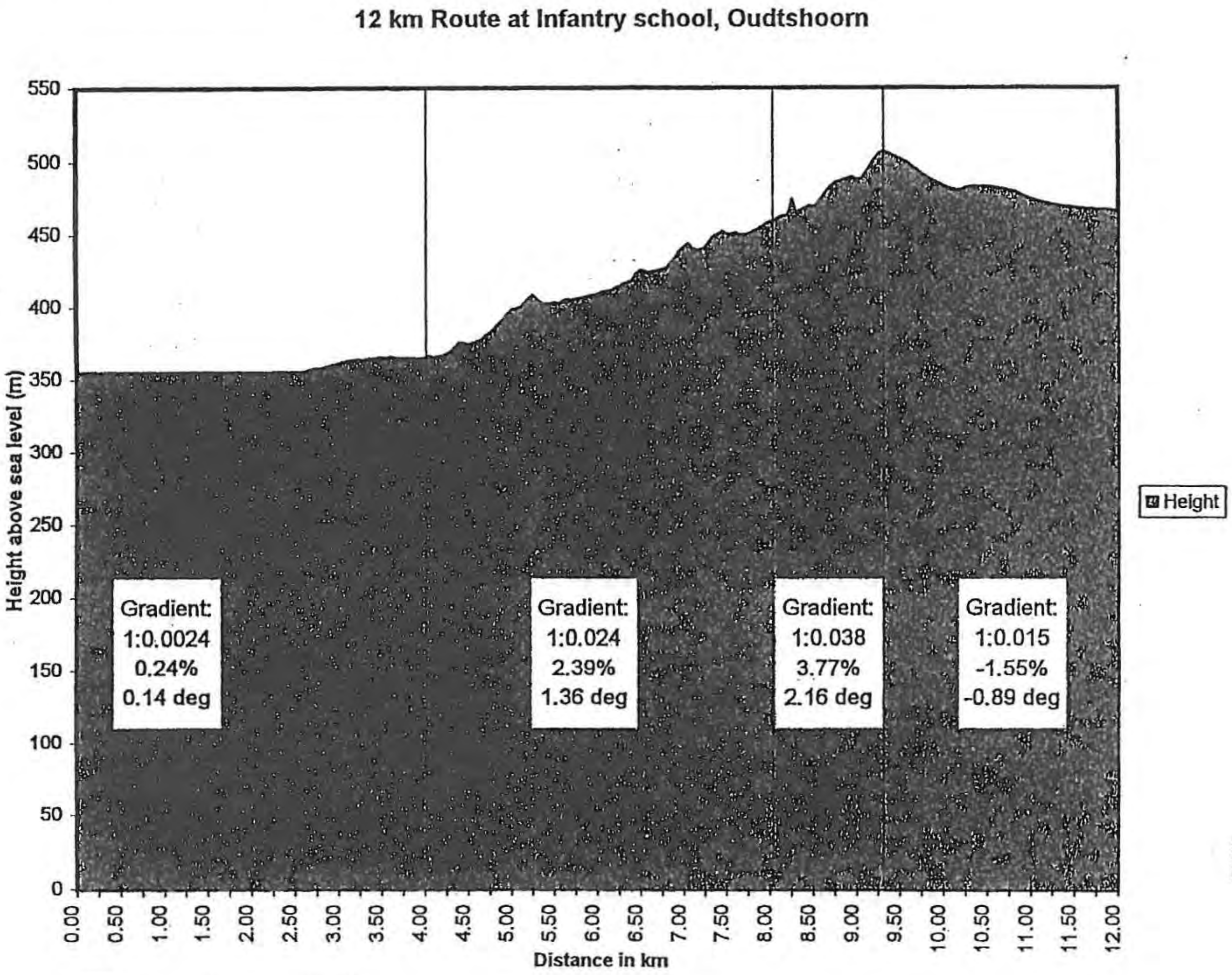
Comments :

....

....

....

ROUTE USED FOR DATA COLLECTION



APPENDIX C : RESULTS

Physiological Formulae and Variables

Ambient Conditions

Polar Heart Rate Monitor Print-out

Metamax Report

Statistics

PHYSIOLOGICAL FORMULAE AND VARIABLES

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

HR_{max} = 220 - age (year)

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

Represents the energy expenditure under completely relaxed, resting conditions, unaffected by extra external loads such as digestion. It represents the energy requirements of cardiac and respiratory muscles, other vital organs and maintenance of body temperature within normal levels.

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

Amount of breaths per minute.

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

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

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

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

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

The number of times per minute that the heart beats.

Metabolic Equivalent (MET):

Used as an expression of unit for resting metabolic rate. 1 MET = 3.5 $m\ell.kg^{-1}.min^{-1}$.

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

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

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

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

The amount of oxygen consumed by the body each minute.

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

Reduction in Response Variability in %:

$$1 - \frac{\text{relative standard deviation}}{\text{absolute standard deviation}} \times 100$$

Relative Speed (V_R) in $stature.s^{-1}$:

$$V_R = \text{velocity } (m.s^{-1}) \times \text{stature } (m)$$

Respiratory Exchange Ratio (R):

$$R = VCO_2 \div VO_2$$

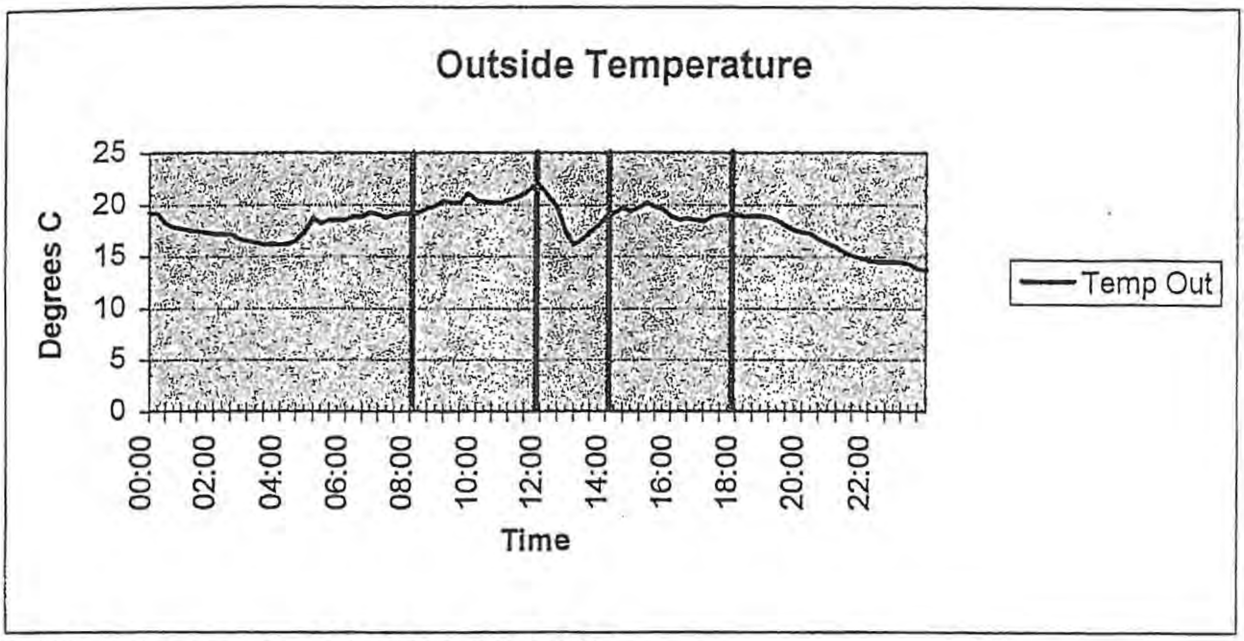
Standard Deviation (SD):

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

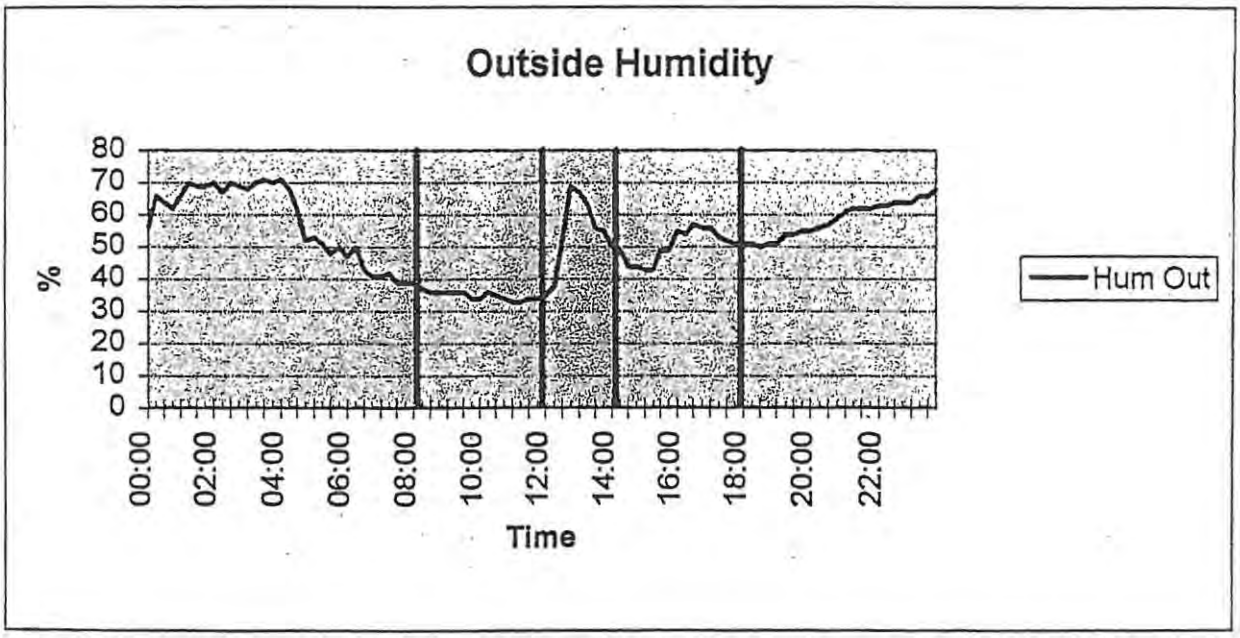
Tidal Volume (V_T) in L:

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

AMBIENT CONDITIONS

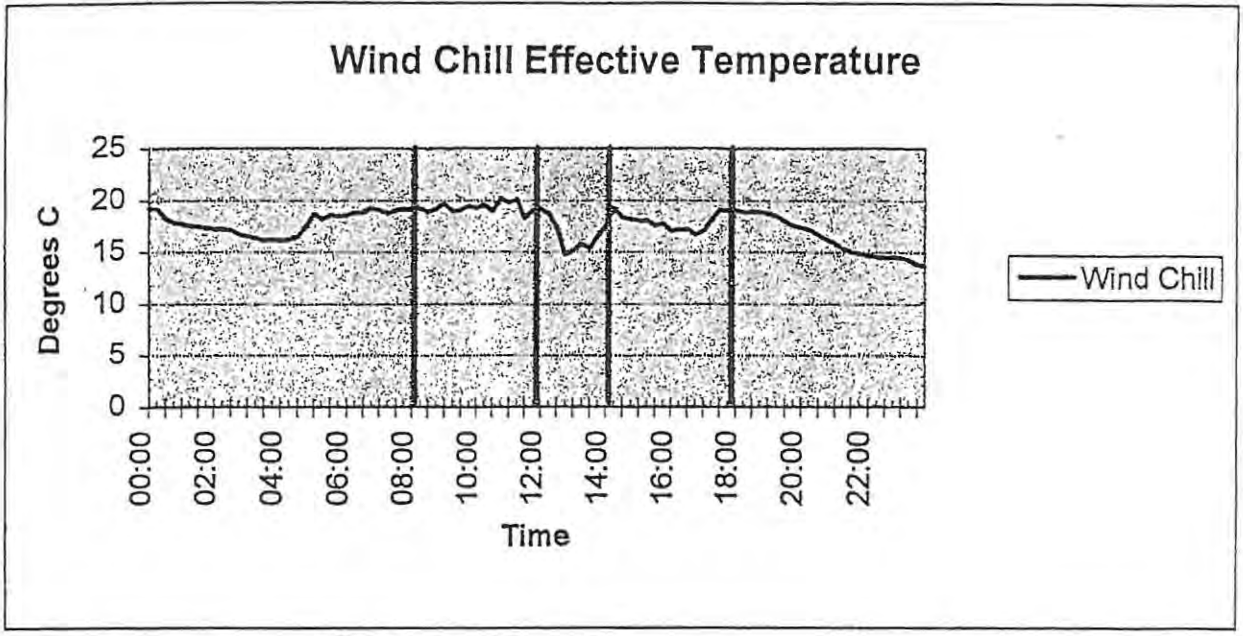


Outside Temperature	0800-1245	1400-1745
Maximum	21.8	20.2
Minimum	17.4	18.4

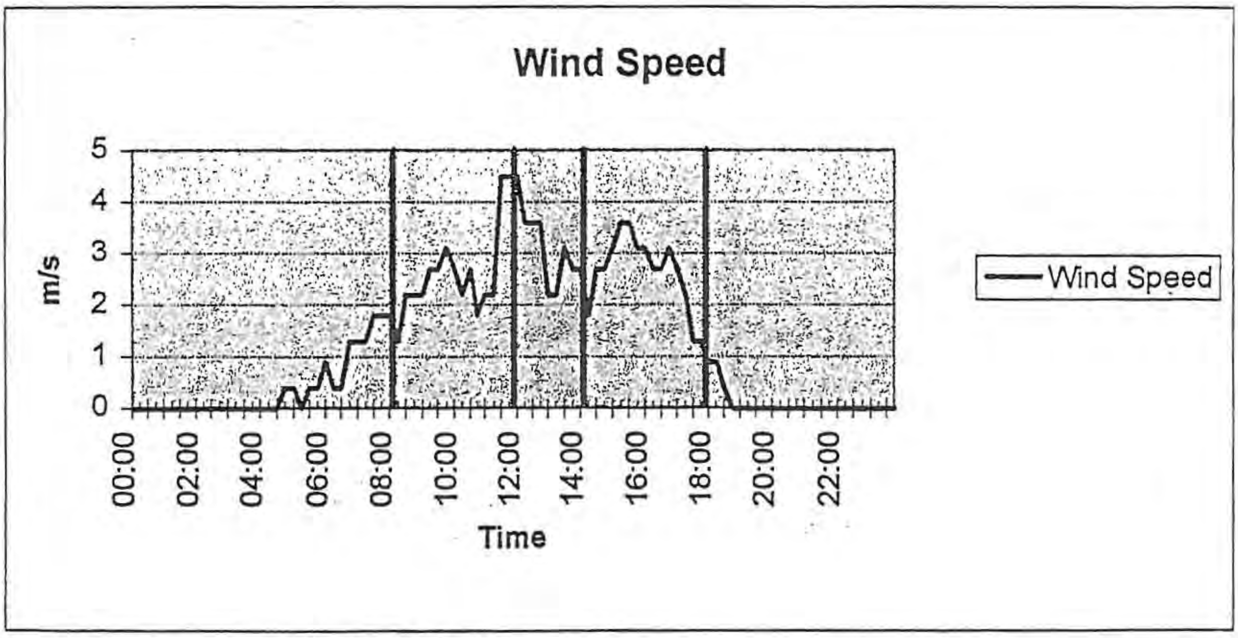


Outside Humidity	0800-1245	1400-1745
Maximum	69	57
Minimum	33	43

AMBIENT CONDITIONS

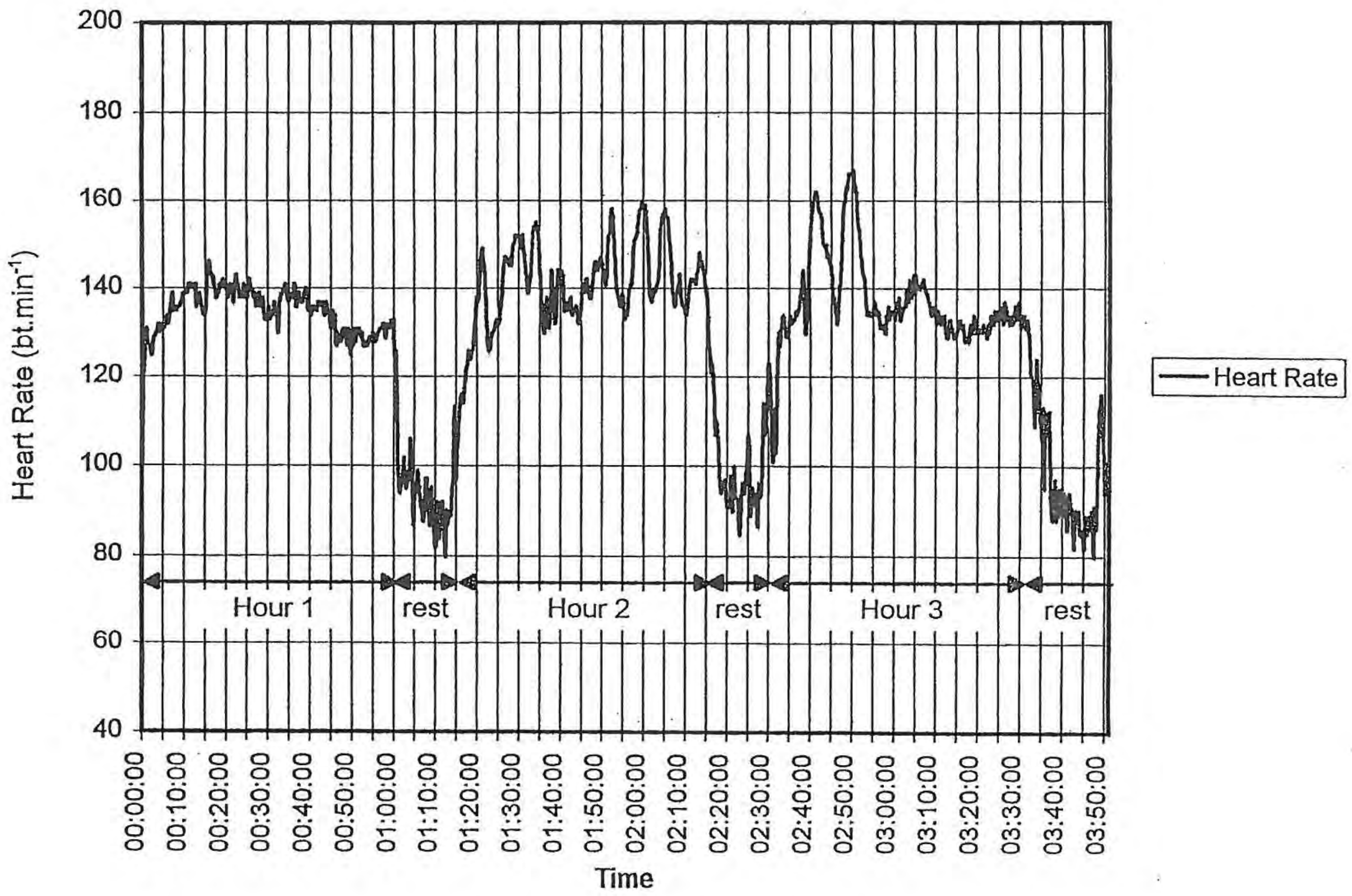


Wind Chill Temperatur	0800-1245	1400-1745
Maximum	20.2	19.3
Minimum	14.8	16.7



Wind Speed	0800-1245	1400-1745
Maximum	4.5	3.6
Minimum	1.3	1.3

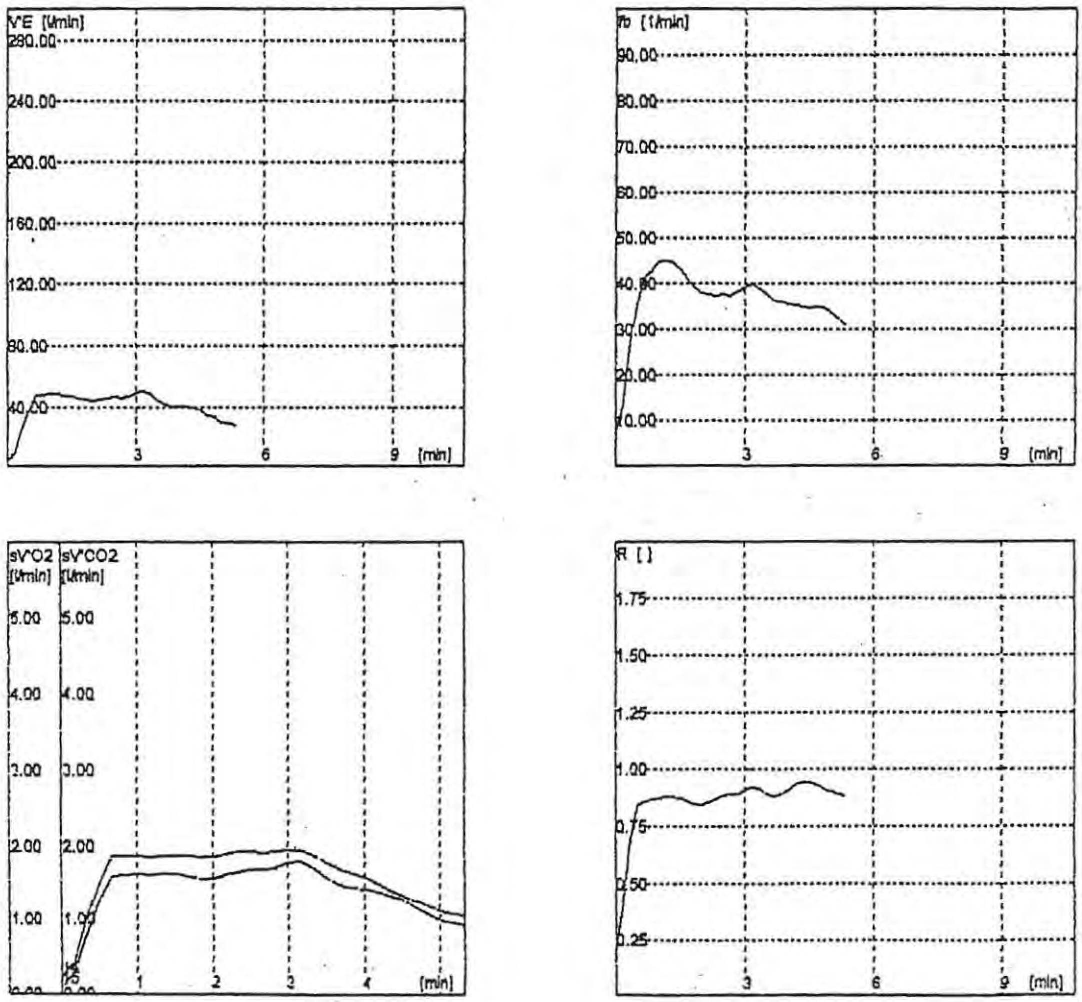
POLAR HEART RATE MONITOR PRINT-OUT


Example of Heart Rate Response over 12 km route

METAMAX REPORT

Name:	(A-hill)	Birth date: 07.05.78	Date: 02.11.1998 11:90
Sex: Male		Height: 169.0 [cm]	Weight: 54.6 [kg]

MetaMax Ergospirometry Test



		AT	VO2 max.	R = 1
Time	[h:m:s]		00:03:00	
sV'O2	[l/min]		1.94	
spec. V'O2	[ml/min/kg]		35.48	
sV'CO2	[l/min]		1.75	
R			0.90	
V'E	[l/min]		48.37	
fc	[1/min]		0.00	

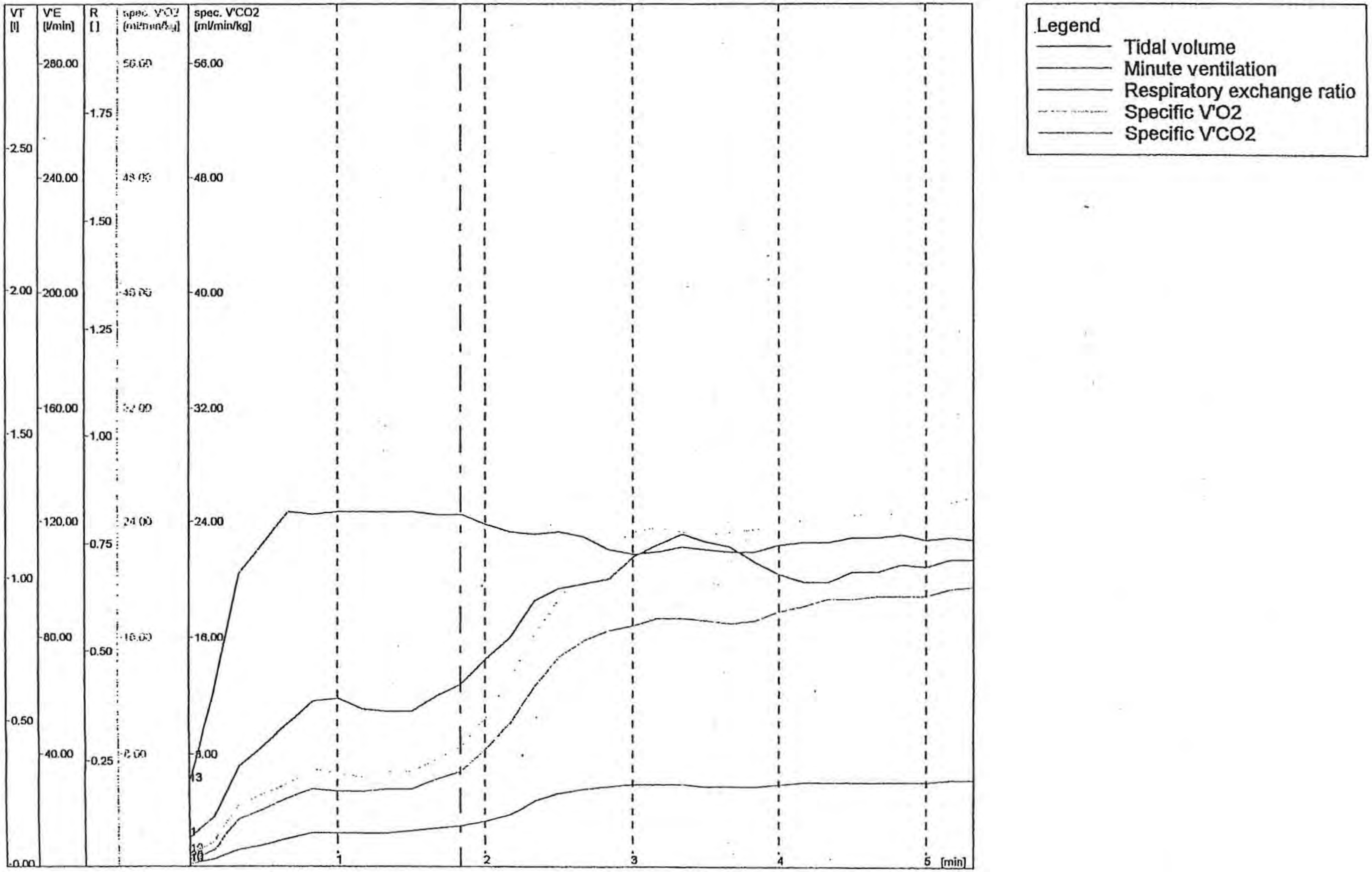
METAMAX REPORT

Name: .	(A-hill)	Birth date: 07.05.78	Date: 02.11.1998 11:90
Sex: Male		Height: 169.0 [cm]	Weight: 54.6 [kg]

MetaMax Ergospirometry Test

Time [h:m:s]	VT [l]	fb [1/min]	V'E [l/min]	R	spec. V'O2 [ml/min/kg]	spec. V'CO2 [ml/min/kg]	T Skin 2 [° C]	T Skin 3 [° C]
00:00:00	0.19	6.95	2.67	0.19	4.01	1.51	36.33	35.03
00:00:30	0.73	25.32	23.47	0.64	18.09	14.34	36.33	34.94
00:01:00	1.11	42.71	47.22	0.86	34.12	29.32	36.33	34.94
00:01:30	1.06	44.12	46.88	0.87	34.02	29.55	36.24	34.94
00:02:00	1.12	39.44	44.09	0.84	33.94	28.65	36.33	34.90
00:02:30	1.20	37.49	44.87	0.86	34.77	29.98	36.33	35.03
00:03:00	1.22	38.12	46.56	0.89	35.00	31.17	36.33	34.99
00:03:30	1.21	38.62	46.68	0.90	33.85	30.67	36.28	35.03
00:04:00	1.12	35.90	40.26	0.88	29.69	26.24	36.33	35.03
00:04:30	1.10	35.01	38.42	0.94	25.77	24.14	36.28	35.03
00:05:00	0.92	34.47	31.71	0.91	21.47	19.65	36.33	35.07

METAMAX REPORT



STATISTICS - DESCRIPTIVE STATISTICS

```
Variable:                  AGE              ME              ST
--------------------------------------------------------------------------
Sample size                43               43              43
Average                    21.4186          1.32558         1.75442
Median                     21               1               1.74
Mode                       20               1               1.68
Geometric mean             21.3159          1.21973         1.7528
Variance                    4.8206          0.51052         5.83953E-3
Standard deviation          2.19559         0.714507        0.0764168
Standard error              0.334824        0.108961        0.0116535
Minimum                    19               1               1.58
Maximum                    27               5               1.96
Range                       8               4               0.38
Lower quartile             20               1               1.69
Upper quartile             22               2               1.81
Interquartile range         2               1               0.12
Skewness                    1.23294         3.5305          0.2131
Standardized skewness       3.30066         9.45136         0.570482
Kurtosis                    1.05302        16.2404          0.190209
Standardized kurtosis       1.4095         21.7383          0.254601
Coeff. of variation        10.2508         53.9014          4.35568
Sum                       921              57              75.44
--------------------------------------------------------------------------
```

```
Variable:                  RPI
----------------------------------------
Sample size                 43
Average                    422.651
Median                     422.2
Mode                       415.6
Geometric mean             422.255
Variance                   341.768
Standard deviation          18.487
Standard error               2.81924
Minimum                    381.6
Maximum                    461.5
Range                       79.9
Lower quartile             408.9
pper quartile              437.7
nterquartile range          28.8
kewness                     -0.0449252
tandardized skewness        -0.120268
urtosis                     -0.519712
tandardized kurtosis        -0.67565
oeff. of variation           4.37405
um                       18174
----------------------------------------
```

STATISTICS - ANOVA

```
                          One-Way Analysis of Variance
--------------------------------------------------------------------------------
Data: HEART.Ahigh

Level codes: HEART.TIME

Labels:

Means plot: Tukey          Confidence level: 95        Range test: LSD


                             Analysis of variance
--------------------------------------------------------------------------------
Source of variation   Sum of Squares   d.f.   Mean square    F-ratio  Sig. lev
--------------------------------------------------------------------------------
Between groups              8577.178      2     4288.5891     26.143     .0000
Within groups              20669.860    126      164.0465
--------------------------------------------------------------------------------
Total (corrected)          29247.039    128

0 missing value(s) have been excluded.
```

```
Tests for Homogeneity of Variances
----------------------------------
Cochran's C test: 0.34343    P = 1
Bartlett's test: B = 1.00024   P(0.0299774) = 0.985123
Hartley's test: 1.05278
```

```
              Multiple range analysis for HEART.Ahigh by HEART.TIME
--------------------------------------------------------------------------------
Method: 95 Percent LSD
Level      Count        Average    Homogeneous Groups
--------------------------------------------------------------------------------
 1          43       116.72093    X
 2          43       128.48837     X
 3          43       136.58140      X
--------------------------------------------------------------------------------
contrast                                  difference  +/-    limits
1 - 2                                       -11.7674         5.46765 *
1 - 3                                       -19.8605         5.46765 *
2 - 3                                       -8.09302         5.46765 *
--------------------------------------------------------------------------------
                * denotes a statistically significant difference.
```

```
                                Sample Correlations
--------------------------------------------------------------------------------
                    HR3a           HR3b           HR3c           HR3d           HR3e          I
HR3a              1.0000          .8629          .8967          .8952          .8714        .58
                (  104)        (  104)        (  104)        (  104)        (  104)       (  10
                  .0000          .0000          .0000          .0000          .0000        .00

HR3b               .8629         1.0000          .8556          .8497          .8546        .48
                (  104)        (  104)        (  104)        (  104)        (  104)       (  10
                  .0000          .0000          .0000          .0000          .0000        .00

HR3c               .8967          .8556         1.0000          .9454          .8968        .56
                (  104)        (  104)        (  104)        (  104)        (  104)       (  10
                  .0000          .0000          .0000          .0000          .0000        .00

HR3d               .8952          .8497          .9454         1.0000          .9139        .53
                (  104)        (  104)        (  104)        (  104)        (  104)       (  10
                  .0000          .0000          .0000          .0000          .0000        .00

HR3e               .8714          .8546          .8968          .9139         1.0000        .53
                (  104)        (  104)        (  104)        (  104)        (  104)       (  10
                  .0000          .0000          .0000          .0000          .0000        .00

L3a                .5858          .4876          .5612          .5312          .5374       1.00
                (  104)        (  104)        (  104)        (  104)        (  104)       (  10
                  .0000          .0000          .0000          .0000          .0000        .00

C3a                .3747          .3768          .3809          .3381          .3328        .72
                (  104)        (  104)        (  104)        (  104)        (  104)       (  10
                  .0001          .0001          .0001          .0004          .0006        .00

L3b                .5355          .5906          .5772          .5476          .5596        .81
                (  104)        (  104)        (  104)        (  104)        (  104)       (  10
                  .0000          .0000          .0000          .0000          .0000        .00

C3b                .3375          .4344          .3849          .3451          .3182        .65
                (  104)        (  104)        (  104)        (  104)        (  104)       (  10
                  .0005          .0000          .0001          .0003          .0010        .00

L3c                .4234          .3780          .5074          .4732          .4763        .72
                (  104)        (  104)        (  104)        (  104)        (  104)       (  104
                  .0000          .0001          .0000          .0000          .0000        .00

3c                 .3382          .2890          .3642          .3497          .3383        .588
                (  104)        (  104)        (  104)        (  104)        (  104)       (  104
                  .0004          .0029          .0001          .0003          .0004        .000

3e                 .4672          .4271          .5539          .5193          .5504        .687
                (  104)        (  104)        (  104)        (  104)        (  104)       (  104
                  .0000          .0000          .0000          .0000          .0000        .000

3e                 .3447          .3247          .3590          .3442          .3626        .582
                (  104)        (  104)        (  104)        (  104)        (  104)       (  104
                  .0003          .0008          .0002          .0003          .0002        .000
--------------------------------------------------------------------------------
              Coefficient  (sample size)  significance level
```