THE EFFECTS OF RELATIVE SPEED ON SELECTED PHYSIOLOGICAL, KINEMATIC AND PSYCHOLOGICAL RESPONSES AT WALK-TO-RUN AND RUN-TO-WALK INTERFACES

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ABSTRACT

This study examined selected physiological, kinematic and psychological parameters related to human locomotion using absolute speed (m/s) and four relative speed methods based upon measures of morphological linearity (st/s, $v/\sqrt{gh}$, ll/s, fl/s). Particular attention was paid to the movement responses at the walk-to-run and run-to-walk interfaces.

Eleven male caucasian subjects volunteered to participate in the study. Following a period of treadmill habituation all subjects performed a test of maximal aerobic power, an "interface speed" test, an "interface $\dot{V}O_2$" test and 49 4-minute walking and/or running conditions incorporating the five speed methods.

The measured physiological, kinematic and psychological parameters followed presently accepted trends when plotted against increasing walking and running speeds. However, contrary to what the $\dot{V}O_2$ - speed relationship tends to indicate, two distinct locomotor interfaces were identified. Cadence and stride length differed significantly at the two locomotor interfaces. However the energy cost of locomotion for walking and running was not different at the walk-to-run interface. RPE was affected significantly by the locomotor pattern.

Relative speed had no significant effect on the variability of movement responses. It is suggested that unless diverse ranges in morphological linearity are a feature of the subject pool, relative speed does not minimize inter-subject variability in physiological, kinematic or psychological responses.

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CHAPTER ONE

INTRODUCTION

In the science of Human Movement two activities which have received increasing attention and which have been extensively investigated are walking and running (Bhambhani and Singh 1985). Walking as a fundamental movement has been widely studied in relation to two domains; the physiological and the biophysical (Kagaya 1976). Researchers have been very much concerned with aspects related to the latter domain, and have attempted to clarify problems associated with the act of walking itself; that is, those problems related to the temporal, kinetic and kinematic factors associated with human gait (Wall 1986).

Running has been meticulously investigated over the years, particularly in aspects related to the physiological domain. The energetics of running is a topic which continues to engender research (Costill and Fox 1969, McMiken and Daniels 1976, Noakes 1985, Sakurai and Miyashita 1985). One area of research common to both walking and running is concerned with the energy cost of human locomotion (Goslin 1985). However, a topic less well investigated is that related to the so-called locomotor interfaces.

Man, according to Charteris et al. (1976), is the subject of two imperatives, neither of which he can deny. The first is a movement imperative; man must move. The second is a versatility imperative; man was born with the will-to-know. Having established, at a rather simplistic level that man must move, that he must move with the structure provided by the genotype, and that he must, with that same structure exhibit versatility, his specific motives for movement become apparently unimportant. At this stage it is important to realize that there are various impulses to move, and at least some of these will in some way influence how economically and/or efficiently the movement will be.

> " In a broad sense it can be argued that Man's unique morphological adaptations, in answering the call to his behavioural predilection for habitual erectness, have so shaped him that in all gross locomotor functions in which the human body as a whole is moved from point A to point B, the pre-existing design for erect bipedalism predominates, setting limits upon what is moved and in what way........... Accordingly we are justified in regarding all forms of human gross progression as being associated with Man's dominant erectness" (Charteris et al. 1976).

Of necessity the two most fundamental forms of human locomotion are walking and running. In order for these two movement patterns to take place energy is required, as with all forms of human movement.

Differing amounts of energy are required for different tasks by different people. For that matter, for the same walking and/or running task different people require different amounts of energy. Although previous studies have investigated the biological variability of maximal oxygen consumption (Katch _et al._ 1982, Erickson _et al._ 1946), the variability in repeated measures of submaximal exercise has not been extensively examined (Armstrong and Costill 1985).

The causes for biological variation in submaximal oxygen consumption are not well understood. Considering the many homeostatic mechanisms at work in the human body, and considering response patterns to any given stimulus, it is difficult to isolate one or two primary factors contributing to biological variability (Armstrong and Costill 1985).

In particular, studies concerned with the analysis of human gait have used relative speed to reduce the variability obtained in the measured parameters (Charteris _et al._ 1982, Rosenrot _et al._ 1980). The concept of relative speed was first introduced by Grieve and Gear (1966) and is defined as that velocity determined with respect to some physical attribute of any individual and as such is used to "normalise" human locomotion. Initially relative speed was expressed in statures/second. In this form it may be defined as that fraction of the walker's own stature covered in overground distance per second. An alternative method, developed by Alexander (1976), is also in use, the Froude number; a method which apparently accounts for more diverse ranges in stature than statures/second alone does.

Gait parameters vary preeminently with the speed of walking (and probably running as well); for this reason it is misleading to work in terms of raw speed (ie. km/hr or m/s). Several relationships have been seen to be less variable when relative speed was used instead of absolute speed, in particular the relationship between stride length and the speed of walking. In addition, at slow speeds of walking the relationship between relative stride length and relative speed is linearized (Rosenrot et al. 1980). It is tentatively suggested that various physiological parameters, particularly oxygen consumption, would respond in a similar way to relative speed as some of the previously mentioned gait parameters (ie. that there would be less variability in oxygen consumption values with the use of relative speed than there is with the use of raw speed km/hr or m/s).

The presently accepted trends in the oxygen consumption-velocity relationship confirm that there is a distinctly curvilinear relationship between walking speeds and oxygen consumption up to a given speed, beyond which, for walking, the relationship becomes linear and is twice as steep as that for running at the same speeds. The oxygen consumption-velocity relationship for running is essentially linear (Bransford and Howley 1977, Mayhew 1977, Åstrand and Rodahl 1977). The break-point between the curvilinear trend for walking and the linear trend for running speeds is thought to occur at, or very close to, the speed at which people change their pattern of locomotion from a walk to a run (the walk-to-run interface).

It would appear logical on the basis of previous information to assume that since the response, in terms of the reduction in variability of certain gait parameters with the use of relative speed occurred, so too should the energy cost responses of walking and running tasks be less variable using the same , and other relative speed methods. Furthermore, since certain curvilinear relationships are linearized with the use of relative speed, it may be that the oxygen consumption-velocity relationship at the walk-to-run interface will be somewhat linearized using relative speed.

STATEMENT OF THE PROBLEM

Biological variability is a phenomenon which is clearly part of all human research and at present is not wholly understood. It is not easy to precisely portion this variability into specific sources, neither has the exact cause or combination of causes for this variation been identified. Several factors, broadly categorized as intrinsic and extrinsic by Frederick (1985), most certainly contribute to the variability in the energy cost of submaximal treadmill walking and running. These factors include: body mass, leg length, stride length, energy transfer between segments and shoe softness, shoe weight and circadian rhythms respectively.

The use of relative speed in whatever form has, at least in gait analysis, reduced some of the variability in certain measured parameters. It may logically be assumed from this that the physiological responses to specific standardized walking and running tasks will also be less variable when relative speed is used.

The trends in the oxygen consumption-velocity relationship for both walking and running have been established. The break point between the two distinct trends appears to occur at the point at which most individuals would naturally change their pattern of locomotion from a walk to a run.

The specific problem is therefore threefold:

1) To establish which, if any, relative speed method reduces the variability in the speeds at which people choose to change their pattern of locomotion at the walk-to-run interface.

2) To investigate the premise that some method of calculating relative speed will reduce the variation in the submaximal energy cost of standardized walking and running tasks across the walk-to-run interface.

3) To determine whether or not one of the selected relative speed methods will linearize the oxygen consumption-velocity relationship across the chosen range of walking and running speeds.

CONCEPTUAL ISSUES

The conceptual issues facing any form of research in Human Movement are concerned, firstly, with methodology and secondly with specific issues associated with the frequently mentioned "integrative approach".

In most cases both philosophical and scientific (empirical) methods are used. The former allows logical consequences to be traced and rational arguments to be developed on the basis of existing facts. The latter involves the collection of new data in order to test the research hypotheses which have been established for any particular investigation. A combination of the two methods is apparently most appropriate and lends itself in part to the provision of solutions to the problems associated with the integrative approach, as well as providing the best means of elucidating the problems posed in the research hypotheses.

The methodology of this study is staunchly fixed in the integrative approach required in the conceptual model proposed by Charteris *et al.* (1976). Human Movement, in any form, in terms of the focus of this conceptual model is "incompletely and unsatisfactorily elucidated when studied, however meticulously, from the stand-point of only one of the physical, biological or social sciences." (Charteris et al. 1976).

This integrative approach is not, however, without problems. It poses problems for the scholar who can no longer be restricted by the defined boundaries of contributary disciplines within which to study separate aspects of human existence, for they are not separate in this real life situation. It poses problems too for the writer, for a single temporal dimension is implicit in the act of communication and the attempt is to communicate a multi-dimensional rapid succession of events. Nothing can be done but to present one concept and then the next, one section and then the next and trust that the readers' growing awareness elicits for him the synthesis into a multi-dimensional whole (Whiting 1975).

RESEARCH HYPOTHESES

The following research hypotheses were developed for investigation:

1) That there is no difference in the speed at which subjects change from a walk to a run at the walk-to-run interface, and from a run to a walk at the run-to-walk interface.

2) That the use of relative speed reduces the variability in the speeds at which subjects change from a walk to a run at the walk-to-run interface, and from a run to a walk at the run-to-walk interface when compared with the variability in speed at the same interfaces for absolute speed.

3) That there is no difference between walking and running at the walk-to-run interface in the following categories of variables:

a) kinematic
b) physiological
c) psychological (perceptual)

The above hypothesis was applied to all the measured variables in these three categories:

i) KINEMATIC: Stride length, cadence

ii) PHYSIOLOGICAL: oxygen consumption (ml/kg/min) and efficiency of movement (%).

iii) PSYCHOLOGICAL: Ratings of perceived exertion.

4) That the use of relative speed reduces the inter-subject variability in the selected kinematic, physiological and psychological parameters during walking and running.

5) That there is a linear relationship between oxygen consumption and velocity of locomotion across the interface between walking and running when the velocity is made relative to the morphology of the individual.

STATISTICAL HYPOTHESES

1)

$$Ho: \mu wr = \mu rw$$

$$Ha: \mu wr \neq \mu rw$$

where μwr is the mean speed for 11 subjects at the walk-to-run interface.

μrw is the mean speed for 11 subjects at the run-to-walk interface.

2)

$$Ho: \mu rcv = \mu acv$$

$$Ha: \mu rcv \neq \mu acv$$

where μrcv is the coefficient of variation for speed (km/hr and m/s) for all relative speed methods (st/s, $v/\sqrt{gh}$, ll/s, fl/s).

μacv is the coefficient of variation for speed using absolute speed (m/s).

3)

$$Ho: \mu fc = \mu f$$

$$Ha: \mu fc \neq \mu f$$

where μfc is the mean for the "free choice" movement patterns at the walk-to-run interface and run-to-walk interface.

μf is the mean for "forced" movement patterns at both the above mentioned locomotor interfaces.

4)

$$Ho: \mu w = \mu r$$

$$Ha: \mu w \neq \mu r$$

where μw is the mean inter-subject variability for walking in each of the three categories of variables.

μr is the mean inter-subject variability for running in each of the three categories of variables.

DELIMITATIONS

Eleven male caucasian Physical Education students volunteered to participate in this study. The subjects were required to visit the laboratory on six different occasions. For those subjects who had had no previous experience in treadmill walking and running an additional visit was a prerequisite for further testing. During this visit they underwent a period of treadmill habituation.

With the exception of anthropometric measurements all testing was done on a Quinton Model 643 motor driven treadmill. The anthropometric measurements taken on each subject were as follows: stature, sitting height, foot length, body mass, and two skinfold fat measurements; a subscapular skinfold and a thigh skinfold.

The treadmill testing involved firstly a test of maximal aerobic capacity ($\dot{V}O_2$ max test), secondly an interface speed test where each individual's walk-to-run and run-to-walk interfaces were determined, and finally 49 4-minute walking and/or running conditions were done incorporating 5 speed methods namely; absolute speed, statures/s, $v/\sqrt{gh}$ as developed by Alexander (1976), leg lengths/s and foot lengths/s. During the test of maximal aerobic capacity and all the walk-run conditions the following physiological data were collected using a computer aided on-line system:

> $\dot{V}O_2$ (l/min), $\dot{V}O_2$ (ml/kg/min), $\dot{V}CO_2$ (l/min), Respiratory exchange ratio (R), $\dot{V}I$ (l/min), $\dot{V}f$ (breaths/min), and $\dot{V}t$ (l/breath).

In all the treadmill tests walking and running cadence was counted in steps per minute and ratings of perceived exertion obtained using the Borg scale.

LIMITATIONS

There are limitations to all research projects in which human subjects are used (Boring 1969). One of the most common and broadly categorized limitations is that what is "ideal" is not always practical and what is most practical is not always ideal. Clearly then, a compromise between what is "ideal" and what is practical in obtaining acceptably accurate and reliable results must be reached. In keeping with this contention the following were considered to be the limitations of this study:

The number of subjects (11) constitutes a limitation in that the data are insufficient to generate any conclusive results with respect to trend and factor analysis.

That all subjects were Physical Education students may be considered to be a biased selection of subjects from which to generate data. These students tend to be physically better conditioned than others. Responses to exercise are known to differ between fit and unfit people. A more diverse range of "fitness" levels in the subjects tested may have led to a more complete understanding of the problem.

Due to the fact that such small increments in speed over the experimental range of speeds were chosen it may be that the sensitivity of the on-line analysis system was inadequate to accurately reflect these changes. However the fact that each subject performed 49 walking and/or running conditions should mean that the mean responses to these conditions will sufficiently reflect the work done during each 4-minute condition.

Subjects worked at varying times during the day and were exposed to differing environmental conditions. Diurnal variations coupled with mild variations in environmental conditions may have affected performance responses (Åstrand and Rodahl 1977, McArdle et al. 1981).

CHAPTER TWO

REVIEW OF LITERATURE

MORPHOLOGY AND LOCOMOTION

Tall and short people adopt different locomotor strategies when walking at the same absolute velocities. The taller people generally are capable of larger stride lengths than the shorter people and therefore take fewer steps than shorter people at any given speed. In order for the shorter person to maintain the same cadence he must use an exaggerated stride length. From whichever point of view one examines this problem, it appears that the shorter person would have more difficulty maintaining a comfortable gait pattern at any given absolute velocity than a tall person. Certainly the kinematics of locomotion differ according to stature for absolute walking speeds (Murray et al. 1964).

In many studies (Taylor et al. 1970, Alexander 1976, Alexander 1977, Heglund et al. 1982) where morphology has been related to locomotion it has been clearly indicated, for a variety of species, that body length (stature) plays a role in both the mechanics of locomotion and the physiological response to the locomotor task. Several attempts have been made to account for the effects which morphology have on these groups of factors. Initially Grieve and Gear (1966) recognised the significance of stature in modifying the kinematics of locomotion and developed the concept of relative speed to equalise velocity on the basis of stature.

Since then, not only have additional relative speed equivalents been developed, but researchers have used relative speed to equalise locomotor conditions between subjects for the purpose of kinematic or rehabilitative analyses as well as to enable physiological assessment (Das and Ganguli 1979, Wall and Charteris 1981, Charteris 1982).

Allometric principles serve to introduce the relationship between form and function (Goslin 1985). There exists between different parts of an organism definite relationships such that if one structure changes, others will also change by amounts depending on the relationship (Harrison et al. 1977). Body surface area and cross-sectional area of muscle are proportional to linear size raised to the second power, while volumes are generally proportional to linear size raised to the third power (Åstrand and Rodahl 1977). Length, area, and volume are related, in the same way, to the dynamics of muscular contraction and the supporting cardio-respiratory system (Goslin 1985). As a result of these relationships, generally speaking the taller and heavier person is at a disadvantage when it comes to accelerating his body mass.

Leg length is an important linear measure related to locomotion. The correlations between leg length and stature are very high, ranging between r = 0.99 and r = 0.864 (Rosenrot et al. 1980, Harrison et al. 1977). Measurement of leg length has provided some difficulty in that there are differing views about what actually constitutes leg length. However because of the ease of measuring stature and the high degree of relationship between stature and leg length, it has been suggested that stature be used, rather than leg length, in equating the relative velocities of individuals of differing linear dimensions (Rosenrot *et al.* 1980).

The relationship between leg length and the energy cost of locomotion has been explored by a number of authors. Stature was shown by Wyndham and Heyns (1969) to be only a minor determinant of the oxygen consumption in walking and running. However, Wyndham *et al.* (1971) in a study of the energy cost of treadmill and overground walking, found that body mass accounted for 80% of the variance in oxygen consumption between subjects and that stature and leg length were only very slightly negatively related to energy cost. Van der Walt and Wyndham (1973) suggested that differences in stature have no significant influence upon the energy cost of walking but that such differences significantly influence the energy cost of running. These authors found that differences in stature accounted for 2% of the inter-individual variation in oxygen consumption at any given running speed (2.22 - 3.57 m/s). The same authors developed prediction equations for the energy cost of walking and running partially based on morphology. The major determinants were body mass and velocity. Cotes and Meade (1960) identified that the vertical lift per step was a function of leg, foot and step lengths. However Dean (1965) found that ankle flexion was more important than either foot or leg length in contributing to this vertical lift.

Stride length-leg length relationships were examined by Hogberg in the early fifties (1952a and 1952b). These investigations indicated that stride length increased almost linearly with velocity in two subjects running at speeds between 2.22 m/s and 8.31 m/s. Stride length appeared to be significantly related to leg length at speeds between 2.22 m/s and 7.48 m/s. Irrespective of this relationship, Hogberg concluded that it was leg drive and not the length of the legs which made the greatest contribution to increasing stride length during fast running. In direct contrast to these early works, Cavanagh and Williams (1982) found that there was no relationship between stride length and leg length in runners while running on a treadmill above and below their preferred stride length. Leg length may however be an important determinant of the efficiency of locomotion (Caterisano and McMurray 1982).

During free walking, stature and stride length appear to be directly related in that short men tend to take shorter strides than tall men (Murray et al. 1964). The effects of stature on the energy cost of locomotion are not clearly defined. Oxygen uptake has been seen to be proportional to gross body mass and was only slightly influenced by stature (Miller and Blyth 1955). Wyndham et al. (1967 and 1971) found that stature was negatively correlated with $\dot{V}O_2$ max but only 3% of the variability in maximum values could be attributed to height.

In contrast to these findings a number of researchers have reported a direct relationship between stature and the energy cost of locomotion (Goslin 1985). Williams et al. (1966) found that tall men performed a variety of work tasks more efficiently than short men. Wyndham and Heyns (1969) found that stature was negatively correlated with maximal oxygen uptake and accounted for 4% of the difference between individuals. Daniels and Oldridge (1971) examined the effects of training on growing boys. They found that maximal oxygen uptake did not change but that there was a 12.5% reduction in submaximal oxygen consumption. It was suggested that growth (much of it in leg length) could explain the improved economy.

Reference has been made in the literature to the fact that energy expenditure and gross body mass are significantly correlated during walking and running (Durnin and Namyslowski 1958, Wyndham and Heyns 1969, Wyndham et al. 1971). The correlation between body mass and oxygen consumption at any given running speed was found to be between $r = 0.76$ and $r = 0.96$ (Wyndham et al. 1971). Wyndham et al. (1963) reported that gross body mass is the major determinant of oxygen consumption when men lift their body weight against gravity. Wyndham et al. (1971) suggest that oxygen consumption at any given speed is linearly related to body mass. Body mass therefore appears to be the most important determinant of oxygen consumption at any given speed of progression (Erickson et al. 1946, Wyndham et al. 1971, Van der Walt and Wyndham 1973). However as soon as oxygen uptake is expressed as a relative term, per unit of body mass ($mlO_2/kg/min$), individual variations are for all intents and purposes eliminated (Mayhew 1977, McArdle et al. 1981).

Body composition is a factor which in relation to oxygen consumption must be taken into consideration. Fat tissue adds mass to an individual, which must also be moved, but is not metabolically active mass (Goslin 1985). Young sedentary males tend to have between 12% to 18% body fat (Wilmore and Brown 1974, Wells and Plowman 1983). Activity tends to reduce adipose deposits, and the amount of fat which individuals performing different tasks carry differs according to the task which they perform. Males and females of necessity tend to possess differing amounts of body fat. Young sedentary females have from 22% to 28% body fat on average (Wilmore and Brown 1974). This sexual difference has provided information to the effect that the energy cost of locomotion is higher in females than in males; 78% trained and 15% untrained subjects (Sparling and Cureton 1983).

There are several other morphological factors which influence the relative energy cost of locomotion and which differ between males and females. These include the structure of the pelvis and iliofemoral ligaments, femoral convergence, leg mass to body ratio and thigh fat deposition.

Just as in man several factors affect the velocity and mechanics of locomotion as well as the physiological response to given locomotor tasks, the same is true for quadrupedal and bipedal terrestrial animals. The major factor which affects the latter groups of animals is body length (Alexander and Jayes 1980). If meaningful comparisons are to be made between animals of different sizes, an appropriate non-dimensional parameter is needed to serve as a criterion for physical similarity (Goslin 1985). The Froude number, which applies to any situation where inertia and gravity interact, is useful in this respect and assessments of speed, made relative to stature in this way, have been used to examine the gait characteristics of people (Alexander and Jayes 1980) as well as prehistoric animals.

The idea of setting the speed of locomotion relative to stature in order to "normalise" gait characteristics in humans was introduced by Grieve and Gear (1966). They developed relationships between velocity, cadence, swing time and stride length in children and adults. Grieve (1968) compared males and females at the same relative speeds and found that the relationship between cadence and relative speed was best described by a power-fit curvilinear regression and that for an individual this relationship was stable. The duration of swing was found to be related to cycle time and stature and it, too, was very stable within an individual (Goslin 1985).

Rosenrot et al. (1980) found for males that at self-selected slow, comfortable and fast overground walking speeds stride time was more highly related to relative speed (leg lengths/s) than relative speed (st/s) or absolute speed. Charteris et al. (1982) showed that the relationship between stride length and relative speed during walking (0.4 to 1.0 st/s) was linear.

In a study involving 17 young male subjects running overground at slow through maximum speeds cadence was seen to be linearly related to relative speed. Similarly the energy cost data indicated a single linear relationship between relative speed and energy cost per kg body mass. Relative speed has also been used to habituate subjects to treadmill walking (Wall and Charteris 1980,1981). Habituation was required to reduce the variability in the angular kinematics and temporal aspects of human gait.

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

very slow	0.3 st/s
slow	0.4-0.6 st/s
slow medium	0.7 st/s
medium	0.8-1.0 st/s
medium fast	1.1 st/s
fast	1.2-1.4 st/s
very fast	1.5 st/s and up.

Relative speeds of less than 0.3 st/s and greater than 1.6 st/s are considered to be outside the range of speeds in which "normal walking" occurs. Based on data from many empirical studies "preferred speed" was described as 0.85 st/s, where "preferred speed" was that speed freely chosen by the individual.

The use of st/s as a means of "normalising" human gait has tended to dominate the literature to date. However, Alexander (1984) suggests that a dimensionless ratio in the form $v/\sqrt{gh}$ best suits empirical relationships which apply to systems of different sizes. (Where v = velocity (m/s); g = gravity (m/s squared) and h = stature (m). He suggests that the use of this dimensionless ratio accounts for more diverse ranges in stature than st/s alone. Regardless of which relative speed method is used, comparisons between the gait characteristics of individuals should be done using relative speed, taking linear dimension into account, rather than having subjects walk or run at absolute speeds (Grieve and Gear 1966, Alexander 1977, Charteris 1982).

THE MECHANICS OF WALKING AND RUNNING

"Human movement is the result of a network of causation which encompasses man's biophysical, physiological, psychological and conceptual being. Human locomotion is no less complex. Form and function interact intricately with intentionality to produce the locomotor versatility we take for granted" (Goslin 1985).

Fenn (1930) was one of the founders of research which attempted to integrate the mechanics and the energetics of locomotion. Steindler (1935) suggested that horizontal locomotion requires that work be done vertically (against gravity), horizontally (to maintain momentum), and also to swing the multi-segmented pendulum of the leg.

Six major determinants of gait have been identified; pelvic rotation, pelvic tilt, knee and hip flexion, knee and ankle interaction and lateral pelvic displacement (Saunders et al. 1953). The extent to which each of these determinants contributes to a particular gait pattern is not fully understood. During straight, level walking at a constant cadence, energy expenditure is divided equally between rhythmic oscillations of the legs and elevation and depression of the body's centre of gravity. The knee primarily absorbs energy while the ankle and hip do more positive and negative work. Energy transfer and storage are important factors (Saunders et al. 1953).

Increases in the velocity of locomotion can be achieved in one of three ways and tend to be a function of step frequency and stride length. The three means of increasing locomotor velocity are as follows:

1) by increasing the number of steps taken each minute (step frequency)
2) by increasing the distance between steps (step length)
3) by increasing both the length and the frequency of stepping (McArdle et al. 1981).

Increases in speed are usually induced by increases in stride length, with little or no change in step frequency (Åstrand and Rodahl 1977). Joint angle changes appear to be related to stride length changes, and the changes in joint angle are linearly related to power output in sprint running (Fukunaga et al. 1981).

The stride length-speed relationship is linear for both walking (Charteris et al. 1982) and for running (Knuttgen 1961). During fast running stride length is long and cadence low with a high knee lift. McArdle et al. (1981) showed that when running speed was increased, stride length increased by as much as 83%. In additional research the same authors reported that by doubling the running speed from 2.77 m/s to 5.54 m/s, the stride length was increased by 85%, with only a 9% increase in stride frequency. Increases in stride length appear to be the primary means by which people increase locomotor velocity, particularly at speeds greater than 2.77 m/s. Increases in stride length can be achieved in three ways (Hogberg 1952).

1) by extending the lower leg
2) by increasing the angle of the thigh in the sagittal plane
3) by using a more forceful leg drive.

The first of these three procedures is uneconomical because the body's centre of gravity takes longer to reach a point in front of the forward most foot, a position which is necessary to allow the front foot to thrust backwards relative to the floor thereby providing a propulsive force in the direction of the desired progression. The second procedure generally results in an exaggerated lateral oscillation of the pelvis which requires a large compensatory shoulder oscillation (Goslin 1985). Increasing stride length by increasing the force of the leg drive has proved to be the most efficient of these three suggested methods

(Hogberg 1952). Foot contact time decreases with increasing speed (Cavagna et al. 1976) implying that the contractile components play a progressively less important role as speed increases.

The relationship between leg length and stride length is not a clear-cut issue (Goslin 1985). During free walking stride length is apparently directly related to stature in that short people tend to take shorter strides than tall people (Murray et al. 1964). The literature reports conflicting evidence regarding this relationship in that Hogberg (1952a) reports a significant relationship between leg length and stride length for speeds between 2.22 m/s and 7.48 m/s. In contrast to this, Cavanagh and Williams (1982) found no relationship between leg length and stride length when investigating distance runners.

The effects of changes in the energy cost of performing a task with changes in stride length and cadence have been well documented. However, there are conflicting views on the contributions of stride length and leg length to variations in oxygen consumption during walking and running. Van der Walt and Wyndham (1973) found that the latter two factors accounted for only 2% of the variance in oxygen consumption during free running, while in other investigations individual variations in oxygen uptake have been seen to be unrelated to stride length (Booyens and Keatinge 1957, Kram et al. 1985). Under-striding and over-striding result in more than optimal energy cost values for running. There are, both for walking and running, optimal stride lengths which minimize the energy cost and tend to be those freely chosen by individuals (Knuttgen 1961, Cavanagh et al. 1978, Cavanagh and Kram 1983). McArdle et al. (1981) suggest that over-striding is more "costly" than under-striding at any given velocity, although both will tend to result in less than optimal efficiency. This decreased economy with a greater than optimal stride length was felt to be a function of increased vertical oscillation of the centre of gravity (Cavanagh and Williams 1982). On the other hand, under-striding is less efficient because the capacity of the muscles to recover sufficiently between strides is limited as a result of the increased stride frequency (Burke and Berger 1976).

Shields (1982) found that a stride length equal to 80% of total leg length was more efficient than a stride length equal to only 60 or 70% of leg length. These findings tend to augment those of McArdle et al. (1981) who suggested that it was less efficient to adopt a stride length shorter than that freely chosen by the subject at any given speed.

Competition walking provides some interesting data regarding the relationship between stride length and energy cost. Unlike running where there is no period of double support, competition walking requires that the back foot remain on the ground until after the front foot makes contact (Broer 1966). Thus, lengthening the stride becomes an ineffective means of increasing speed in competition walking (McArdle et al. 1981). Due to this standardisation of style in competition walking, additional energy must be expended to enable the trailing leg to move forward very rapidly, this requires a corresponding but opposite involvement of the trunk and arm musculature as well as a corresponding forward rotation of the pelvis. This style allows walkers to attain horizontal speeds of up to 4.05 m/s (14.6 km/hr), speeds far in excess of those attainable during "normal walking" (Menier and Pugh 1968, McArdle et al. 1981). At these high speeds, because of the nature of the relationship between oxygen consumption and walking and running speeds, it would be far more economical to run than it would to walk, but the nature of the event stipulates a walking pattern (Menier and Pugh 1968).

Stature may be related to the energy cost of locomotion. Slocum and James (1968) showed that a short legged runner using a rapid cadence compared with a long legged runner with a slow cadence will be less efficient at the same velocity. Cadence also appears to affect the energy cost of locomotion. Some investigators found that cadence increases linearly with velocity during walking, but does not change much at all during running (Ogasawara 1934, Knuttgen 1961). Grieve (1968) found that when cadence and relative speed are related during walking, a power-fit curve best describes this stable relationship. Energy cost is minimized during movement at freely chosen cadence (Zarrugh 1981). This optimum depends upon cadence being directly proportional to step length. Zarrugh et al. (1974) found that optimal energy expenditure occurred when the step length to cadence ratio was 0.007 m/step/min.

For many relationships which include the energy cost of performing a task there are energetic minima or "optimal phenomena" (Cavanagh and

Kram 1985). Hagberg et al. (1981) proposed some reasons for the existence of these "optimal phenomena" in movement tasks; a lot of their work referred to cycling, but in terms of the frequency of limb movement the principles are the same as those for cadence during walking and running. They suggested that above preferred pedal speed the muscle fibre recruitment rate was increased and below preferred pedal speed more force per pedal stroke was required. At both above and below preferred speed oxygen uptake, lactate, respiratory exchange ratio and minute ventilation were higher; muscle fibre type may be another influential factor. It is suggested that the predominant use of slow-twitch fibres at rapid pedal rates may require a substantial increase in energy expenditure (Suzuki 1979). This is related to the fact that slow-twitch fibres become glycogen depleted first, thus the slow-twitch group must call upon less economical fast-twitch fibres at higher speeds (Goslin 1985).

The amount and type of work done and the way in which the work is accomplished has proved to be a contentious issue over the years. Winter, in his several publications (1978a, 1979a, 1982a, 1982b) has attempted to outline the concept of work in some detail, and how it is related to human locomotion. The work done during locomotion is substantial and energy is transferred from one part of the body to another (Goslin 1985). Winter (1978a) amongst other classifications of work, refers to internal and external work. Internal work refers to the mechanical work done to move the body segments through the desired pattern to accomplish a given movement. External work is the mechanical work done by the body on an external load. The total work done by the body is therefore the sum of the internal and external work (Winter 1982a). The only external work done during locomotion on the level is that necessary to overcome air and ground friction. This implies that most of the work done during locomotion at 0% grade comprises internal work. The measurement of the total work done therefore requires the summation of the potential, kinetic and rotational energies of each of the segments of the body (Winter 1982a). The importance of internal work can be illustrated by research done by Kaneko et al. (1979). They found that as cadence increased, internal work increased from 0.5 to 2.0 kcal/min while external work decreased from 2.7 to 1.7 kcal/min. Power output and the work done during locomotion are of necessity related. Cavagna et al. (1977) found that the total power output during locomotion is a linear function of velocity. Horizontal power output is a function of the velocity of movement squared (Åstrand and Rodahl 1977).

Work done during locomotion includes the forces involved in the movement task. Investigations of the forces involved in locomotion show that horizontal power output increases progressively with increases in speed, but that vertical power output remains constant or even decreases (Goslin 1985). As the speed of running increased from 3.9 to 9.3 m/s Komi and Bosco (1978) showed that the change in the displacement of the centre of gravity decreased from 11cm to 4cm. Cavagna and Margaria (1966) examined the horizontal and vertical force output during overground walking. They found that work due to velocity in the horizontal direction increases progressively with speed, but vertical work stays constant. They also found that forward work is greater in walking than in running at the same speed and speculated that this was due to extra isometric work done while walking.

The compensatory activity of the upper limb movement during walking and running is fundamental to efficient performance of these tasks. Arm and shoulder movements increase as the speed of walking increases to counteract pelvic oscillations and leg movements (Menier and Pugh 1968). Hinrichs and Cavanagh (1983) found that the arms contribute very little angular momentum about the transverse or anterior-posterior axes but they contribute substantially about the vertical axis during running. The arms counter the effect of leg angular momentum in the opposite direction. These authors noted substantial variations in arm contribution to angular momentum which could account for part of the variance in efficiency.

The specific actions of the musculature of the legs in particular during walking has provided some interesting data. Van der Straaten <u>et al.</u> (1975) examined the electromyographic activity of quadriceps, hamstrings and gastrocnemius during overground walking. These authors showed that the muscles demonstrated the same patterns at all speeds (0.55,1.39,and 1.94 m/s), but at 0.55 m/s there was greater muscular activity during the stance phase of the walking cycle and at 1.94 m/s muscular activity was greater during the swing phase. Muscular activity at 1.39 m/s appeared to exhibit an optimal balance between intrinsic and extrinsic forces while there was considerable inter-subject variability in the patterns of muscular activity at 0.55 m/s and 1.94 m/s. These variations may also contribute to often marked inter-subject variations in economy and efficiency (Goslin 1985).

With the growing use of the treadmill as an experimental tool for evaluating locomotion (Shields 1982), the question often arises as to whether the results obtained from treadmill studies can be directly applied to and/or compared with the results obtained from studies evaluating overground locomotion. Several investigations have shown that no significant difference in oxygen consumption exists between overground and treadmill running at least up to a speed of 4.33 m/s (15.6 km/hr) (Bobbert 1960, Wyndham et al. 1971, Dal Monte et al. 1974, McArdle et al. 1981). However the above suggestions are based on the assumption that wind/air resistance is equal for both treadmill and overground running. Investigations concerning the effects of air resistance have shown that there is a significant increase in oxygen consumption with increases in air resistance (Dressendorfer 1979, McArdle et al. 1981, Daniels 1985). Depending on running speed, overcoming air resistance accounts for 3.6% to 9% of the total energy requirement for running in calm weather (McArdle et al. 1981). It follows therefore, that as the air resistance increases, the oxygen cost of running at a given speed increases proportionally. The magnitude of the effect of air resistance upon the energy cost of locomotion varies with three factors: 1) the density of the air, 2) the body surface area of the runner, and 3) the square of the wind velocity (McArdle et al.

1981). Pugh (1970) reports that the slope of the oxygen consumption-speed relationship was much steeper for overground than for treadmill running. The coefficient of variation for oxygen consumption was significantly greater for road walking than for treadmill walking (24% and 14% respectively) (Wyndham et al. 1971). This reflects the inter-subject variance in oxygen consumption for the two modes.

Variations in the kinematics of locomotion have been observed between initial treadmill running and overground running (Cavanagh and Williams 1982). For example, treadmill running was characterised by longer support times, lower vertical velocity and less variable vertical and horizontal velocities (Goslin 1985). Support time was shorter in overground locomotion and cadence was higher (Nelson et al. 1972). Walking at various relative speeds tended to reverse these patterns (Taves et al. 1985). They found that cadence was greater on the treadmill, and that there were some kinematic differences between the two modes of locomotion during double support and during the early and late parts of the swing phase. These discrepancies are however to a large extent eliminated following habituation to the treadmill (Wall and Charteris 1981). In fact, following such habituation, the energy cost of treadmill running is highly correlated to the energy cost of normal running in conditions of minimal air resistance.

THE LOCOMOTOR INTERFACES

It is generally and correctly understood that, as a means of locomotion, walking is suitable for slower speeds up to a certain limit which differs from individual to individual, whereas running is more suitable for higher speeds (Ogasawara 1934). The average man cannot sustain normal walking at very high speeds, nor can he execute the normal movements of running at very slow speeds (Ogasawara 1934). The muscular mechanisms of the body are adapted to run instead of walk when higher speeds are required, and to walk instead of run at slower speeds (Broer 1966).

Oxygen consumption is directly related to the mass of active muscle tissue involved in exercise and both of these determine the dynamics of the cardiovascular response to exercise (Lewis et al. 1983). Oxygen consumption increases as the velocity of locomotion increases. Early researchers (Ogasawara 1934, Knuttgen 1961) reported this relationship to be linear for walking and a power-fit relationship for running. However, more recently most investigators have reported the opposite results (Åstrand and Rodahl 1977, McArdle et al. 1981). The oxygen cost of walking has been seen to be curvilinearly related to velocity, in such a way that the oxygen uptake increases as a function of velocity squared. Generally speaking the energy cost of running has been found to be linearly related to the speed of movement (Ogasawara 1934, Menier and Pugh 1968, Mayhew 1977, Fukunaga et al. 1980).

Ralston (1958), investigating the energy expenditure of walking at various speeds found that a "natural" or "comfortable" speed of walking corresponded to an optimal speed which required minimum energy per unit distance walked. Furusawa et al. (1924) and Ogasawara (1934) observed that the energy expenditure for walking was greater than that for running at high speeds. The lines relating energy expenditure to velocity for walking and running intersect at about 2.22 m/s (8 km/hr) (Menier and Pugh 1968, Kagaya 1976). This implies, and concurs with data obtained from Furusawa and Ogasawara (1924, 1934), that walking is more economical than running at speeds slower than 2.22 m/s, but that running is the more economical form of locomotion at speeds faster than 2.22 m/s. Van der Walt and Wyndham (1973) and Åstrand and Rodahl (1977) have also reported that this intersection point occurs at about 2.22 m/s. Other studies have however, reported different speeds at which this "metabolic intersection point" occurs: Bobbert (1960) and Daniels (1985) quote 1.99 m/s (7.2 km/hr) as being the intersection speed; Shields (1982) suggests a speed of 2.13 m/s (7.7 km/hr), and Shephard (1969) refers to a speed as high as 2.47 m/s (8.9 km/hr) as being the speed at which the intersection occurs. Kagaya (1976) reported the "metabolic intersection speed" to occur at 2.15 m/s (128.9 m/min ± 6.01). Noble et al. (1973), on the other hand, suggest that this intersection occurs at 2.22 m/s which compares extremely favourably with the speed at which Candler (1986) reported the walk-to-run interface to occur (2.22 m/s). Noble et al. (1973), however, used heart rate as an indicator of metabolism, whereas the majority of studies to date have used oxygen consumption as an indicator of metabolism. The differences appear to reflect, as do so many measurable responses to exercise, the fact that there is a large inter-subject variation in the point at which the "metabolic intersection speed" occurs. McArdle et al. (1981) recognise the fact that inter-individual differences in the location of the intersection point do exist, and suggest that running becomes more economical at speeds between 1.94 m/s and 2.49 m/s (7 and 9 km/hr respectively). Kagaya (1976) suggests that the "metabolic intersection speed" lies between 2.0 m/s and 2.33 m/s for ordinary male subjects. This range is slightly higher than that suggested by McArdle et al. (1981), but nevertheless acknowledges the fact that there is inter-individual variation which affects the location of this interface speed. Candler (1986) reported that the run-to-walk interface speed occurred at 2.05 m/s which is a slower speed than that at which the "metabolic intersection speed" occurs. In addition to this, he suggests that the use of oxygen consumption as a means of locating the locomotor interfaces creates a false impression in that the energy cost curves tend to imply a single interface speed. The intersection point between the energy cost curves appears to closely reflect the position of the walk-to-run interface, however, the run-to-walk interface speed occurs at a significantly slower speed and is therefore apparently non-existant when the energy cost curves are used as a means of locating the locomotor interfaces.

There is however, a range of speeds either side of the "metabolic intersection point" within which normal walking and running are possible although several investigators have suggested that running is more economical at these speeds (Benedict and Murschhauser 1915, Ogasawara 1934). When the speed of movement is essentially the same, the differences in the energy cost for walking as compared to running range from approximately 4% at a speed of 2.01 m/s (7.4 km/hr), to 15% at 2.52 m/s (9.1 km/hr) and 20% at 2.88 m/s (10.4 km/hr) (Ogasawara 1934). These data suggest that it may be more costly in terms of energy expenditure to run at a speed of 3.88 m/s (14 km/hr) than it is to walk at a speed of 2.77 m/s (10 km/hr) (Åstrand and Rodahl 1977).

Several reasons have been proposed for the increased oxygen requirement of walking at speeds in excess of 1.94 m/s to 2.49 m/s (as opposed to running at the same speeds). In the case of running, fewer movements are made than in walking although the speed of progression and the total distance covered may be the same (Ogasawara 1934). Calculations of the actual oxygen required per stride show that at the same speed of movement, whether walking or running, each stride necessitates approximately the same energy expenditure. In as much as the length of stride in normal walking is less than in running (Knuttgen 1961), more strides must be taken to maintain the speed and cover the distance, and the difference in the oxygen requirement appears to be a function of the number of strides taken per unit of distance covered (Ogasawara 1934).

Furthermore, Benedict and Murschhauser (1915) suggest that the action of the arms during locomotion causes a marked increase in energy expenditure. In walking at high speeds the compensatory arm actions become more vigorous in order to counteract the leg action. This vigorous, across-the-chest arm action may account for the increased oxygen consumption of walking as compared to running during which the arm action is less pronounced (Ogasawara 1934).

Excessive movement of the hips as a result of pelvic oscillation, resulting in compensatory shoulder movement is also characteristic of walking at high speeds. The result of this is that large groups of muscles are working unnecessarily and the walking becomes less efficient (Hogberg 1952). The common factor which appears to determine the differences in oxygen consumption between walking and running at the same speed is the amount of the total musculature being utilized. In walking the proportion is larger than during running (Ogasawara 1934). The increased number of muscular movements are themselves a function of:

i) the shorter length of stride which necessitates a greater number of strides per unit distance.

ii) the excessive compensatory arm movements across the chest during fast walking.

iii) the exaggerated transverse plane rotation of the hips and corresponding action of the shoulders, and

iv) the sustained contraction of the muscles of the legs due to the straight-leg action; walking degenerates into running by virtue of a bent-knee action at high speeds.

Strict comparisons of walking and running, in terms of the energy cost of these tasks could only be made if the speed of movement was equal, and the same length of stride were adopted in each case (Ogasawara 1934). In relation to these comparisons, Candler (1986) found that, despite the fact that the speed of movement was constant (2.22 m/s), and set at the average speed at which the walk-to-run interface occurred, oxygen uptake values were essentially the same for walking and running. The physiological intensity of the work done at the walk-to-run interface speed was reported by Kagaya (1976) as being 64.9% of maximal oxygen uptake. This was substantially higher than the relative intensity for walking at the "optimal speed" (22% of maximal oxygen uptake).

The kinematics of locomotion at the interface speeds have been less well investigated than the metabolic and respiratory responses. However, Candler (1986) reported that for walking and running at the speed at which the walk-to-run interface occurred cadence and stride length patterns differed significantly. Walking was accomplished by means of a large stride length and relatively slow cadence which induced exaggerated pelvic oscillations and compensatory upper body movement. Running on the other hand was achieved by shorter strides and a faster cadence which reduced the pelvic oscillations but increased vertical displacement of the centre of gravity. Despite these kinematic differences, oxygen uptake was essentially the same for both locomotor patterns.

In general, there is a large body of literature which suggests that running should be the preferred pattern of locomotion at speeds in excess of 1.94 m/s to 2.49 m/s (7 km/hr to 9 km/hr), but individual preference must be taken into account (Shephard 1969). Something which lends itself favourably to this suggestion is the proposition that for walking the limit for purely aerobic exercise is approximately 2.49 m/s, whereas for running this limit occurs at about 5.54 m/s (20 km/hr) (Margaria _et al._ 1963, Cavagna and Kaneko 1977). For locomotion in excess of these speeds the metabolic demands must be met to a large extent by anaerobic sources with the result that there is an accumulation of blood and muscle lactic acid which can cause severe physiological and psychological stress which limit the duration of the activity.

PHYSIOLOGICAL RESPONSES TO WALKING AND RUNNING

By definition, one foot must be in contact with the ground at any instant during walking (Grieve and Gear 1966). Walking is probably the most common form of regular exercise undertaken by man today, and for the majority of individuals it represents the primary, if not only, form of physical activity that falls outside the realm of sedentary living (McArdle _et al._ 1981).

In contrast, as soon as human locomotion involves an instant when both feet are airborne it is defined as running (Broer 1966). Thus, running differs from walking in that 1) there is a period of no support and, 2) there is no period of double support (Grieve and Gear 1966). Defined as such, running is today one of the most popular recreational exercise activities (McArdle et al. 1981).

The exact nature of the oxygen consumption-velocity relationships for walking and running have been outlined in the previous section. The relationship for walking speeds fits an upward concave curve becoming almost vertical between 2.22 m/s and 2.49 m/s (Margaria et al. 1963, Knuttgen 1961, Menier and Pugh 1968, McArdle et al. 1981). This relationship for running is essentially linear (Margaria et al. 1963, Menier and Pugh 1968, Van der Walt and Wyndham 1973, Howley and Glover 1974, Cavagna and Kaneko 1977, Mayhew 1977, Åstrand and Rodahl 1977, Daniels 1985), at least up to a speed of 5.82 m/s (21 km/hr).

For walking speeds in excess of 2.22 m/s the relationship between oxygen uptake and velocity becomes a straight line with a gradient twice that of the line representing the oxygen uptake-velocity relationship for running (Menier and Pugh 1968). Erickson et al. (1946) conclude, as a result of this, that the energy expenditure of walking is a more stable function at higher speeds.

Several studies of walking, running and cycling have indicated the existence of an optimal point for an individual in the relationship between energy cost and velocity of movement (Goslin 1985). This minimization is reported to generally coincide with the preferred speed, cadence, stride length. During walking and running this optimal point has been repeatedly referred to in relation to both preferred cadence and preferred stride length (Erickson et al. 1946, Bobbert 1960, Cavanagh et al. 1978, Kaneko et al. 1979). This optimal speed of walking has been reported to range from 1.11 m/s (Cavagna et al. 1963) to 1.23 m/s (Ralston 1958) to 1.31 m/s (Zarrugh 1981). Leg length appears to constitute an important factor in the variation of these optimal walking speeds (Cotes and Meade 1960). Howley and Glover (1974) reported a self-selected preferred running speed for men as being 3.25 m/s (11.7 km/hr, or just over 5 min/km).

It has been suggested that the energy cost of walking plotted against the square of velocity will produce a linear relationship (Bobbert 1960, Cotes and Meade 1960, Knuttgen 1961). Because of this linear relationship for running, it follows that the total caloric cost of running a given distance is approximately the same whether the velocity is fast or slow. This means that the net energy consumption per kilogram per kilometer is, in effect, constant and independent of speed (Margaria et al. 1963, Van der Walt and Wyndham 1973, Howley and Glover 1974, Cavagna and Kaneko 1977, McArdle et al. 1981). This is a function of the direct relationship between the time and speed of locomotion - if one runs at half the speed it takes twice as long to cover the given distance as if one increases the speed by half. The energy expenditure will remain the same (McArdle et al. 1981). However, in a study which included both walking and running (Fellingham et al. 1978), the energy cost per distance factor was found to increase with speed. This may not have been an entirely valid result because the energy equivalent of the excess post- exercise oxygen consumption was added to the exercise energy cost in order to determine the total energy cost for the activity. However not all the post-exercise oxygen consumption is related to the demands of exercise (Gaesser and Brooks 1984).

For horizontal running the energy cost per kilogram of body weight per kilometer travelled is approximately 1 kCal (Margaria et al. 1963, McArdle et al. 1981). The energy cost of running can therefore be expressed as 1 kCal/kg/min (McArdle et al. 1981), although Howley and Glover (1974) suggest a value of 1.43 ± 0.08 kCal/kg/min (0.98 ± 0.08 kCal/kg/km).

Energy expenditure in kCal can easily be transformed into oxygen consumption (l/min) in the following way:

5 kCal = 1 litre of oxygen

This means for an individual with a body mass of 80 kg, the net energy requirement for running 1 km would be about 16 l of oxygen regardless of the speed of movement (Åstrand and Rodahl 1977, McArdle et al. 1981).

Grade walking and running have been found to have a significant effect upon the energy cost of locomotion (Goslin 1985). Most studies report that oxygen consumption increases as a direct function of increased gradient (Margaria et al. 1963, Shephard 1969).

Body composition has a significant effect on the metabolic responses to locomotion. Lean body mass is an important factor since it is the active muscle tissue involved in exercise which determines the oxygen consumption and the cardiovascular responses to exercise (Lewis et al. 1983). Males tend to carry between 12 to 16% body fat (Pate and Kriska 1984). Body mass is probably the single most important determinant of energy expenditure during locomotion, or for that matter any exercise (McArdle et al. 1981).

Training, in particular endurance training, is something which significantly modifies the response to any given exercise task. Therefore the responses to locomotion must be altered by training and differ between trained and untrained groups of people (Goslin 1985). Endurance trained people have smaller increases in muscle and blood lactate, a slower rate of glycogen depletion, lower carbohydrate metabolism and increased fat metabolism at any given submaximal oxygen consumption compared with the untrained (Åstrand and Rodahl 1977). Hormonal regulation of energy substrate may differ in fit and unfit people (Goslin 1985). More highly trained individuals demonstrate a more rapid accommodation to exercise than those of lower fitness levels (Åstrand and Rodahl 1977). Maximal oxygen consumption tends to be increased by training, and submaximal oxygen consumption appears to be lowered although the effects of training on submaximal oxygen consumption are less well defined. Some studies have shown that submaximal oxygen consumption decreases with training (Cotes and Meade 1959, Margaria et al. 1963), while others have indicated that there is no change (Holloszy and Coyle 1984).

Exercise responses differ according to whether the work done is sustained largely by aerobic or anaerobic metabolic pathways (Daniels 1985). In this respect the anaerobic threshold is extremely important. (In this case it is assumed that the term anaerobic threshold is synonymous with ventilatory threshold since this issue is one of extreme controversy). The anaerobic thresholds of trained men and women (79.2% and 73.3% of maximal oxygen uptake respectively) are significantly higher than those of untrained men and women (66.5% and 58.9% of maximal oxygen uptake respectively) (de Mello et al. 1985). For the same locomotor task therefore, trained and untrained people may have significantly different responses because of the fact that the former may be working at an intensity well below the anaerobic threshold, whereas for the untrained person the intensity may be well above his or her anaerobic threshold. A knowledge of the intensity of the work being performed as well as its relationship to the intensity at which the onset of anaerobiosis occurs is essential for comparative purposes (Daniels 1985).

Endurance training increases muscle mitochondria and the activity level of mitochondrial enzymes (Åstrand and Rodahl 1977). Furthermore, the relative area of the slow-twitch muscle fibres has been shown to increase with endurance training (Edgerton 1976). The removal rate of lactate is related to the area of slow-twitch muscle fibres, in addition to the fact that these muscle fibres utilize lactate as a fuel substrate. Endurance training also enhances the lactate formation potential of the fast-twitch muscle fibres. This lactate may then be transported to the adjacent slow-twitch fibres where it is oxidised (Åstrand and Rodahl 1977).

The muscles themselves play a major role during locomotion primarily as a means of transferring energy from one step to the next (Winter 1982b). This means that during locomotion various body parts are absorbing energy or doing negative work, while others are doing positive work (Goslin 1985). The performance of negative work is substantially more economical than is positive work (Williams and Cavanagh 1983). Negative work economy is related to the fact that muscle fibre cross-bridges can develop tension during stretching without the splitting of ATP (Cavanagh and Kram 1985).

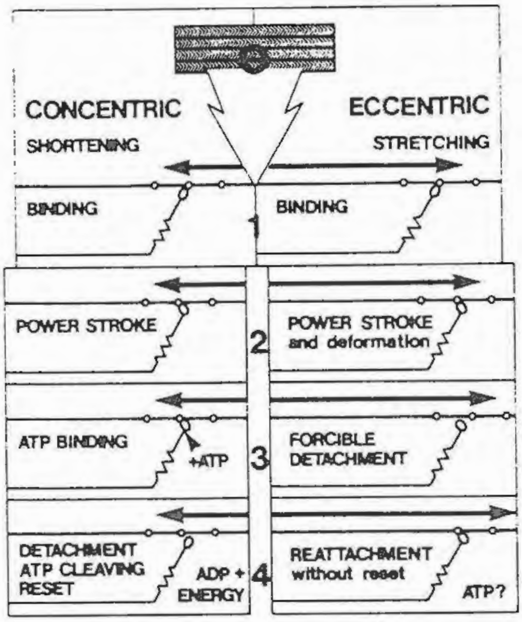


FIGURE 1: The schematic cycle of tension in skeletal muscle, suggesting a mechanism at the level of the cross-bridges for reduced energy cost in negative work. ATP is required for the detatchment and reset of the cross-bridges in concentric work but not in eccentric work (From White 1977).

Winter (1983b) examined ankle and knee energy absorption patterns during walking, the results of which help to enhance the understanding of the contributions of positive and negative work to movement during the gait cycle. He found that the ankle has two power phases, a negative one when weight is accepted and a positive one as weight is released. The knee has four phases during the cycle: negative as weight is accepted, slightly positive at mid-stance, substantially negative as weight is released and during the initial stages of the swing phase and, finally, at the end of the swing phase energy is absorbed. During locomotion the ankle and hip do more positive work than negative work. The knee primarily absorbs energy and does negative work (Saunders et al. 1953).

Much of the reduced energy cost of negative work has been attributed to the process of energy storage by means of elastic recoil in the working muscles (Cavagna et al. 1964). Elastic energy is stored during the stretching of the contracted muscle, but this only occurs if positive work immediately follows the negative (Asmussen and Bonde-Petersen 1974). In order to examine this process of storage of elastic energy most of the studies to date have used jumping as the exercise mode and force platforms to determine the amount of force applied at various stages in the movements (Thys et al. 1972, Asmussen and Bonde-Petersen 1974, Komi and Bosco 1978). During walking elastic recoil increases as the speed of movement increases due to greater stretching of the muscles.

THE VARIABILITY OF RESPONSES DURING HUMAN LOCOMOTION

Unlike physical properties of chemicals or some simple organisms where function and response may be virtually 100% consistent, the human system is inherently less stable. This inherent biological variation is most likely a consequence of the tremendously complex response patterns to any one given stimulus. Thus, attempting to single out one or perhaps two major factors contributing to the biological variation is difficult (Katch et al. 1982). Several sources of variation in human responses have been identified, some of them such as motivation provide particular difficulty in trying to find a solution to the problem because there is no way to quantify this motivational aspect other than to acknowledge its presence (Katch et al. 1982). Cavanagh and Kram (1985) support this feeling by stating that it is not possible to precisely partition this variability into particular factors (such as biochemical, biomechanical or physiological), because each individual probably has a unique set of coefficients for the factors contributing to efficient performance.

Variability in human responses to locomotion can be divided into biological and technological. The former is a very vague classification since within it there are numerous subdivisions of factors which could effect how variable or not a given response is. In their investigation of biological variability in maximal aerobic power, Katch et al. (1982) identified these two sources of variability, biological (Si) and technological (Se). Their results showed that Si + Se = 5.6%. However, biological variability accounted for 90% of this variability and technological error accounted for less than 10%. Taylor (1944) found similar results in that of the total variability in response to a 4-minute submaximal treadmill test followed by an incremental maximal oxygen uptake test, 30% could be ascribed to biological variation and less than 1% to technological error. Henry (1951) also showed that the extent of technological error was small in relation to biological error.

In attempting to clarify the exact components of "biological variability" and its contribution to the total variability in human responses it may help to examine particular aspects of human performance such as the economy of locomotion, efficiency of locomotion, the effects of circadian rhythms on performance amongst others in which variability is a common factor.

There are two types of variability in relation to human performance, intra-individual variability and inter-individual variability (Daniels 1985). Both are characterised by different factors. Costill <u>et al.</u> (1973) suggest that intra-individual variations in running economy at standardised speeds are "random" and of little importance in differentiating distance running ability. However, intra-individual differences in economy have been reported at a variety of levels. Passmore and Durnin (1955) suggested that the coefficient of variation (CV) of economy of walking at a constant velocity was 15%. Wyndham <u>et al.</u> (1971) compared treadmill and road walking, finding that the CV of economy on the treadmill was 14% while on the road the same subjects had a CV of economy of 24%. Daniels (1985) reports a CV of economy for running against a wind as being 18%. Cavanagh and Kram (1983) reported a 12 to 17% CV in economy based on their review of literature.

In contrast, lower values for intra-individual variations in economy have been reported. For example, Pollock et al. (1980) reported values for marathon and middle distance runners of 7.3% and 8.3% respectively. Costill et al. (1973) found that the CV of economy differed with changes in movement velocity. At 14.5 km/hr it was 4.1% and at 16 km/hr it was 3.6%. Daniels (1985) cites such factors as increases in body temperature and variations in stride length from day-to-day as being responsible for these within-subject variations. A stride length of 80% of total leg length was more efficient than was a stride length equal to 60 or 70% of leg length. These variations could quite easily occur in the same subject from day-to-day. Changes in body mass may also affect the economy of locomotion as would foot strike patterns (rear, mid- or fore-foot). The relative effectiveness of different enzyme systems from day-to-day has been, according to Sjodin (1983), related to variations in economy.

Inter-individual differences in economy also exist and have been reported at various levels. In a study investigating running economy in highly trained athletes, Conley and Krahenbuhl (1980) found that 64.5% of the variation in race performance time over 10 km could be explained by variation in running economy. These authors go on to say that the variation in performance not accounted for by the economy of the subjects may be due to "inter-individual differences in muscle fibre composition, anaerobic threshold and peak muscle and blood lactate tolerance".

Armstrong and Costill (1985) examined the day-to-day variations in metabolic measurements during submaximal exercise using cyclists and runners. They reported a CV for oxygen uptake in the cyclists as being 4.42% and in the runners as being 3.80%. These authors also reported coefficients of variation for minute volume ($\dot{V}E$) and blood lactate levels in their subjects (CV of $\dot{V}E$: cyclists 3.86%, runners 4.82%; CV of lactate: cyclists 13.4%, runners 16.3%). Significant day-to-day differences were found in oxygen uptake of the cyclists during cycling and running, of runners while cycling and running and in $\dot{V}E$ of cyclists during running. There were no significant differences in day-to-day differences in blood lactate levels.

Dill *et al.* (1930) suggest that the absolute oxygen cost of a standard running speed may vary by as much as 50% between individuals. Their data reveal that a difference in excess of 30% still exists if the oxygen uptake is expressed in relative terms (ml/kg/min). Data from Daniels (1974) supports these data in that he studied two equal-performing runners who varied by 30% in oxygen uptake at a common submaximal running speed. Farrell *et al.* (1979) found that differences in submaximal oxygen consumption values of a similar magnitude exist between trained female and male runners (26 and 20% respectively). Cureton and Sparling (1980) and Daniels *et al.* (1984) found submaximal oxygen uptake differences of 20% between individuals. Inter-individual differences also appear to be a function of speed, amongst other factors. Costill et al. (1973) examined 16 trained distance runners running at 4.46 m/s and found a variation of 12% in submaximal oxygen uptake, while Williams (1980) reported a variation of 17% in a group of 31 recreational runners at 3.57 m/s.

The reasons for differences in the economy of locomotion between individuals are many and varied (Goslin 1985). Economy seems to be independent of the total lean body mass of an individual. However, a potential mechanical source for individual differences in economy between two individuals is differences in the distribution of mass on the limb segments. These differences can be marked between individuals with identical body mass. Paradoxically however, animal experiments conducted by Taylor et al. (1974) on two species (cheetah and gazelle) with similar total body mass and similar limb segment lengths but extremely divergent distributions of mass in the limbs have revealed no great differences in metabolic cost during locomotion. Other anatomical variations may also have a potential impact on between-individual variations in economy. Although there is a paucity of data, it is not unreasonable to suppose that there is a large variability between individuals of the same body size in the distance of insertions of key muscles from joint centres (Cavanagh and Kram 1985). Other aspects of muscle architecture, such as fibre orientation, and fibre length in a given muscle, could also effect economy (Goslin 1985).

Differences in such factors as substrate utilization, number and activity of mitochondria, effectiveness of aerobic and anaerobic enzymes, muscle and blood pH, and the muscle fibre type influence economy (Goslin 1985). Fast-twitch fibres have three times more ATP turn over compared with slow-twitch fibres to generate the same tension (Cavanagh and Kram 1983). During heavy exercise hydrogen ion concentration and strength are high (and pH is low). Furthermore, there is an increase of two to three times in free radical concentrations (Goslin 1985). Sjodin (1983), having found that training performed at a velocity equivalent to the onset of blood lactate accumulation improved economy at 15 km/hr, suggested that this could have been due to a more efficient motor unit recruitment pattern, changes in capillary density and/or alterations in enzyme activity.

It is well documented that stride length has a significant effect on economy (Hogberg 1952a, Åstrand and Rodahl 1977). Van der Walt and Wyndham (1973) investigated oxygen consumption and stride frequencies at 4 walking and 4 running speeds in an attempt to produce prediction equations for the energy expenditure of walking and running. They noted that pace length and leg length account for only 2% of the total variance in oxygen consumption during running and are therefore not important factors in the prediction of energy cost.

Cavanagh and Kram (1985) in their review of mechanical and muscular factors affecting the efficiency of human movement refer to what they call "optimal phenomena". For example there are optimal seat heights on a cycle ergometer, preferred pedal rates, optimal stride lengths in walking and running all of which minimize the energy cost of a given task. All of these phenomena may, under certain circumstances explain why two individuals exhibit differences in economy while performing the same task. The two individuals may simply be operating on different regions of the parabolic optimal phenomena curves. They may also be exhibiting different efficiencies, since the work performed in different conditions may also vary.

Mechanical factors also influence economy. For example, Catlin and Dressendorfer (1979) showed that a 100g increase in total shoe weight (50g to each shoe) caused approximately 1% increase in metabolic energy cost in subjects running at moderate speeds. Frederick et al. (1983) showed that an approximate 2.8% energy saving is realized for treadmill running using well-cushioned shoes compared to poorly cushioned shoes of the same weight. The reason for this was felt to be the extra cushioning provided at heel-strike enabling energy to be stored in the mid-stance and returned at toe-off.

Gross changes in surface have been shown to have a predictable effect on the economy of locomotion. Walking across a ploughed field requires 35% more energy than walking at the same speed on smooth, firm pavement.

In a review paper on the synthesis, experimentation, and biomechanics of economical movement, Frederick (1985) listed a number of factors which are either known to directly influence economy or have been shown to be significantly associated with economy. He has identified two groups of factors, intrinsic and extrinsic factors. The former were: body weight, leg length, stride length, state of relaxation, hypnotic suggestion, body centre of mass excursion, energy transfer between segments, net positive mechanical work rate, impact force, foot strike, foot contact time, less arm motion, greater trunk angle of inclination, greater shank angle, lower knee flexion velocity in support phase and less plantar flexion at toe off. The extrinsic factors were: ambient temperature, wind, grade, circadian rhythms, surface compliance, surface resilience, orthotics, shoe softness, shoe weight and load carriage. He states that " many of these factors are immutable or simply a consequence of the circumstances of the movement or the environment in which the movement is perfomed". Others, however, are changeable and beg to be explored as potential keys to explaining the variability in the economy of locomotion.

Variability in efficiency has been reported to range from 29.5% to 2.5% (Erickson et al. 1946, Williams et al. 1966 respectively). Variations in muscular efficiency, when defined as the ratio of the mechanical work to the metabolic energy expended (Stainsby et al. 1980), range from between -120% for downhill treadmill walking to +250% for level treadmill walking (Margaria 1968, Pierrynowski et al. 1980). In a review of a number of studies it was reported that the variability of efficiency of cycling was 4.5%, of stepping was 7% and of treadmill locomotion was 10% (Shephard 1976). It has also been suggested that age, sex, race and food intake combined, only contribute to approximately 6% of the variability in oxygen consumption during stepping and walking after the effects of body mass were accounted for (Mahadeva et al. 1953).Furthermore, Mayhew (1977) suggests that the coefficient of variation in efficiency is minimal for running at 4 m/s but that it is 30% at slow (2.7 m/s) and fast extremes (6.3 m/s).

As can be seen from the few examples quoted above regarding the variability in efficiency of various tasks there is a vast discrepancy between the results obtained by different investigators. Certainly part of the problem lies in the fact that "there is no consensus as to how mechanical energy of movement should be calculated and interpreted" (Winter and Robertson 1978). Different people are using different means of calculating efficiency and reporting different values of variability between subjects.

There appears to be more universal agreement on the numerous factors which influence efficiency and thereby result in inter- and intra-individual differences whatever the magnitude of these differences. Elftman (1939b) identified several muscular factors which affect efficiency: the cost of maintenance of tension, the energy necessary to overcome frictional resistance and non-elastic deformation, the extent to which tension production is due to external forces, and the limitations placed on muscles by the necessity of nervous co-ordination (Goslin 1985). There appears to be conflicting evidence regarding the effects of anthropometric differences and temperature on efficiency. Passmore and Durnin (1955) report that efficiency is unaffected by these factors. However, factors such as leg length, body weight distribution, hip width and femoral convergence do influence efficiency (Pate and Kriska 1984). A wider pelvis, short legs and greater femoral convergence may contribute to a less mechanically efficient gait in females (Goslin 1985).

Mechanical factors also affect efficiency. Fenn (1930) expressed a view that the kinetic energy of the limbs during running makes up an appreciable fraction of the total energy required, which suggests that changes within a runner or differences between runners in style or technique can affect energy expenditure. Efficiency is reduced (by an estimated 24%) by losses in the bone-muscle connections and the human-ergometer (Cavanagh and Kram 1985). Rotational kinetic energy is not important in walking but it is in running (Winter 1978a). He goes on to state that as positive horizontal work is greater than negative there must be some loss to air and foot friction. Cavanagh and Kram (1985) suggest that the energetic bargain of negative work and the storage of elastic energy in the muscle and connective tissue are the major biological processes which have profound effects on muscular efficiency during locomotion.

Thys et al. (1972) and Asmussen and Bonde-Petersen (1974) measured the energy cost for two different methods of performing the same mechanical work in a stand-sit-stand task. In the first case, this motion was continuous with no pause between the two motions. In the second case, the stand-sit motion was followed by a brief pause which allowed the muscles to relax, this was then followed by the standing phase. The energy cost was 25% lower in the continuous protocol, the reason being that energy could be stored elastically during this protocol, whereas stored energy would be lost during the brief relaxation in the discontinuous protocol. These observations suggest differing abilities to store and utilize elastic energy between individuals may be another source of inter-subject variation in efficiency. Hinrichs and Cavanagh (1983) suggested that substantial variation in the contribution of the arms to momentum could also influence efficiency.

The locomotor pattern itself may play an important role in efficiency. Bipedal locomotion is suspected to be less efficient than quadrupedal locomotion (Goslin 1985). Running efficiency has been found to be higher than walking efficiency (Lloyd and Zacks 1972), particularly when walking and running are performed at the same speed (Wyndham and Strydom 1971). The main reason for this difference in efficiency between these two forms of locomotion is the beneficial effect of the elastic recoil of running (Cavagna et al. 1964). Elastic recoil is lower at walking speeds because the energy is absorbed due to increased contraction time (Goslin 1985). Increases in the stretch of the muscle and speed of movement tend to increase elastic recoil (Fardy and Hellerstein 1978). This idea has been supported by Thys et al. (1972) who state that running is so efficient because the stretch shortening interval is very short. Efficiency tends to increase with increased running speed (Heglund et al. 1982) but decreases with increased walking speed (Donovan and Brooks 1977). In fact, it has been pointed out that in normal walking it becomes more efficient to run once the speed exceeds

2.22 m/s. The idea that the speed of movement has a significant effect on efficiency is a contentious issue in that some investigators have found that it drops with increasing speed (Brooks et al. 1984), while others have reported no speed effect at all (Ito et al. 1983). Davies (1971) appeared to clarify these discrepancies somewhat by suggesting that at both high and low speeds muscular efficiency is least. At high speeds complete cross-bridge formation is less likely, while at low speeds the internal work associated with the oscillating action in the sarcomere reduces efficiency.

In a study involving preferred cycling cadences against different resistances Taguchi et al. (1980) found that personal rhythm was very stable within and between days but that there was no relationship between preferred rhythm and mechanical efficiency. They also suggested no relationship between the variability in preferred rhythm and the observed variability in efficiency. Zarrugh (1981) suggests that the walking speed-efficiency relationship takes the form of an inverted "U". He investigated this relationship with respect to segmental summation of energy during "free" and "forced" cadence walking, and found that efficiency rose from 9% at 0.84 m/s to 23% at 1.7 m/s and decreased again to 18% at 2.35 m/s.

In relation to relative speed Grieve and Gear (1966) indicated that males have the least variability in cadence at 0.6 st/s, and that this velocity coincided with that at which maximum walking efficiency was found.

State of training is another factor which can influence efficiency (Goslin 1985). Margaria et al. (1975) and Cavagna et al. (1964) reported differences of between 5 to 7% respectively in efficiency between trained and untrained runners. Dill (1965) tested two champion runners who varied by 17% in efficiency; one was a world-class miler and the other, more efficient runner was a champion marathoner. Daniels (1985) hypothesizes that marathon training induces greater changes in running economy than results from training for shorter races or that runners who are basically more economical find greater success in longer endurance races. Cavanagh and Kram (1985) suggest that the body tends to "self-optimise" but that the question of just how precise this process is, remains unmeasured. It is, however, at the level of the novice or unskilled performer that modifications are likely to show the greatest effect, since practice and therefore time for self-optimization has been limited. Skill levels therefore also appear to play an important role in efficiency (Goslin 1985). Williams et al. (1966) suggested that "skill" accounted for inter-individual differences in the energy cost of a variety of lifting and moving tasks, to the extent that in an experiment in which the subjects were asked to walk down steep grades there was an improvement of 43% in movement efficiency with habituation. The subjects improved co-ordination and curtailed waste movements with habituation (Davies and Barnes 1972). Results from an experiment involving cyclists showed that the ratio of unloaded cycling oxygen cost to overall work oxygen uptake showed that this ratio was 62% for untrained cyclists and 41% for trained people. Garry and Wishart (1931) suggested from these data that skill allows the trained person to use fewer accessory muscles to hold his body in the working position.

For two groups of subjects, one with high maximal aerobic power (65.4 ml/kg/min) and the other with low maximal aerobic power (49.7 ml/kg/min), Weltman and Katch (1976) found that the first group was more efficient than the second (24% versus 22% respectively). They suggested that this increased efficiency was probably related to the fact that less energy was needed for circulation, ventilation and temperature regulation.

Just as there are differences in efficiency between trained and untrained people, so too does the type of training effect efficiency. It is suggested that the greater maximal oxygen uptake of endurance trained runners allows them to be somewhat less efficient while running yet still maintain an adequate oxygen supply to meet the energy demands at high speeds (Goslin 1985). Mayhew (1977) reported that there was a distinct optimal running speed at 3.1 m/s when the oxygen uptake was minimized. This optimal point occurred at a mean relative speed of 1.76 st/s.

Much of the work done in relation to attempting to identify the causes of human variability has been centred on circadian rhythms and the operation of biological clocks in man. In one of the early studies of this nature Durnin and Namyslowski (1958) examined the exact effect of different times of day and of different days on the energy expenditure of standardized activities. They looked at four strictly controlled conditions; lying, sitting, walking at 1.44 m/s and 0% grade, and walking at 1.19 m/s at a 1 in 10 gradient. Results for both sexes showed no significant differences attributable to different times of day or to different days. However, there was a tendency for measurements at 2.0 o'clock to be slightly higher than the other measurements. These investigators suggested that there seems to be little justification for the common belief that differences in pressure (20-30 mmHg) and temperature ("several degrees centigrade") cause significant changes in energy expenditure, at least in activities of this nature. Furthermore, they state that it is possible to disregard, except in abnormal cases, the effects of emotion.

Reilly et al. (1984) found that circadian rhythm in heart rate response to exercise should be considered when a heart rate variable is used as a criterion in fitness testing or as an index of physiological strain. They noted a significant circadian rhythm for resting heart rate lying and sitting prior to exercise. This rhythm persisted during submaximal exercise and at a maximal rate. Ratings of perceived exertion at submaximal and maximal exercise intensities, as well as time to exhaustion on an ergometric test were found not to vary significantly with the time of day. Oral temperature showed similar trends. Reilly et al. (1984) also noted that observations of systolic and diastolic blood pressures pre- and post- exercise were inconclusive.

The speed and accuracy with which people perform their work, and large inter-individual differences in the times of optimal performance and subjective alertness have been observed by Zani <u>et al.</u> (1984). Their investigations led to two classifications on the basis of temperature and efficiency curves; 1) "morning types" and, 2) "evening types". Intermediate gradations exist between these two extremes.

A lot of research has been done on these two types of person concerning sleep-wake habits and preferred times for physical and mental activity. The biological clocks of these two diurnal types have been shown to keep time in a different way producing a phase difference in their physiological indices and performance levels in motor and cognitive tasks. For example, in comparison to "evening types", "morning types" have a phase advance in body temperature, subjective alertness, fatigue and reaction time. These authors conclude that it is vitally important that one is aware of the cyclic oscillations shown by psychological and physiological functions and the differential adaptations that may result from the latter. Fluctuations of this sort may result in both intra- and inter-individual variance in many measureable parameters.

Irvin and Drummond (1982) investigated the existence, magnitude and interplay of rhythmic 24-hour variations in human functions; maximal aerobic power, resting heart rate, body temperature, and ratings of perceived exertion during exercise. They noted that resting body temperature and heart rate were lower in the morning than in the afternoon or evening, and that ratings of perceived exertion at heart rates of 130, 150, 170 beats/min were higher at 02.00 and 0.400 hours than at 20.00 and 24.00 hours. Maximal aerobic capacities did not change significantly over time.

Arousal has been found to peak in the late afternoon with improvements in pattern recognition, reaction speed and muscle force generation as indicators. Body temperature also peaks at about this time with ratings of perceived exertion being somewhat lower. Heart rate responses tend to mirror temperature responses. There appears to be no diurnal variation in exercise efficiency (Shephard 1984a).

While the kinematics of gait differ distinctly between quadrupedal and bipedal locomotion it is also true that humans display relatively small but very important ranges of variability in almost all measurable gait parameters (Charteris et al. 1982). Kram et al. (1985), while trying to elucidate the reasons for the variation in economy, found that there were small day-to-day variations in stride length. The coefficients of variation in stride length at various speeds were as follows: 1.28% at 3.15 m/s, 1.11% at 3.35 m/s, 1.07% at 3.58 m/s, 0.96% at 3.83 m/s and 0.94% at 4.13 m/s. These seemingly small variations in stride length have little effect on economy but are important in relation to the act of walking or running. The use of relative speed in whatever form was introduced to "normalise" variations such as these in stride length, and many other kinematic parameters in human gait.

PERCEIVED EXERTION AND HUMAN LOCOMOTION

Currently one of the most widely used subjective response scales is the Rating of Perceived Exertion (RPE) as developed by Borg (1970). Regardless of whether one is concerned with muscular performance in athletics, industry, in the military or under everyday circumstances subjective, self-reported estimates of effort expenditure may be quantified using ratings of perceived exertion. As an investigative tool, ratings of perceived exertion have proved to be useful adjuncts for studies in exercise physiology. They have been used to examine issues involving the hormonal, metabolic and circulatory responses to exercise, supplementing objectively measured variables. Many factors such as pain threshold, individual sensory acuteness, experience in the activity, and overall conditioning influence the individual's estimate of effort expenditure (Carton and Rhodes 1985).

As early as 1892 initial experimental work involving the subjective perception of effort was being done (in Fullerton and Cattell 1982). Their work involved the estimation of force generation using hand grip dynamometers. Between this early study and the development of the Borg scale (Borg 1970) several other studies incorporating the perception of effort were carried out, most of which involved isometric activity (Eisler 1962, Hueting 1965, Bakers and Tenney 1970). Unlike early studies, Borg (1962) investigated the perception of effort during aerobic work employing large muscle masses from which he produced a 21-point category rating scale. This scale was based upon a correlation between RPE and heart rate which was found to be 0.80 to 0.90 during light to heavy exercise performed on a cycle ergometer. At a later date (Borg 1970) a 15-point graded category scale was derived to increase the linearity between the ratings and the workload. Alternative scales have also been utilized for the rating of perceived exertion. For example, Robertson et al. (1979a, 1979b) and Stamford and Noble (1974) used a 9-point category scale. The RPE values from this scale were found to correlate highly (0.92) with those on the 21-point Borg scale. Following this a ratio scale method was developed for measuring RPE. Using this method, it is possible to compare one level of RPE with another, but it is not possible to ascertain whether that level is high, moderate or low (Borg 1973). This factor makes inter-individual comparisons difficult to perform. Recently Borg (1982) has developed a 10-point category scale with ratio properties which permits the use of decimals in RPE determinations. The verbal expressions which are used with the scale are set so that the semantic intensity grows according to a power function. For this reason, this scale may be particularly useful for measuring the perception of effort during anaerobic activity (Carton and Rhodes 1985). This is because certain physiological measurements, such as lactic acid production and pulmonary ventilation, which reflect anaerobic metabolism, grow according to a power function with increases in exercise intensity (Noble 1982).

In order to assess the reliability and validity of the 15-point Borg scale for RPE evaluation Lollgen et al. (1975) exercised subjects on a bicycle ergometer, varying the pedal rates between 40 and 100 kmp on separate occasions. A test-retest reliability coefficient of 0.92 was established. However, measurements of RPE were found to be more highly variable at increasing pedal rates. This information concurs with the findings of Borg (1973) which indicated that coefficients between heart rate and RPE were lower when using hard to very hard workloads. In order to assess the validity of this scale Michael and Eckhardt (1972) exercised 6 male subjects (3 trained and 3 untrained) for 15 minutes at a work intensity which subjects considered to be "hard" at 0% grade on a treadmill. When asked to reproduce an equivalent level of work at 10% grade no significant difference was found between the exercise intensities using the two different protocols. No differences were observed in the relative intensities selected by the trained and untrained subjects. Mihevic and Morgan (1980) have postulated that the threshold for detection of changes in exercise intensity lies near an absolute workload of 15 to 20 W.

There are several factors which influence RPE, both physiological and psychological. In relation to the former, after considerable research in attempting to identify sensory cues which provide direct input to the effort sense, Ekblom and Goldbarg (1971) were the first to distinguish between factors affecting the perception of effort which arise in the active muscles and/or joints (peripheral), and those which are manifested in a more generalised cardiopulmonary response (central). Borg's initial proposal, that RPE co-varies directly with heart rate, has been challenged by a number of investigators. In addition to heart rate, central parameters which are purportedly linked to effort perception include respiratory rate ($\dot{V}E$) and oxygen uptake ($\dot{V}O_2$) (Carton and Rhodes 1985).

While heart rate and RPE may be highly related, at no point has it been implied that these measures are causally related. The RPE scale was designed to follow the heart rate response to increasing exercise intensity, and these variables are probably related through their common dependence upon physiological strain (Carton and Rhodes 1985). A number of sources however, have reported that the connection between heart rate and RPE can be disturbed when exercise is performed under irregular conditions. For example, it is possible to manipulate heart rate through the use of parasympathetic and sympathetic blocking agents without affecting RPE at a given percentage of maximal aerobic power (Davies and Sargeant 1979, Ekblom and Goldbarg 1971). Lewis et al. (1980) found that following 11 weeks of training, RPE remained the same even though heart rate was reduced during submaximal exercise involving untrained limbs. Furthermore, at the same heart rate, treadmill exercise evoked lower effort ratings than bicycle ergometer work (Michael and Hackett 1972). Morgan (1973) stated that the important consideration is frequently "not what the individual is doing but rather, what he thinks he is doing" which is important in determining RPE values. This may be true since although physiological parameters are highly correlated with RPE, none has been causally related.

When performing at the same heart rate, RPE is greater for eccentric than concentric exercise (Pandolf et al. 1978). Using a motor-driven laddermill, they reported that for positive work an increase in heart rate of 10 beats/min was associated with a 0.9 rise in RPE. However for negative (eccentric) work, an RPE increase of only 0.5 was associated with the 10 beats/min increase.

Morgan *et al.* (1976) evaluated perceptual and metabolic responses to exercise by using hypnosis. During the experiment reactions to a suggestion of uphill work were investigated. These suggestions elicited increases in effort ratings, although heart rate and oxygen uptake remained stable. However, elevations in $\dot{V}E$ were found to parallel the alterations in RPE. Numerous other workers also support the role of minute ventilation ($\dot{V}E$) as a sensory cue which has an impact upon the perception of effort. Correlation coefficients ranging from 0.52 to 0.94 have been demonstrated between RPE and both $\dot{V}E$ and respiratory rate (Edwards *et al.* 1972, Morgan and Pollock 1977, Pandolf *et al.* 1972, Sargeant and Davies 1973, Skinner *et al.* 1969). Wigertz (1970) analysed the dynamic characteristics of the ventilation and heart rate responses of 11 highly trained athletes (maximal oxygen uptake; 63.8 ml/kg/min) who cycled at varying workloads ($\bar{X}$ 650 kpm/min). Although changes in $\dot{V}E$ were delayed with respect to shifts in exercise intensity and heart rate, the perception of peak exercise intensity and heart rate, corresponded more closely to peak $\dot{V}E$ than the actual time of maximum exercise intensity.

The idea of blood reinfusion has been used in several studies in an attempt to elucidate the relationship between $\dot{V}E$ and RPE (Robertson *et* *al.* 1979c, Williams *et al.* 1978, Williams 1981). These studies are based on the rationale that by withdrawing a given volume of blood and reinfusing it at a later date, hemoglobin concentrations will be augmented, thereby increasing the oxygen carrying capacity of the blood. If $\dot{V}E$ and RPE are related, then it would be expected that increased arterial oxygen content, which reduces the stimulus for ventilation, would be reflected in similar adaptations in RPE. Robertson *et al.* (1979c) exercised subjects on a bicycle ergometer at 45 and 75% of their maximal aerobic capacities. Following reinfusion, $\dot{V}E$ was depressed at both workloads, but RPE were significantly modified only at the higher workload. These results suggest that the onset of the ventilatory signal to effort perception is related to the relative exercise intensity being performed, and the point at which $\dot{V}E$ begins to significantly contribute to the perception of effort is close to the aerobic threshold, about 50% of maximal aerobic power which is approximately the same intensity at which peak tidal volume occurs (Robertson 1982).

It has been suggested that any impact that $\dot{V}E$ or heart rate exert upon RPE may be eliminated in terms of relative metabolic demand (Sargeant and Davies 1973). Correlations between oxygen uptake and RPE of between 0.76 and 0.97 have been reported by Edwards *et al.* (1972), Sargeant and Davies (1973), Smutok *et al.* (1980). Increases in maximal aerobic power following blood reinfusion may result in reduced RPE for a given workload, but these are abolished at comparable exercise intensities (Robertson *et al.* 1979c). However, other reports indicate that the relationship between RPE and oxygen uptake may be spurious. When exercise intensity and relative metabolic demand are held constant, RPE fluctuates as a function of pedalling frequency on a bicycle ergometer (Pandolf and Noble 1973, Stamford and Noble 1974). Borg and Noble (1974) and Mihevic (1981) have noted that while oxygen uptake grows linearly with respect to workload, RPE increases according to a positively accelerating function which closely approximates $\dot{V}E$ and blood lactate response curves.

The comparison of exercise at equivalent relative intensities does not account for physiological responses such as lactate production, ventilatory hyperpnoea and catecholamine elevation which may differ between individuals (Åstrand and Rodahl 1977). On this basis it cannot be concluded that oxygen uptake is consciously monitored per se. It is more plausible that oxygen uptake, like heart rate, is indirectly related to RPE, since the input of certain physiological parameters such as $\dot{V}E$ and blood lactate are linked to relative metabolic demand (Carton and Rhodes 1985).

Studies which have focused upon the factors involved in the perception of effort during muscular work have cited local factors such as mechanoreceptor and chemoreceptor sensitivity (Cain and Stevens 1971), and tendon, skin and joint ligament receptors (Cain 1973). These same factors have also been shown to exert significant input into the perceptual response during aerobic exercise performed on a bicycle ergometer (Ekblom et al. 1975, Pandolf and Noble 1973, Stamford and Noble 1974). Support for the role of kinesthetic or proprioceptive feedback may also be inferred from the findings of a variety of comparative studies.

Several investigators have shown that ratings differ at equivalent power outputs and metabolic rates when pedalling frequency is modulated on a cycle ergometer (Cafarelli 1977, Lollgen et al. 1977, Pandolf and Noble 1973, Stamford and Noble 1974). Similarly during treadmill exercise at the same oxygen consumption, RPE may vary, depending on whether the work is achieved through constant (steady-state) or irregular (progressive) exercise (Davies and Sargeant 1979). These studies suggest that RPE is related to the degree of strain which is experienced in the active musculature. If this construct is valid, then it would be expected that differences in RPE associated with the performance of a given task would be partially explained in terms of mechanical efficiency. Efficiency is known to be greater for running than for walking (Donovan and Brooks 1977, Pugh 1971), for a given heart rate, RPE is significantly greater during treadmill walking than treadmill running (Noble et al. 1973). Physical strain in the working muscles may also be perceptually prominent at higher workloads if mechanical efficiency is poor. This was demonstrated by Horstman et al. (1979a) who found local RPE to more markedly dominate central RPE when walking was compared to running at 80% of maximal aerobic power. These findings help to confirm that sensations originating in the working muscles are important determinants of RPE.

Using a variety of modalities (Ekblom and Goldbarg 1971), intensities (Morgan and Pollock 1977), environmental conditions (Horstman 1977), fitness levels (Ekblom and Goldbarg 1971), and continuous or intermittent protocols (Edwards et al. 1972), strong correlations between RPE and blood lactate concentrations have been demonstrated. During incremental exercise, both blood lactate and RPE exhibit a similar, positively accelerating function when plotted against time (Noble et al. 1973).

Lewis et al. (1980) trained sedentary young men for 30 minutes per day, 4 days per week, for 11 weeks at 75 to 80% of maximal aerobic power. Post-training RPE values were found to be lower at any given submaximal workload, but only in trained limbs. This is consistent with the expected lactate response to training, where lower blood lactate concentrations have been found with trained but not untrained limbs (Ridge et al. 1976).

In contrast to this work, Stamford and Noble (1974) were unable to show that arterial lactate during exercise at 960 kg/min and pedalling rates of 40 rpm differed from those at 60 rpm when work time was held constant. However, RPE was significantly lower at the slower pedalling speed. These data were collected from a fit group of subjects (maximal aerobic capacity: 61.4 ml/kg/min), and the exercise intensities employed were probably insufficient to stimulate a lactate response. Exercise was performed at or less than 65% of maximal oxygen uptake, and this intensity has been shown to be below the anaerobic threshold of highly trained athletes (Costill 1970).

Although some evidence supports the role of lactate concentration as a potent stimulus for the perception of effort, the mechanism by which this influence might be mediated is vague. It has been suggested that pain and discomfort in the working muscles may be related to the stimulation of free nerve endings, due to the metabolic acidosis which is induced by elevations in muscle lactate concentrations (Kay and Shephard 1969, Stamford and Noble 1974, Pandolf 1978). Experimental research does not support this position. Kostka and Cafarelli (1982) found that neither induced acidosis (NH_4Cl) or alkalosis ($NaHCO_3$) had any affect upon effort sensations during moderate exercise (50% of maximal aerobic capacity). However, during heavy exercise (80% of maximal aerobic capacity) acidosis increased sensory intensity by 20% after 15 minutes. Thus although evidence is conflicting, it appears as though blood lactate concentrations may influence perceived exertion by some presently unidentified pathway, rather than through a reduction of pH.

Following identification of the physiological factors that purportedly affect the perception of effort, numerous attempts have been made to assess the relative contribution of central versus local factors to RPE. Originally it was proposed that local factors dominate effort perception during work with small muscle groups, but that perceptual cues could be complemented by central inputs when large muscle groups were employed

(Ekblom and Goldbarg 1971). However, it has been shown that local components may still provide the most intense sensory stimulus, irrespective of the size of the muscle mass which is recruited (Pandolf and Noble 1973, Stamford and Noble 1974).

To effectively distinguish between the magnitude of the peripheral versus central cues, differentiated ratings of perceived exertion have been utilized (Pandolf 1982). While undifferentiated exertion may be representative of non-physiological variables and generalised physiological events, differentiated reports may closely reflect discrete physiological symptoms (Robertson et al. 1979b).

During cycling exercise, it has been shown that overall and local effort consistently override central sensations (Cafarelli et al. 1977, Mihevic et al. 1982, Pandolf 1977, Robertson et al. 1979a). At high speeds of walking while carrying loads, local RPE is higher than overall RPE, and central RPE is lower than overall RPE (Robertson et al. 1982a). During treadmill exercise, central factors exert a proportionally greater influence (Pandolf et al. 1972). The same authors have suggested that on a relative basis, more high-glycolytic, fast-twitch motor units are recruited during cycling than running. Consequently, greater afferent input to the reticular activating system from peripheral pain receptors, muscle spindles and Golgi tendon organs may occur during cycling than running.

A recent study by Mihevic et al. (1982) suggests that central and local RPE are related to the absolute and relative intensity of exercise respectively. In this experiment, subjects cycled under normoxic and hyperoxic conditions. Test protocols included cycling at 75% of maximal oxygen uptake (normoxic), 75% of maximal oxygen uptake breathing 70% oxygen, and 75% hyperoxic maximal oxygen uptake, breathing 70% oxygen. Central RPE was elevated during the third condition, when the workload was absolutely higher, but relatively equivalent to the first condition. Overall and local RPE were greater during the second condition, when the absolute workload was the same, but was relatively less than during the first condition.

Mihevic et al. in an earlier study (1981a), showed that when extremely fit subjects (maximal oxygen uptake: 66.5 ml/kg/min) self-regulated their running pace at perceptually comfortable (62% maximal oxygen uptake) and hard (79% maximal oxygen uptake) levels, local RPE was higher than central RPE only during the hard run. Lollgen et al. (1980) found that when cycling at zero load, 70% of maximal oxygen uptake, or maximal intensities, RPE was not always related to any of the central (heart rate, $\dot{V}E$, $\dot{V}O_2$) or local (muscle lactate, blood lactate, NAD, glycogen, adenosine triphosphate, creatine phosphokinase) cues which were monitored. However, RPE was linked to central factors at high speeds of limb movement, even during unloaded pedalling. A relationship between central RPE and speed of limb movement, independent of workload, has also been shown elsewhere (Croisant 1982). These studies highlight the complexity of effort perception, and the need for a better understanding of the physiological components upon which it is based.

Clearly, the perception of effort cannot be adequately understood or described in terms of physiological input alone. Morgan (1973) has calculated that physiological variables are able to account for only 67% of the total variance in RPE. Many factors such as time of day, sleep deprivation, depressive state, age and sex, environment, nature of the exercise test, duration of exercise, training and fitness levels amongst others, influence RPE significantly.

A theoretical basis may exist for alterations in RPE following sleep loss since anxiety, depression, confusion, and fatigue have been associated with this variable (Koller et al. 1966). Morgan (1973) has demonstrated that neurotics and depressives may lack the ability to accurately rate perceived exertion. In addition, the same author has shown that extroverts have a higher pain tolerance threshold than introverts, and differ significantly in RPE. Extroversion and tension affect RPE most markedly when subjects are unfit (Mihevic 1979). Because chronic exercise provokes a significant decrement in depression (Morgan et al. 1970) and different degrees of depression have been found to occur on a treadmill versus bicycle ergometer in the work range 150 to 160 rpm (Morgan et al. 1971) this factor may be diffucult to control.

The effects of age and sex on RPE have been studied on numerous occaisions (Bar-Or 1977, Borg and Linderholm 1967). Sidney and Shephard (1977) found no significant differences to exist between young and old or male and female subjects when work was expressed as a relative percentage of maximal aerobic power.

The nature and duration of exercise appear to influence RPE. Aronchiuk and Burke (1976) suggest that pre-exercise warm-up may not influence the results which are obtained, a minimal degree of previous exercise experience is necessary to guage RPE accurately (Horstman et al. 1979c). Cafarelli et al. (1977) found that central factors grew more dramatically than local factors as a function of exercise duration. However, during extended activity symptoms of fatigue may be incorporated into RPE, and reduce the validity of these readings. In an attempt to assess the relative input of various psychometric and physiological factors which correlate with the ability to maintain steady-state work on a cycle ergometer Weiser and Stamper (1977) found the following. In order of increasing magnitude, leg fatigue, motivation, perceived effort, general fatigue and cardiopulmonary distress accounted for 76% of the variance in exercise time maintained by their subjects. Dishman (1978) has reported that as much as 18% of performance variance in the 12-minute run may be accounted for by motivation.

When investigating the effects of training on RPE Linderholm (1967) was able to demonstrate that 4 months of intensive exercise could result in a modified evaluation of effort at an absolute workload. Six weeks of rapid walking, stair climbing and stool stepping have been shown to result in decrements in RPE during submaximal exercise in subjects suffering from rheumatoid arthritis (Ekblom and Goldbarg 1971). However, several studies have indicated that although reductions in RPE are visualised at absolute workloads following training, no changes occur with respect to relative intensity (Docktor and Sharkey 1971, Ekblom and Goldbarg 1971, Kilbom 1971). Relative exercise intensities based upon percentage of maximal aerobic power do not account for adaptations in physiological responses such as lactate production, ventilatory hyperpnoea and catecholamine elevation (Åstrand and Rodahl 1977). These results and those obtained elsewhere (Stamford and Noble 1974) indicate that training may typically involve neuromuscular adjustments as well as cardiovascular gains.

Regarding the relationship between the level of fitness and RPE various differing conclusions have been suggested. Michael and Eckhardt (1972) requested trained and untrained subjects to choose a treadmill work level which they considered to be "hard" at 0% grade. They were then asked to reproduce an equivalent workload, with the treadmill reset at a 10% grade. No differences were detected between groups in either of the workloads selected. Patton et al. (1977) found no differences in RPE during a 6-minute run at 6 mph on a treadmill in military conscripts who differed in fitness levels. However, following six weeks of training, an 11% reduction in RPE occurred for all subjects during submaximal exercise.

Part of the problem in reaching conclusions on the issue of RPE trainability centres upon agreement as to what should be described as a "significant" decrement in RPE. Morgan (1977) has pointed out that a reduction of 1 to 2 RPE units on the Borg scale translates to a 10 to

20% change, which potentially could be very significant in endurance events such as marathons.

In summary, the complexity of the economy, efficiency, variance of response and perception of effort in human locomotion as separate entities alone has resulted in several as yet unanswered questions. In relation to the walk-to-run interface and the run-to-walk interface it is hoped that the foregoing review will provide the basis for an integrated approach to shedding some light on the problems in the research hypotheses of this study.

CHAPTER THREE

EXPERIMENTAL METHODS AND PROCEDURES

INTRODUCTION

Eleven male caucasian Physical Education students volunteered to participate in the study. Each subject was required to complete an informed consent form (Appendix 1) prior to participation. In addition to this consent a pre-test questionnaire was completed by each subject prior to every testing session (Appendix 1).

Each subject, unless completely inexperienced in treadmill walking and running, was required to visit the laboratory on six different occasions. For those subjects not habituated to treadmill locomotor patterns an additional visit was a prerequisite for further testing. The first visit comprised a test of maximum aerobic capacity ($\dot{V}O_2$ max test) performed on a Quinton Model 643 motor driven treadmill. The second test involved the following:

a) a series of anthropometric measurements
b) an "interface speed" test
c) an "interface $\dot{V}O_2$" test.

During the subsequent visits to the laboratory each subject was required to complete a total of 49 walking and/or running conditions in which five different "speed methods" were used: Absolute speed (m/s); Relative speed in Statures / second (st/s); Relative speed in Leg Lengths /

second (ll/s); Relative speed in Foot Lengths / second (fl/s); Relative speed ($v/\sqrt{gh}$) (After Alexander 1976).

ENVIRONMENTAL CONDITIONS

All testing was done in the Work Physiology Laboratory in the Department of Human Movement Studies at Rhodes University. The diurnal ambient conditions in the laboratory remained fairly stable throughout the two - month testing period from September through October. It was considered unnecessary to standardize the time of day at which to test each subject as variations in the energy cost of walking and running due to differences in the time of day are insignificant (Durnin and Namyslowski 1958, Shephard 1969).

INDIVIDUAL DIFFERENCES

Each subject was requested to report to the laboratory wearing similar clothing each time (running kit and "sensible" shoes). The wearing of different shoes, particularly, has been seen to have considerable effects upon the energy cost responses to given walking and running tasks (Frederick 1985).

Subjects were requested to refrain from vigorous exercise and excessive eating for up to 2-3 hours before testing, particularly before the test of maximum aerobic capacity.

PILOT TESTING

All the testing during the pilot test phase was done using two of the eleven subjects who had volunteered to participate in the main study. Both were very experienced in treadmill walking and running as well as being familiar with all the data collection techniques that were to be used. (Subject one: 31 years; body mass 64.5 kg. Subject two: 22 years; body mass 62.9 kg). Pilot testing was essentially carried out to establish the validity and reliability of the test data, however, the primary reason for the pilot testing was to establish the latter and eliminate any procedural problems which may have arisen during actual data collection sessions.

The reliability in this case refers to the "repeatability" of the results between test one and test two. The validity of the data is determined by the ability of the specific equipment used to measure what in fact it is purported to measure.

A test-retest design was used in which the protocol for all tests remained the same, but all conditions during the treadmill tests were randomly assigned to prevent any bias in the results obtained.

Pilot test protocol

Each subject was required to sign an "informed consent" form before any testing was done. The protocol used involved two separate visits to the laboratory for each subject. The first test was divided into three separate parts:

PART ONE: Anthropometry

PART TWO: "Interface speed" test

PART THREE: 8 4- minute walking and/or
running tasks.

The retest comprised only parts TWO and THREE above. The only anthropometric measurement repeated during the retest was the body mass of each subject.

Anthropometry

The following anthropometric measurements were taken using the methods proposed by Tanner (1964). Stature, body mass, sitting height, foot length. Two skinfold measurements were also made; a subscapular skinfold and a thigh skinfold. Each measurement was taken five times. The reliability of these test data was established by calculating the coefficient of variation for each of the variables measured and then comparing these with acceptable limits of inter- and intra-subject variability found in the literature. Since these values were considered to fluctuate very little over the test-retest period the method used was deemed adequate to establish both the reliability and validity of the data collected.

Measures of stature and sitting height were obtained using a Holtain stadiometer. Body mass was measured using a Seca Beam Balance. A Holtain Digital Anthropometer was used to measure foot length, and the skinfolds were measured using a pair of Harpenden Skinfold Fat Calipers.

The interface speed test

This test was designed to identify the speed at which each subject would change his pattern of locomotion from a walk to a run at the walk-to-run interface. The test protocol was identical for both the test and retest conditions; it involved a double blind technique. Neither the tester nor the subject was aware of the speed at which the interface occurred. A Quinton Model 643 motor driven treadmill was used and the treadmill speed was monitored by an on-line computer system developed at Rhodes University (Goslin et al. 1985).

Each subject performed five increasing speed trials and five decreasing speed trials. The speed at which the pattern of locomotion changed from a walk to a run in the former and a run to a walk in the latter were recorded. Cadence in steps per minute was counted manually at each interface speed with the subject either walking or running.

The walk/run tests

Both subjects performed a total of 16 4-minute walking and/or running conditions during both tests. The protocol for each test was the same but individual conditions were randomly presented to each subject to avoid any bias in the results obtained.

Resting heart rate was palpated at the radial artery for a 15 second period at the start of each test. The prerequisite for the recommencement of each 4-minute condition was that the heart rate return to within 10 beats of the previously measured resting value. During each 4-minute condition a 1-minute gas sample was analysed between minutes 3 and 4 using the computer-aided on-line data acquisition system. Treadmill speed was accurately set using the computer monitor, after which cadence in steps per minute was manually counted and recorded. Ratings of perceived exertion, using the Borg scale, were obtained during the last minute of each condition.

Two speed methods were used during the pilot testing phase; Absolute speed (km/hr) and relative speed (st/s).

TREADMILL HABITUATION

It is well documented that for subjects who are naive to treadmill walking and running there should be a period of treadmill habituation prior to any data collection taking place (Wall and Charteris 1980, 1981). Three of the subjects who volunteered their services for this study had no previous experience on the treadmill. For these subjects a 30-minute period of habituation was a prerequisite for further testing. A total of six speeds were chosen; three walking and three running speeds. The subject was on the treadmill for five minutes at each speed. The slowest walking speed was 4 km/hr (1.11 m/s) and the fastest running speed was 10 km/hr (2.78 m/s). This range of speeds was the same as that selected for the 4-minute walk/run conditions.

In addition to becoming familiar with walking and running on the treadmill, the subjects had also to adapt to the mouthpiece of the on-line data collection system. For this reason the first 3 5-minute conditions were done without the mouthpiece and the last 3 conditions were done with the subject on the mouthpiece for the last 3 minutes of each 5-minute condition. The walking speeds were 4, 5, and 6 km/hr (1.11, 1.39, and 1.67 m/s) and the running speeds were 8, 9, and 10 km/hr (2.22, 2.50, and 2.78 m/s). Each condition was randomly assigned beginning with a walk followed by a run. The speeds were set using the speed control dial on the Quinton treadmill control unit.

THE COMPUTER-AIDED ON-LINE DATA ACQUISITION SYSTEM

In the following data collection protocols the computer-aided on-line system was used to analyse samples of expired air and compute results using this information:

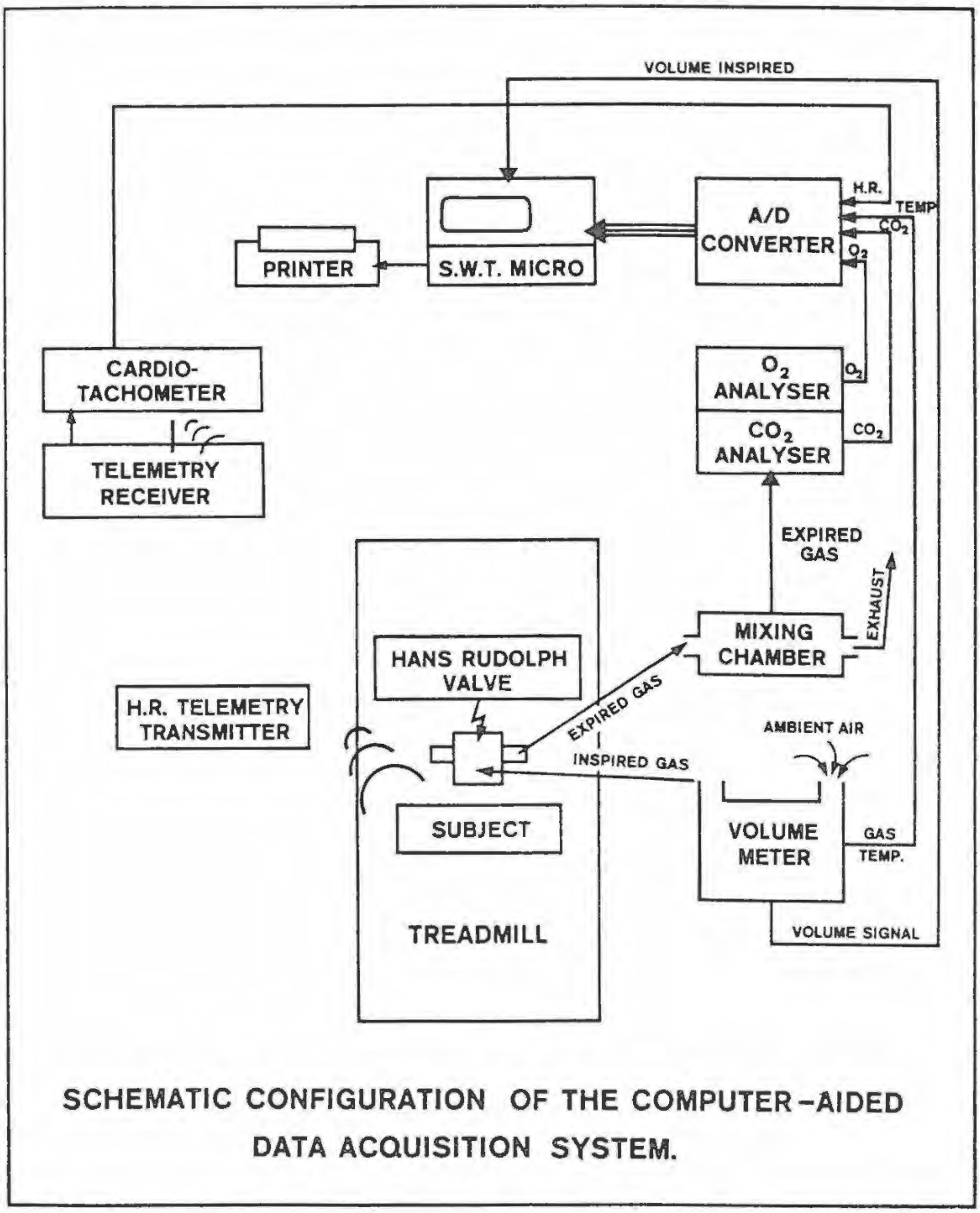
1) The test of maximum aerobic capacity

2) The "interface $\dot{V}O_2$ test"

3) All the 4-minute walk/run conditions

It is necessary that a brief description of this system be given in order that these research protocols be fully understood.

The hardware configuration (Figure 2) enabled the subject to inhale ambient air through the inlet port of the Mijnhardt dry gasmeter where inspired gas volume was measured. The air proceeded from the outlet of the gasmeter through Collins ridged tubing (3 cm diameter) to a Hans Rudolf # 2700 pulmonary valve. Overall inspiratory resistance was low. Expired air was directed through the same type of ridged tubing to a 4 litre Plexiglass mixing chamber. A small circulating fan in the chamber ensured smooth mixing of air which was sampled from the chamber at a rate of 750 ml/minute for analysis. Upon exiting from the flow-through mixing chamber, the air passed through 1 metre of ridged tubing openly vented into the room. This prevented the contamination of the contents of the mixing chamber with room air. Inspired air temperature was measured by a solid-state thermister inside the gasmeter. Expired gas analysis was performed by a calibrated Metek oxygen analyser S.3AI and Gould Goddart Capnograph Mark III carbon dioxide analyser. Calibration of these two gas analysers was done with gases of known concentrations from two different pressurized gas cylinders. One gas cylinder contained gas in the following concentrations: 17.2% oxygen and 2.9% carbon dioxide. The other cylinder contained 13.8% oxygen and 6.00% carbon dioxide.



SCHEMATIC CONFIGURATION OF THE COMPUTER-AIDED DATA ACQUISITION SYSTEM.

FIGURE 2: A schematic of the hardware configuration of the on-line computer assisted data collection system used in this study.

Analogue signals from the temperature probe and the two gas analysers were fed via a multiplexor into a 12 bit, 8 port analogue-to-digital converter. The digital signals generated were sampled at a speed of 220 per minute by a South-West Texas 6800 microprocessor. Continuous visual display of oxygen consumption, respiratory exchange ratio and elapsed time was provided by the system VDU. In addition, 10 sequential readings of the treadmill speed were shown, to allow for accurate speed setting prior to each sample being started. (Only for the walk/run conditions).

A hard copy of measured and derived parameters was output to the C-Itoh dot matrix printer immediately after each sample.

COMPUTER SOFTWARE

Test of maximum aerobic capacity ($\dot{V}O_2$ max test)

A computer programme entitled "CONT 30" was used during all $\dot{V}O_2$ max tests. This programme, as do all programmes for this system, required the following initial data for each subject:

Subject name, age (years), sex (male or female), body mass (kg), maximal $\dot{V}O_2$ (ml/kg/min) (If not known a zero was entered), barometric pressure (mmHg), and relative humidity (%).

Following this input the computer was ready to sample data from the exercising subject. A 25-second sample was taken every 30 seconds throughout the full duration of the test. This amounted to two samples being taken at each new 1-minute work bout during the test. This programme operates continuously and automatically once the sampling process has been initiated by the investigator.

The "interface $\dot{V}O_2$ test" and the walk/run tests

For each of these tests the programme entitled "MANUAL" was used. The initial input was the same as that for "CONT 30" mentioned above. However, the sample period was a continuous 60-second one which was initiated by the investigator at the beginning of the last minute of each 4-minute condition. Prior to the 60-second sample commencing, 10 speed samples were sequentially displayed on the computer's video display screen.

At the end of each sample, irrespective of which programme was being used, the following data were printed out:

Experiment, elapsed time, sample duration, $\dot{V}O_2$ (ml/kg/min), $\dot{V}O_2$ (l/min), $\dot{V}CO_2$ (l/min), respiratory exchange ratio, minute volume inspired (l/min), breathing frequency (breaths/min), fractions of oxygen and carbon dioxide, ventilatory equivalents for oxygen and carbon dioxide (l/100ml), cardiac output (l/min), stroke volume (ml/beat), tidal volume (l/breath), oxygen pulse (ml/beat), and treadmill speed (km/hr).

In the case of the "MANUAL" programme the percent of maximal aerobic power at which each subject was working for each condition was also recorded.

THE RESEARCH PROTOCOLS

Maximal aerobic capacity ($\dot{V}O_2$ max test)

Prior to the test each subject was required to complete a pre-test questionnaire (Appendix 1). Body mass (kg) was measured in running clothes, without shoes, using a calibrated Seca Beam Balance. A standardized instruction sheet concerning the use of the Borg scale for ratings of perceived exertion was read by all subjects (Appendix 1).

The test protocol comprised a continuous treadmill run at progressively increasing work intensities. The subject was on the mouthpiece of the on-line system from the start of the test to it's termination; a nose clip was also worn. For administrative purposes a continuous treadmill run appears to be the test of preference for testing the aerobic capacity of large numbers of healthy subjects (McArdle et al. 1981).

The subject jogged for five minutes at 0% grade and 8 km/hr (2.22 m/s) at which time, and every minute thereafter, the treadmill speed was increased by 1 km/hr until the subject was running at 17 km/hr (4.72 m/s). The treadmill grade was then increased by 1% every minute until exhaustion. All these tests were performed on a Quinton Model 643 motor driven treadmill. Two samples were analysed during each minute of the test beginning at minute 4 of the 0% grade and 8km/hr condition. Cadence in steps per minute was manually counted at each speed and grade condition. At the end of the test, immediately after the subject had left the treadmill, a retrospective maximal rating of perceived exertion using the Borg scale was recorded (ie. retrospective in the sense that the subject was asked to rate his perception of exertion at the time he terminated the test).

Certain specific criteria have been identified as being indicative of maximal oxygen consumption (McArdle et al. 1981), and were used in this study. These criteria are as follows:

1) peaking of oxygen consumption values
2) changes in $\dot{V}O_2$ of less than 2 ml/kg despite increases in speed and/or grade
3) ratings of perceived exertion greater than 17
4) the attainment of age predicted maximum heart rate
5) respiratory exchange ratio of greater than 1.0
6) subjective exhaustion

These criteria indicate maximal oxygen consumption when any three are met simultaneously.

More recently, Katch, Sady, and Freedson (1982), have suggested that the peak oxygen consumption value on a continuous treadmill test is of sufficient magnitude to warrant calling it the maximal value. In cases where the previously mentioned criteria could not be met the peak oxygen consumption value alone was used.

The $\dot{V}O_2$ max test was done in order to establish the following:

1) To determine the percent of this maximal value at which each subject was working during each of the 4-minute walk/run conditions.

2) To determine the aerobic fitness levels of all subjects.

3) To determine the ventilatory threshold of all subjects. Firstly, the speed at which the ventilatory threshold occurred, and secondly the percent of the maximal oxygen consumption at which it occurred.
The ventilatory threshold was obtained by plotting the ventilatory equivalents for oxygen and carbon dioxide against speed (m/s). The point at which the two lines (V.E. for oxygen and carbon dioxide) diverged is termed the ventilatory threshold. Responses to a given exercise task differ according to whether the intensity is higher or lower than the ventilatory threshold (Davis 1985). It was therefore essential to know, for each walk/run condition, whether the subject was working above or below the ventilatory threshold.

4) To determine a maximal rating of perceived exertion. This allowed the calculation of relative ratings of perceived exertion (ie. as a percentage of the maximal value) for the "interface $\dot{V}O_2$" tests as well as for the walk/run conditions

Anthropometery

Because of its noninvasive approach, anthropometry is one the oldest and most popular methods of estimating body composition (Lohman 1982). The following anthropometric measurements were obtained from each subject prior to the "interface speed" test:

> Stature (cm), sitting height (cm), foot length (cm), body mass (kg), subscapular skinfold (mm), thigh skinfold (mm).

The specific procedures for each measurement are outlined in detail below.

1) STATURE was measured using a Harpenden Holtain Stadiometer. The subject was instructed to stand as erect as possible, barefoot with heels together. The buttocks, upper back and rear of the head were in contact with the vertical backboard of the stadiometer. The upper limbs were pendant, with the head in the Frankfurt Horizontal plane. The feet were kept flat on the base of the stadiometer. Stature was measured from the vertex in the median sagittal plane using the stadiometer branch. The reading was recorded in centimeters to the nearest millimeter (Tanner 1964).

2) SITTING HEIGHT was also measured using a Harpenden Holtain Stadiometer. The subject sat on a box 50 cm in height, his back and rear of the head were in contact with the backboard of the stadiometer. The feet hung unsupported over the edge of the box. The subject sat up as erect as possible and, with the head in the Frankfurt Horizontal plane the stadiometer branch was lowered on to the vertex. The reading was recorded in centimeters to the nearest millimeter having subtracted the box height (Tanner 1964).

3) FOOT LENGTH was measured using a Harpenden Holtain digital anthropometer. The reading was taken from the most posteriorly projecting point on the heel (acropodian), to the tip of the most anteriorly projecting toe (pternion), with the subject standing erect on top of a laboratory work bench. All readings were taken on the right foot and were recorded in centimeters to the nearest millimeter (Tanner 1964).

4) LEG LENGTH was derived from subtracting the sitting height from stature. It is commonly known as subischial length since the ischial tuberosities are the prominences that one sits upon, and this measurement is essentially the distance from these points to the ground (Tanner 1964).

5) BODY MASS was measured on a Seca Beam Balance. The subject stood on the scale in running clothes without shoes. Body mass was recorded in kilograms to the nearest gram.

Skinfold measurements

Two skinfold measurements were taken on each subject using a Harpenden Skinfold Fat Caliper. All readings were recorded in millimeters to the nearest 0.1 millimeter.

1) SUBSCAPULAR SKINFOLD. A skinfold was taken between the thumb and forefinger immediately below the inferior angle of the right scapular in an oblique plane descending laterally (outwards) and downwards at an angle of approximately 45 degrees to the horizontal.

The subject was standing erect with the upper limbs pendant (Tanner 1964). The Harpenden calipers were placed 1 cm below the grasp of skin and at a depth of 1 cm from the top of the fold. The dial indicator was allowed to stabilize before taking the measurement.

2) THIGH SKINFOLD. A skinfold was taken parallel to the long axis of the thigh mid-way between the trochanterion and the patella of the right leg in the same way as mentioned above. The fold was also centred in the transverse plane. The subject's foot was elevated so that the angle behind the knee joint was approximately 120 degrees (Tanner 1964).

The following derived data were calculated from those anthropometric measurements described above:

1) Percent body fat (%)
2) Ideal body mass (kg)
3) Lean body mass (kg)
4) Body surface area (metres squared)
5) Leg length as a percent of stature (%)
6) Foot length as a percent of leg length (%)

(Refer to Appendix 3 for calculation equations).

Interface speed test

The purpose of this test was to establish the speeds at which each subject changed his pattern of locomotion at the walk-to-run interface and at the run-to-walk interface. All the testing was done on a Quinton

Model 643 motor driven treadmill. The treadmill speed was set and accurately monitored using the South-West Texas 6800 microprocessor in the on-line system. The software programme used was entitled "SPEED" and it gave a continuous sequential display of treadmill speed on the computer's VDU.

The protocol used was similar to that used by Bhambhani and Singh (1985) to determine self-selected, most comfortable speeds of walking and running. Each subject performed 10 increasing speed trials and 10 decreasing speed trials. All speed trials were randomly presented to the subjects.

For the increasing speed trials the subject started walking at 4 km/hr (1.11 m/s); the treadmill speed was slowly and continuously increased until, by means of visual observation, the subject was seen to have changed his pattern of locomotion from a walk to a run. At this point the treadmill speed control was released. For each of the 10 trials the "interface speed" was recorded and cadence (steps/min) was manually counted on the running subject. The same procedure was used for the 10 decreasing speed trials, however the subject started running at 12 km/hr (3.33 m/s), and the treadmill speed was slowly and continuously reduced until the subject had changed his pattern of locomotion from a run to a walk. The "interface speed" and a walking cadence (steps/min) were recorded.

The protocol was "double-blind" in nature in that neither the subject nor the researcher was aware of the "interface speeds" during each trial. The video display screen of the computer was covered to prevent either of the two participants seeing the speeds.

The following parameters were derived from the raw data collected during these tests:

Stride length (m), and the "interface speeds" in each of the following relative speed equivalents; st/s, $v/\sqrt{gh}$, ll/s and fl/s.

All these parameters were calculated for walking and running at the run-to-walk interface and walk-to-run interface respectively. (Refer to Appendix 3 for calculation equations). Stride length was calculated in the following way:

STRIDE LENGTH = 2 * (VELOCITY (m/s)/CADENCE).

where cadence is in steps/s.

Interface $\dot{V}O_2$ test

The protocol used for this test was the same as that used for the 49 walking and/or running conditions. (To be described later). The purpose of this test was to establish, primarily, the energy cost of a "freely chosen" locomotor pattern (walking or running), and a "forced" pattern of locomotion.

The treadmill speed was set accurately (using a voltmeter output equivalent of raw speed) to the speed previously chosen by the subject as his walk-to-run interface speed. The subject was then asked to choose either to walk or to run at this speed; whichever felt more comfortable. Having selected a locomotor pattern the subject was required to remain either walking or running, depending on his choice, for 4 minutes.

During the 4-minute period cadence (steps/min) was manually counted and recorded. At the start of minute 2 the subject went on to the mouthpiece of the on-line system. Between minutes 3 and 4 a 1-minute gas sample was taken using the on-line data collection system. In addition to the physiological data collected during the 1-minute sample, a rating of perceived exertion was also obtained using the Borg scale. At the end of the 4 minute period the subject left the treadmill and rested in a sitting position until his heart rate was within 10 beats/minute of a previously palpated resting heart rate. All heart rates were palpated at the radial artery in the wrist; a 15-second count was used in all cases.

Between each condition the oxygen analyser and the carbon dioxide analyser were calibrated using dry gases of known concentrations.

The second condition was similar to the first in that the protocol used was identical, however the subject was "forced" to walk if he had run and run if he had walked in the first condition. The treadmill speed was kept constant for both conditions.

Four-minute walk/run tests

Each subject was required to complete 49 randomly assigned walking and/or running tasks on a treadmill. These conditions were as follows:

Ten absolute speed conditions between 4km/hr and 10km/hr (1.11 m/s and 2.77 m/s)

Eleven relative speed conditions (statures/s) between 0.6 and 1.6 st/s. (In increments of 0.1 st/s)

Eleven relative speed conditions ($v/\sqrt{gh}$) between .27 and .67 $v/\sqrt{gh}$ (In increments of 0.04 $v/\sqrt{gh}$)

Nine relative speed conditions (leg lengths/s) between 1.24 and 3.16 ll/s. (In increments of 0.24 ll/s)

Eight relative speed conditions (foot lengths/s) between 4.6 and 11.6 fl/s. (In increments of 1.0 fl/s).

The 49 conditions were completed over a period of four visits to the laboratory. During the first three visits 12 walk/run conditions were completed in each visit. During the fourth visit 13 conditions were completed.

Prior to any treadmill testing body mass was measured on a calibrated Seca Beam Balance. The subjects were wearing running clothes (without shoes). Following this, resting heart rate was palpated at the radial artery. A 15-second count was used in each case. The prerequisite for commencing any given exercise bout was that the subject's heart rate had returned to within 10 beats/minute of the measured resting value.

The protocol was the same for each 4-minute condition. The treadmill speed was set using a voltmeter equivalent of raw speed. All speeds were preselected. With the subject on the treadmill a clock was started to time the duration of each condition and the treadmill speed rechecked by means of the ten sequential indicators of speed on the video display screen of the computer. Cadence (steps/min) was manually counted and recorded after the treadmill speed had been accurately set. At minute two the subject went on to the mouthpiece of the on-line data collection system, and a nose clip was placed over the nose to occlude the flow of air through the nostrils. At minute 3, a one-minute gas sample was taken. In addition to the physiological data, a rating of perceived exertion was also obtained (Borg scale). At the end of each 4-minute condition the subject came off the treadmill and rested in a sitting position until his heart rate was down to within 10 beats/minute of the previously palpated resting value.

Between each 4-minute condition the oxygen and carbon dioxide analysers were calibrated with gases of known concentrations and the treadmill speed was reset to the new predetermined speed.

RATINGS OF PERCEIVED EXERTION

All subjects were given a standard instruction as to how to respond to the Borg scale prior to the test of maximal aerobic capacity. (Appendix 1). Subjects responded by pointing to the rating of their choice. This was then verbally verified by the investigator before being recorded.

Only ratings of general perceived exertion were obtained (Pandolf 1982).

Statistical significance of RPE

Correlation coefficients of 0.87 to 0.9 have been reported between heart rate and RPE, and RPE versus other physiological parameters (Borg 1962, 1973, and Mihevic, 1981). Skinner *et al.* (1973), have demonstrated high reliability coefficients (0.6 to 0.9) and high validity using RPE in a study to determine whether subjects could perceive small differences in varying work intensities presented in random order.

THE SPEED METHODS

Five speed methods were used in all. Absolute speed (m/s), and four relative speed methods; statures/s, $v/\sqrt{gh}$, leg lengths/s and foot lengths/s. For each 4-minute walk/run condition the speed was preset according to which speed method was being used.

The absolute speeds for each relative speed method were based upon "average" morphological measurements of stature, leg length and foot length. The average stature was 175 cm, the average leg length was 89 cm, and the average foot length was 25 cm. These were considered "average" for the total population. Table I indicates the absolute speeds in km/hr and m/s for all five speed methods based on the above mentioned "average" measurements. Table II indicates the same

Table I : Absolute speeds (km/hr and m/s) and all relative speed methods for an individual of stature 1.85m, leg length 0.91m, and foot length 0.27m.

Absolute		st/s		ll/s		fl/s		$v/\sqrt{gh}$	
4-10 km/hr		0.6-1.6		1.24-3.16		4.6-11.6		.27-.67	
km/hr	m/s	km/hr	m/s	km/hr	m/s	km/hr	m/s	km/hr	m/s
4	1.11	3.99	1.11	4.03	1.12	4.46	1.24	4.14	1.15
5	1.39	4.66	1.30	4.86	1.35	5.44	1.51	4.75	1.32
6	1.66	5.33	1.48	5.65	1.57	6.41	1.78	5.36	1.49
6.5	1.80	5.99	1.67	6.41	1.78	7.38	2.05	5.98	1.66
7	1.94	6.66	1.85	7.2	2.00	8.35	2.32	6.59	1.83
7.5	2.08	7.33	2.04	7.99	2.22	9.32	2.59	7.20	2.00
8	2.22	7.99	2.22	8.78	2.44	10.3	2.86	7.81	2.17
8.5	2.35	8.68	2.41	9.58	2.66	11.3	3.13	8.42	2.34
9	2.49	9.32	2.59	10.4	2.88			9.04	2.51
10	2.77	9.99	2.78					9.65	2.68
		10.7	2.96					10.3	2.85

Table II: Absolute speeds (km/hr and m/s) and all relative speed methods for a "reference man". Stature 1.75m, leg length 0.89m, and foot length 0.25m. This table indicates the 49 walking and /or running conditions performed by each subject.

Absolute		st/s		ll/s		fl/s		$v/\sqrt{gh}$	
4-10 km/hr		0.6-1.6		1.24-3.16		4.6-11.6		.27-.67	
km/hr	m/s	km/hr	m/s	km/hr	m/s	km/hr	m/s	km/hr	m/s
4	1.11	3.78	1.05	3.96	1.10	4.14	1.15	4.03	1.12
5	1.39	4.48	1.23	4.75	1.32	5.04	1.40	4.62	1.28
6	1.66	5.04	1.40	5.51	1.53	5.94	1.65	5.22	1.45
6.5	1.80	5.69	1.58	6.26	1.74	6.84	1.90	5.81	1.62
7	1.94	6.30	1.75	7.06	1.96	7.74	2.15	6.41	1.78
7.5	2.08	6.93	1.93	7.81	2.17	8.64	2.40	7.01	1.95
8	2.22	7.56	2.10	8.60	2.39	9.54	2.65	7.60	2.11
8.5	2.35	8.21	2.28	9.36	2.60	10.4	2.90	8.20	2.28
9	2.49	8.82	2.45	10.1	2.81			8.80	2.44
10	2.77	9.47	2.63					9.39	2.61
		10.1	2.8					9.99	2.77

information but for an individual of stature 185 cm, leg length 91 cm, and foot length 27 cm.

The range of absolute speeds chosen was between 4 km/hr (1.11 m/s) and 10 km/hr (2.77 m/s). Using the "average" morphological values above several relative speed equivalents were calculated for each relative speed method. In order to illustrate the procedure statures/s is used below:

1) $$\text{STATURES/SECOND} = \frac{\text{VELOCITY (m/s)}}{\text{STATURE (m)}}$$

2) For a stature of 175 cm the following relative speed in statures/s at 4 km/hr (1.11 m/s) was calculated:

$$\text{STATURE/SECOND} = \frac{1.11}{1.75}$$

$$= 0.63$$

3) The same procedure was used to calculate the statures/s equivalent for 10 km/hr.

$$\text{STATURES/SECOND} = \frac{2.77}{1.75}$$

$$= 1.6$$

The range of relative speeds (st/s) used was 0.6 to 1.6, a total of 11 conditions.

The same procedure was used for all the other relative speed methods.

Using the relevant anthropometric data from each subject the absolute speed (km/hr and m/s) for each relative speed condition was calculated. To illustrate statures/s are again used. In this case a stature of 185 cm will be used.

For relative speed 1.0 st/s and a stature of 1.85 m:

1) $$\text{STATURES/SECOND} = \frac{\text{VELOCITY(m/s)}}{\text{STATURE (m)}}$$

2) $$\text{Velocity (m/s)} = \text{st/s} * \text{stature (m)}$$

3) $$\text{Velocity (m/s)} = 1.0 * 1.85$$

$$= 1.85 \text{ m/s.}$$

The same procedure was used for each relative speed method.

STATISTICAL ANALYSIS

Related "Student's" t-tests (Ferguson 1981) were computed to determine whether significant differences existed between test-retest parameters recorded during pilot testing. This was necessary to determine whether the test procedures adopted were reliable.

Related "Student's" t-tests were also done on all the data collected during the "interface speed" test and the "interface $\dot{V}O_2$" test in order to determine whether there were significant differences between the following parameters:

1) The walk-to-run interface speed and the run-to-walk interface speed, cadence, stride length, and the coefficient of variation for speed at the two interfaces.

A one-way Analysis of Variance (Ferguson 1981) was done on all the data from the "interface $\dot{V}O_2$" test to determine whether there were significant differences between "free choice" and "forced" patterns of locomotion (walking and running), and all the measured parameters associated with these locomotor groups. In addition, to test for differences in the variability of the measured parameters, the same statistical technique was used on the coefficients of variation for each parameter. This test was also used to assess differences between the five different speed methods used. In all cases the Sheffe Test was used as a post hoc test where significant differences were found.

One-Independent Regression Analyses were done in order to establish the relationships between the following parameters:

1) Oxygen consumption and absolute speed.

2) Oxygen consumption and all relative speed methods.

3) Relative stride and relative speed (st/s) for all walking and running conditions.

These regression analyses were done across all walking and running speeds as well as across the walk-to-run interface only.

A One-Way Analysis of Variance was done using the coefficients of variation for oxygen consumption for walking and running to establish whether or not there were significant differences in the variability of the responses using the five different speed methods.

In all cases the 0.05 level of probability was used in order to optimize the balance between creating both Type I and Type II errors.

CHAPTER FOUR

RESULTS AND DISCUSSION

PILOT TEST RESULTS

The primary aim of the pilot testing was to establish the reliability of the test protocol which was employed. Two male subjects were used in a test-retest design. The results of a Related "Student's" t-test indicated that there were no significant differences ($p<0.05$) between walk-to-run interface speeds and run-to-walk interface speeds for the two tests.

Furthermore, the results of 8 4-minute walking and/or running conditions indicated no statistically significant differences ($p<0.05$) between the two tests in the following parameters:

$\dot{V}O_2$ (l/min and ml/kg/min), ratings of perceived exertion (RPE), cadence (steps/min), % $\dot{V}O_2$ max (ml/kg/min) and respiratory exchange ratio (R).

The duration of each condition (4 minutes), was found to be sufficient for even unconditioned subjects to attain steady-state by minute 3 of each condition (Goslin 1985).

The walking and running speeds for each subject were the same and were randomly selected from speeds between 1.11 m/s and 2.77 m/s. Four absolute speeds and four relative speeds (st/s) were used. The eight speeds were determined prior to each subject participating in the test.

The results of Related "Student's" t-tests indicated the following:

1) that there were no significant differences ($p<0.05$) between the pre-set speeds and the actual speeds given by the South-West Texas 6800 microprocessor in the on-line system.

2) that there were no significant differences ($p<0.05$) between the actual speeds recorded during each test.

The following anthropometric data were collected during pilot testing:

stature (cm), body mass (kg), sitting height (cm), foot length (cm), subscapular skinfold (mm), thigh skinfold (mm).

The coefficients of variation (%) for all parameters were well below the upper tolerance limit for error based on biological and technological variation (3.3%) cited by Lohman (1982).

Table III indicates the pilot test results for the two male subjects used during this phase of the study.

SUBJECT CHARACTERISTICS

It is clear from Table IV that the subjects were well conditioned with high physical working capacities as indicated by the high mean $\dot{V}O_2$ max value. This value is substantially higher than the 43 $mlO_2/kg/min$ recorded by Åstrand and Rodahl (1977) for untrained individuals.

Table III: Pilot test results for two male subjects.

PARAMETER	SUBJECT A			SUBJECT B		
	MEAN	SD	CV	MEAN	SD	CV
STATURE (m)	1.75	0.09	0.05	1.62	0.13	0.08
BODY MASS (kg)	62.1	0	0	64.5	0	0
SITTING HEIGHT (m)	0.95	0.63	0.66	0.89	0.43	0.48
FOOT LENGTH (m)	0.24	0.15	0.62	0.24	0.06	0.23
SUBSCAPULAR (mm)	7.8	0.14	1.81	13.9	0.11	0.79
THIGH (mm)	13.1	0.18	1.36	10.1	0.18	1.77

	TEST ONE		TEST TWO	
	MEAN	SD	MEAN	SD
$\dot{V}O_2$ (l/min)	1.50	0.45	1.57	0.51
$\dot{V}O_2$ (ml/kg/min)	23.8	7.08	24.7	7.98
RPE	11	1.95	10.9	1.88
CADENCE (steps/min)	154	24.9	159	21.3
W-R INTERFACE (m/s)	2.18	0.42	2.09	0.28
R-W INTERFACE (m/s)	2.12	0.51	2.07	0.21
PRE-SET SPEED (m/s)	2.09	1.66	2.09	1.65
COMPUTER SPEED (m/s)	2.09	1.66	2.09	1.66

Table IV: Anthropometric and performance characteristics of the eleven male subjects.

PARAMETER	MEAN	STANDARD DEVIATION
AGE (yrs)	21.6	3.72
ANTHROPOMETRY		
STATURE (cm)	180.3	7.47
BODY MASS (kg)	71.7	6.49
LEG LENGTH (cm)	86.7	6.29
LEG LENGTH/STATURE (%)	48.1	2.18
FOOT LENGTH (cm)	26.3	1.54
FOOT LENGTH/LEG LENGTH (%)	30.4	1.75
% BODY FAT	8.39	2.45
LEAN BODY MASS (kg)	65.7	6.18
BODY SURFACE AREA (m^2)	1.91	0.12
PERFORMANCE		
$\dot{V}O_2$ max (ml/kg/min)	60.2	5.54
V.T. (%$\dot{V}O_2$ max)	74.5	3.94
V.T. (ml/kg/min)	44.8	5.02
V.T. (velocity m/s)	4.03	1.29
RPE max	17.6	1.63

The measures of proportion, namely the leg length to stature ratio and the foot length to leg length ratio compare favourably with those obtained by Goslin (1985) from 20 male subjects.

The equation used to predict body density from which % body fat was calculated was developed by Sloan (1967). Sinning _et al._ (1985) found the following equation;

Body density = 1.1043 - 0.001327 (thigh) - 0.00131 (subscapular)

where thigh = thigh skinfold (mm), and subscapular = subscapular skinfold (mm)

to overestimate fat by only 0.5%. However, it is suggested that the values obtained in this study using the above equation are under-predicted. Goslin (1985) reported % body fat values of (15.2 ± 3.3%) for 20 males with similar anthropometric and performance characteristics using the following equation:

Body density = 1.1599 - (0.0717 * LOG SUM of 4 skinfolds).

The use of 4 skinfolds in Goslin's work may have produced more representative data on the distribution of subcutaneous fat than the 2 skinfold measurements used in this study.

ENVIRONMENTAL CONDITIONS

The average environmental conditions that the subjects were exposed to during the testing period are given in Table V.

Table V : Average environmental conditions for the testing period, August through October 1986.

PARAMETER	MEAN	STANDARD DEVIATION
BAROMETRIC PRESSURE (mmHg)	717.48	3.29
TEMPERATURE (°C)	20.73	1.27
RELATIVE HUMIDITY (%)	59.36	11.36

Relative humidity was the least stable of the three environmental parameters measured. However, all of them fluctuated within very narrow limits over the testing period.

THE ENERGY COST - VELOCITY RELATIONSHIP

The relationship between the energy cost of walking and movement velocity is clearly curvilinear (Figures 3 to 7). This trend appears to be the same for all the speed methods investigated in this study. This finding is consistent with the findings of many authors in this respect (Ralston 1958, Margaria et al. 1963, Menier and Pugh 1968, Falls and Humphrey 1976, Åstrand and Rodahl 1977).

For walking speeds between 1.11 m/s and 2.35 m/s the nature of the relationship between movement velocity and oxygen consumption is the same for absolute and relative speeds, an exponential one. Most of the research into this relationship has indicated that oxygen consumption increases as a function of velocity squared; a least-squares power fit

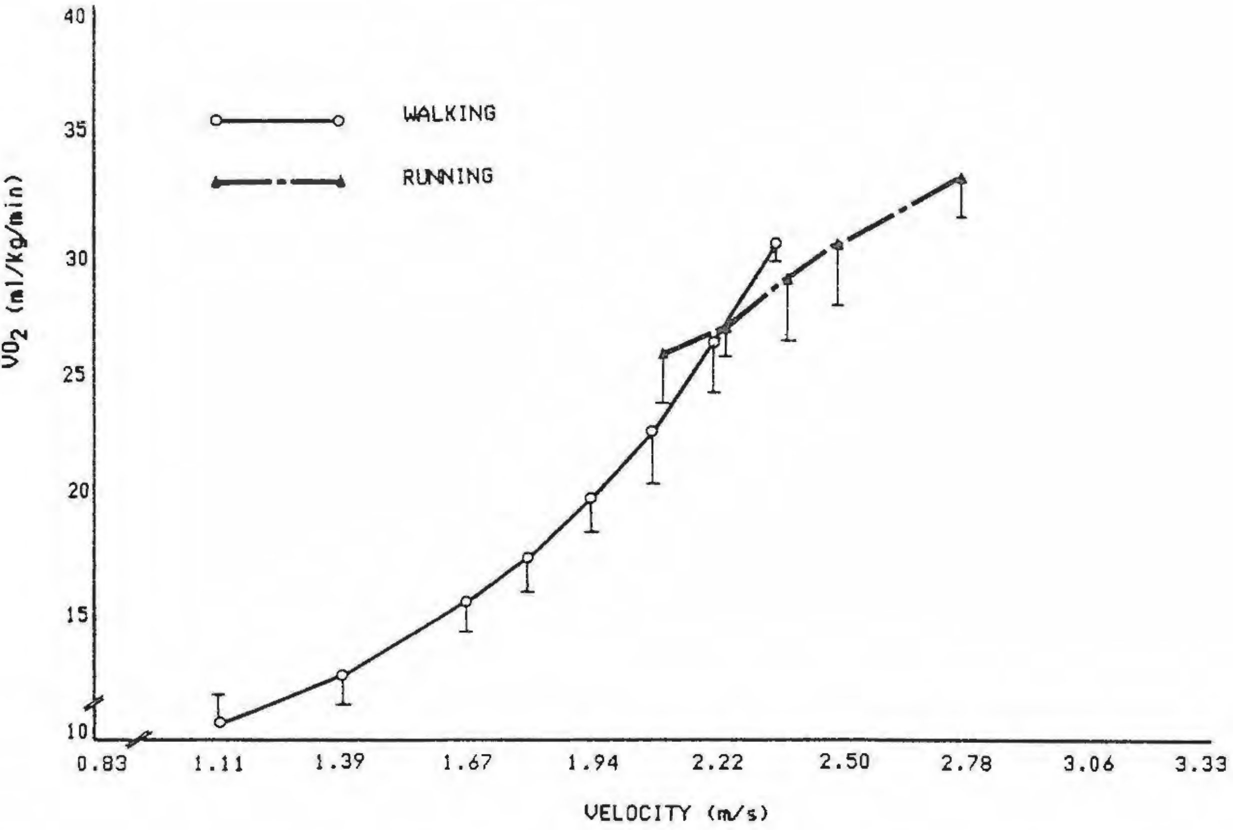


FIGURE 3: Mean energy cost responses (mlO_2/kg/min) at increasing walking and running speeds (m/s). The energy cost of walking and running at the same speeds was not significantly different ($p < 0.05$).

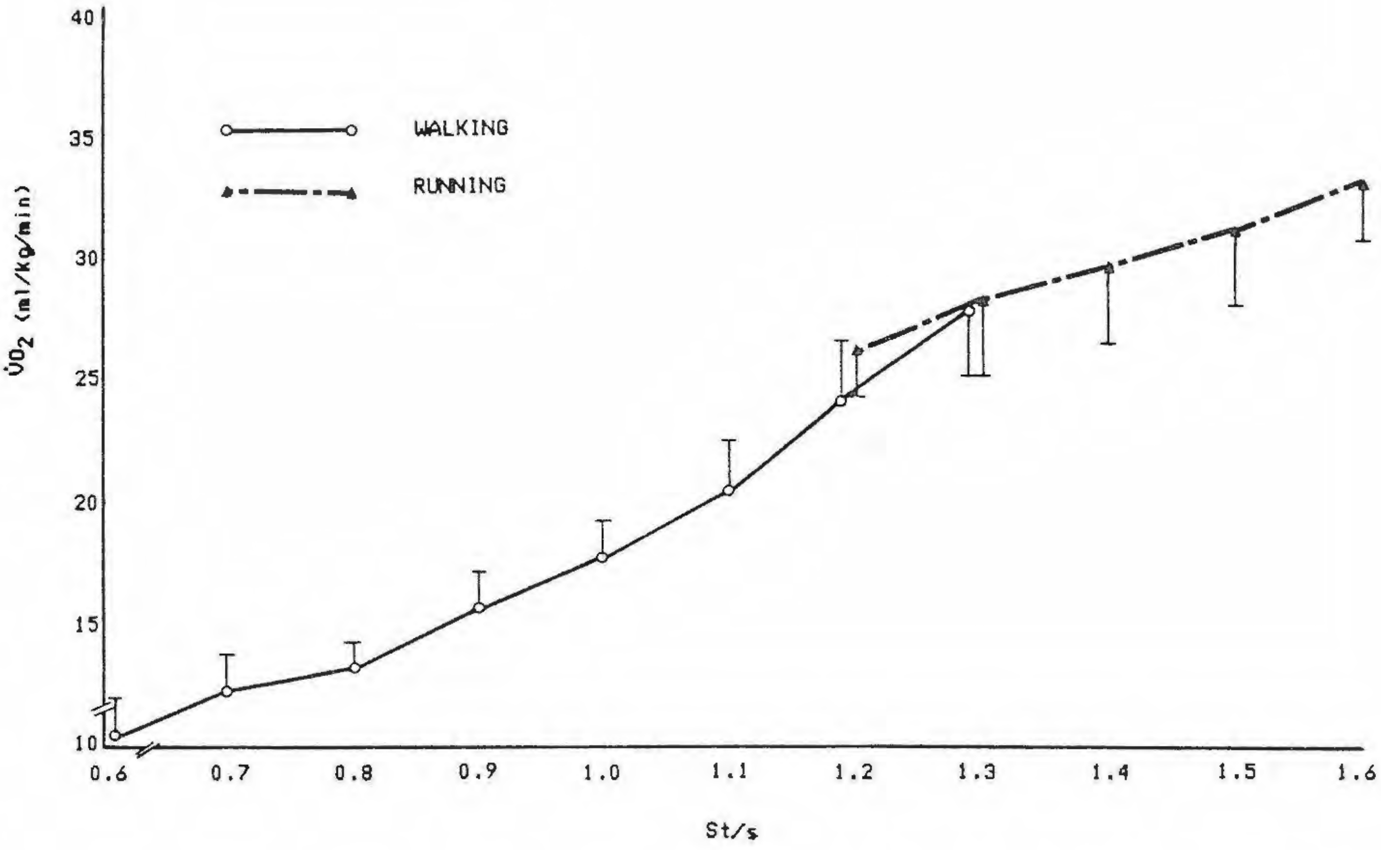


FIGURE 4: Mean energy cost responses (mlO_2/kg/min) at increasing walking and running speeds (St/s). The energy cost of walking and running at the same speeds was not significantly different ($p < 0.05$).

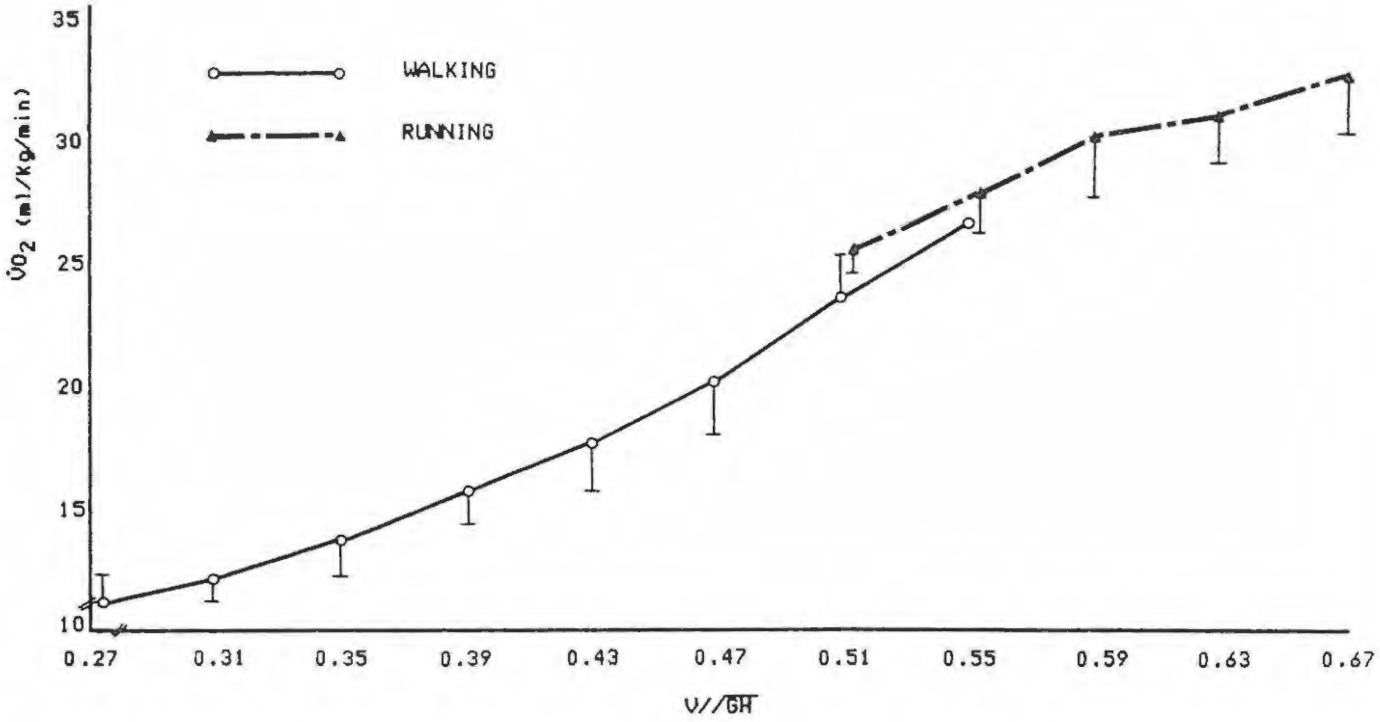


FIGURE 5: Mean energy cost responses ($mlO_2/kg/min$) at increasing walking and running speeds ($v/\sqrt{gh}$). The energy cost of walking and running at the same speeds was not significantly different ($p < 0.05$).

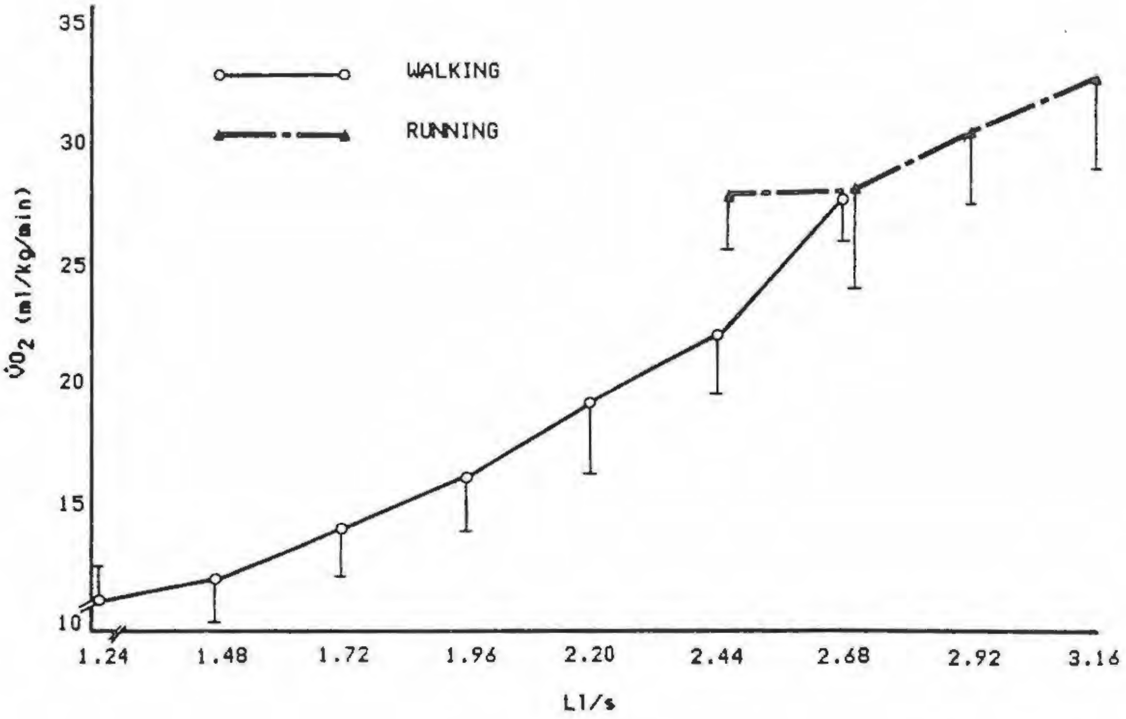
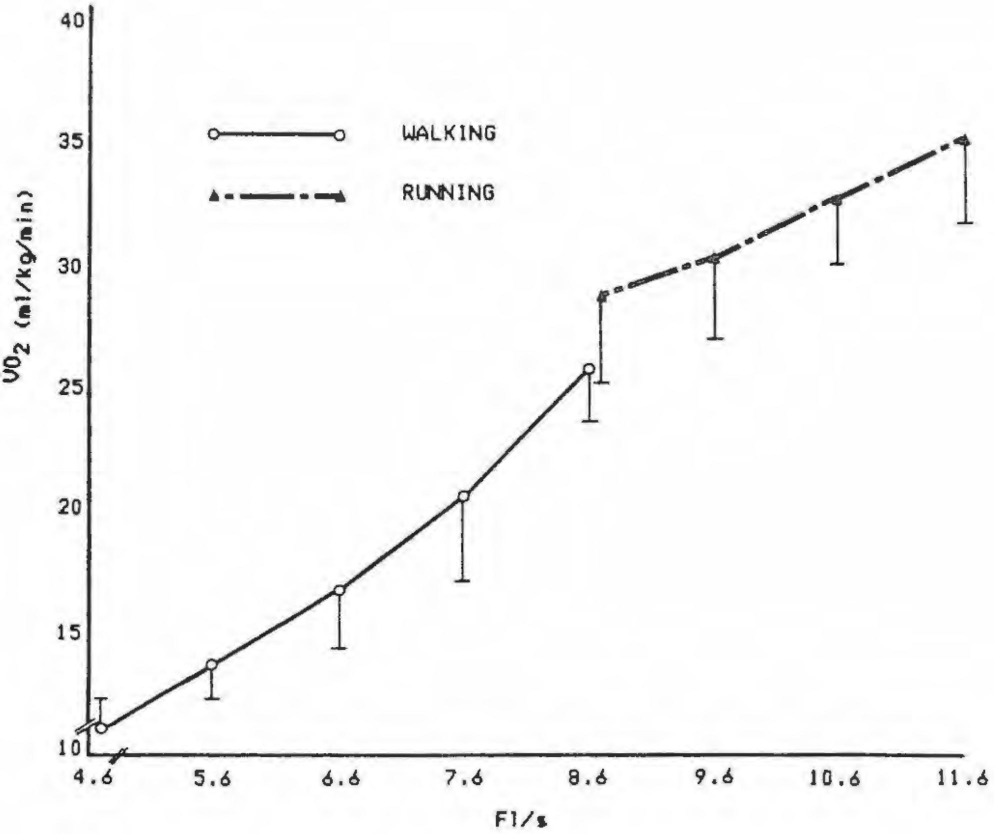


FIGURE 6: Mean energy cost responses (mlO_2/kg/min) at increasing walking and running speeds (Ll/s). The energy cost of walking and running at the same speeds was not significantly different ($p < 0.05$).



<u>FIGURE 7:</u> Mean energy cost responses ($mlO_2/kg/min$) for increasing walking and running speeds (Fl/s). The energy cost of walking and running at the same speeds was not significantly different ($p < 0.05$).

(Lukin and Ralston 1968, Wyndham et al. 1971, Fardy and Hellerstein 1978, Marchetti et al. 1983). Goslin (1985), using a similar experimental protocol also reports an exponential relationship for walking velocities and oxygen uptake. He suggests that the discrepancy between the two types of relationship (exponential versus power fit) may be due to the fact that in most of the previous work, the subjects did not walk at extremely fast speeds, and a power fit may be more appropriate for slower walking speeds. Furthermore it is possible that the use of relative speed, in whatever form, is a procedure sufficient enough to slightly alter the nature of this curvilinear relationship from power to exponential in nature. In each case, despite the fact that an exponential relationship provides the best fit, the correlation coefficient for the power fit equations are little different from those for the exponential equations (Table VI).

Table VI :Correlation coefficients for exponential and power fit equations relating walking $\dot{V}O_2$ to absolute speed (m/s) and relative speed (st/s, $v/\sqrt{gh}$, ll/s, fl/s).

SPEED METHOD	CORRELATION COEFFICIENTS (r)	
	EXPONENTIAL EQUATIONS	POWER FIT EQUATIONS
Absolute (m/s)	0.9564	0.9414
st/s	0.9299	0.9123
$v/\sqrt{gh}$	0.9388	0.9293
ll/s	0.904	0.8903
fl/s	0.9185	0.9102

In this study, for each speed method, fewer running speeds were examined than walking speeds. The data do not present as clear a picture regarding the oxygen consumption-velocity relationship as do the walking data. Table VII indicates that for three of the five speed methods a power fit provides the best least-squares fit for these data, while a linear equation and exponential equation provide the best least-squares fit for relative speed methods ll/s and fl/s respectively. Despite the rather random association of specific equations with different speed methods at first glance, on closer examination a pattern does appear to emerge, the significance of which is not altogether clear. For absolute speed (m/s) and those relative speed methods which use stature as a basis for equalizing movement velocity, a power equation provides the best least-squares fit. The remaining two relative speed methods, which use measurements of limb length as a means of equalizing movement velocity, ll/s and fl/s, are represented by equations other than a power fit.

The majority of research into the relationship between running velocity and oxygen consumption has indicated that this is a linear relationship (Margaria et al. 1963, Shephard 1969, Åstrand and Rodahl 1977, Leger and Mercier 1984). A close examination of Figures 3 to 7 indicates that although the regression analyses show that the best least-squares fits are not linear, the trends themselves are very close to being linear. Table VIII shows the correlation coefficients for the equations which provide the best least-squares fit for running velocity and oxygen uptake and the correlation coefficients for the linear equation for each

Table VII: Regression analysis summary for $\dot{V}O_2$ (ml/kg/min) (Y) versus relative speed (X) in four different forms. The first equation represents the relationship between $\dot{V}O_2$ (ml/kg/min) and absolute speed. (A correction factor of 0.2777 was used to convert speed (km/hr) to (m/s)).

SPEED METHOD	BEST FIT	COEFFICIENTS A	B	EQUATION FORM	r^2
WALKING					
Absolute	Exp	4.181	0.224	Y=A*EXP(B*X)	91.47
st/s	Exp	4.802	1.306	Y=A*EXP(B*X)	84.64
$v/\sqrt{gh}$	Exp	4.526	3.202	Y=A*EXP(B*X)	88.13
ll/s	Exp	4.929	0.618	Y=A*EXP(B*X)	81.72
fl/s	Exp	16.59	0.064	Y=A*EXP(B*X)	35.50
RUNNING					
Absolute	Power	4.477	0.868	Y=A*X^B	55.07
st/s	Power	22.69	0.799	Y=A*X^B	41.10
$v/\sqrt{gh}$	Power	45.14	0.798	Y=A*X^B	48.25
ll/s	Linear	8.911	7.440	Y=A+B*X	22.77
fl/s	Exp	16.59	0.064	Y=A*EXP(B*X)	35.50

speed method. As can be seen from this table there is little difference between the two in each case.

Table VIII : Correlation coefficients for the equations which provide the best least-squares fit for running velocity and $\dot{V}O_2$ (ml/kg/min) and those for the linear equations for each speed method.

SPEED METHOD	BEST FIT	CORRELATION COEFFICIENT	CORRELATION COEFFICIENTS FOR LINEAR EQUATIONS
Absolute	Power	0.7421	0.7324
st/s	Power	0.6404	0.6309
$v/\sqrt{gh}$	Power	0.6946	0.6745
ll/s	Linear	0.4772	------
fl/s	Exponential	0.5958	0.5892

The linear equation which describes the relationship between absolute velocity and oxygen consumption in this study has an almost identical form to that presented by Williams (1985) for subjects of medium height from his investigation of the effects of stature on oxygen consumption during walking and running.

Williams (1985):

$\dot{V}O_2$ (ml/kg/min) = 4.2602 + 2.6771 * velocity (km/hr).

Present study:

$\dot{V}O_2$ (ml/kg/min) = 4.1497 + 2.8935 * velocity (km/hr).

Williams (1985) classified people of medium height as having a stature of between 170 cm and 185 cm. The mean stature for the subjects in the present study was 180.3 cm (± 7.47) which falls within the range quoted above.

OTHER MOVEMENT RESPONSE - VELOCITY RELATIONSHIPS

It is clear from Figures 8 to 12 that cadence and stride length increase in a linear fashion with increases in movement velocity for walking and running. Charteris et al. (1982) reported that the stride length versus speed of locomotion relationship is linear for walking, while Hogberg (1952b) and Knuttgen (1961) both suggest that this relationship is also linear for running. The former author reported an almost linear relationship in two subjects running at 8 to 30 km/hr on a treadmill. The stride length - relative speed (st/s) relationship has been described as linear (Charteris et al. 1982) for speeds between 0.4 and 1.0 st/s.

Some investigators have found that cadence during walking increases with velocity while it does not change much at all during running (Ogasawara 1934, Boje 1944, Knuttgen 1961). Others have found that cadence varies as the square root of velocity of running between 40% and 100% of maximum speed (Luhtanen and Komi 1978). Grieve and Gear (1966) found that the relationship between cadence and walking speed was best

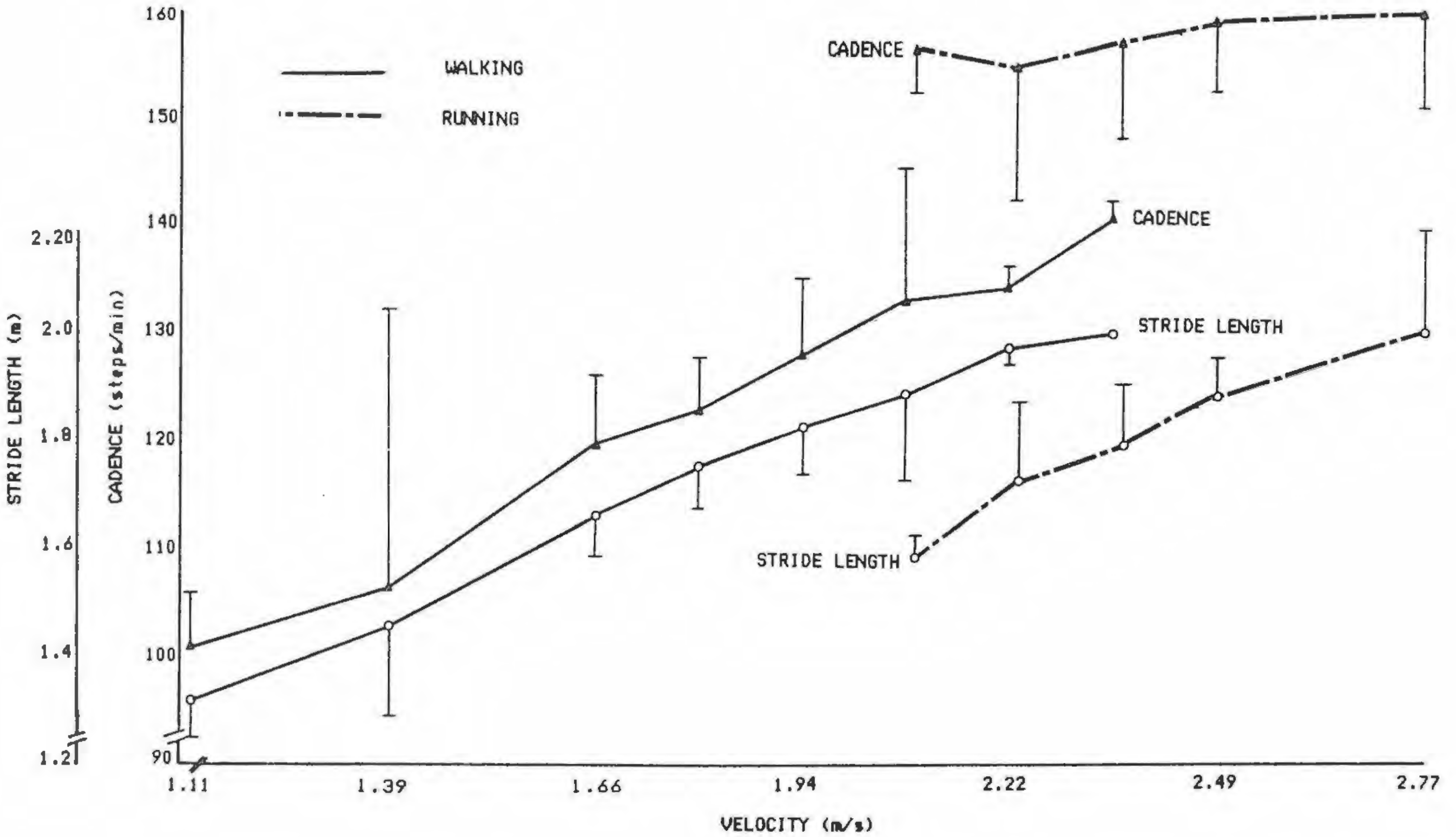


FIGURE 8: Mean cadence (steps/min) and stride length (m) for increasing walking and running speeds (m/s). Cadence and stride length values for walking and running, when performed at the same speeds, were significantly different ($p < 0.05$).

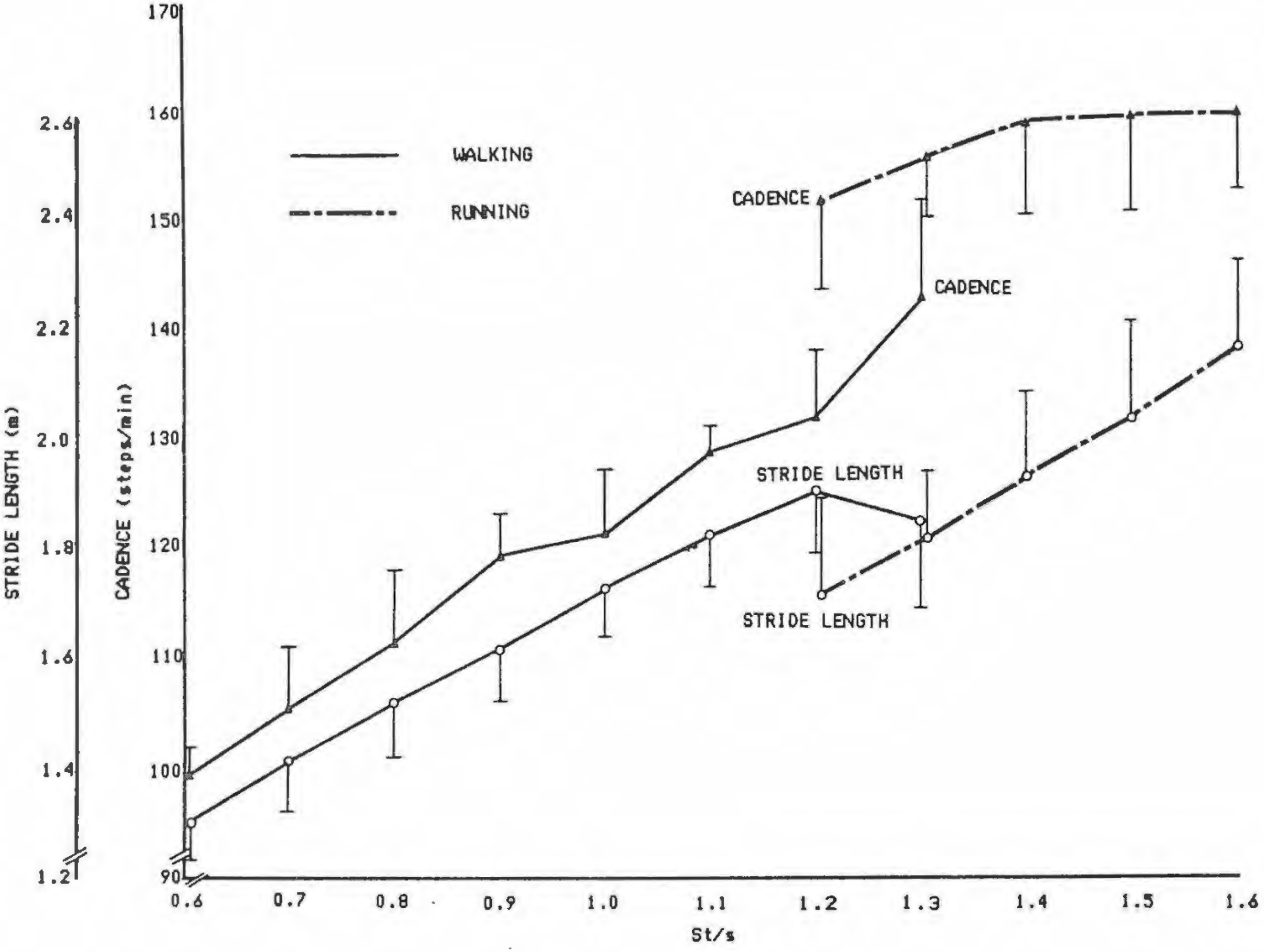
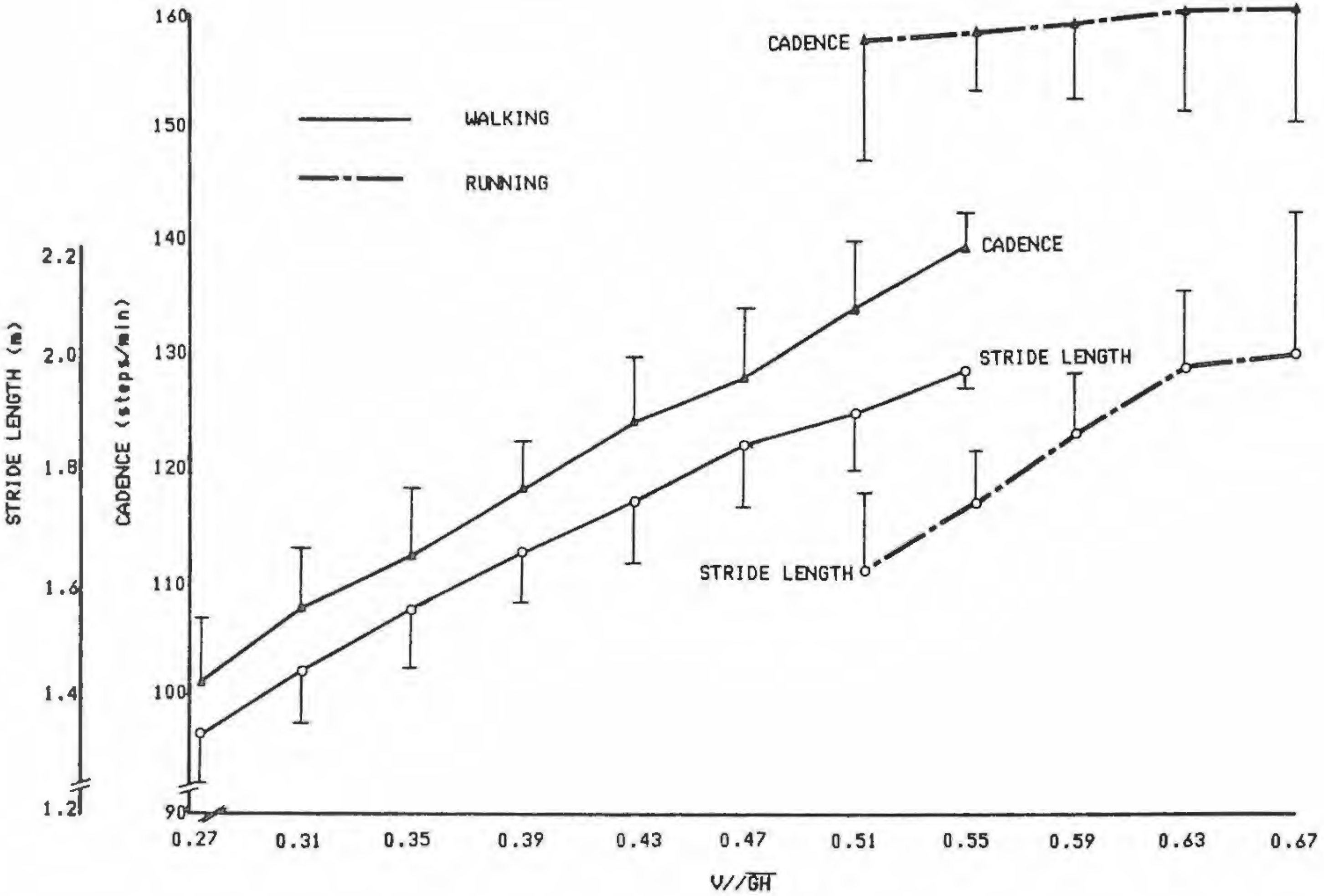
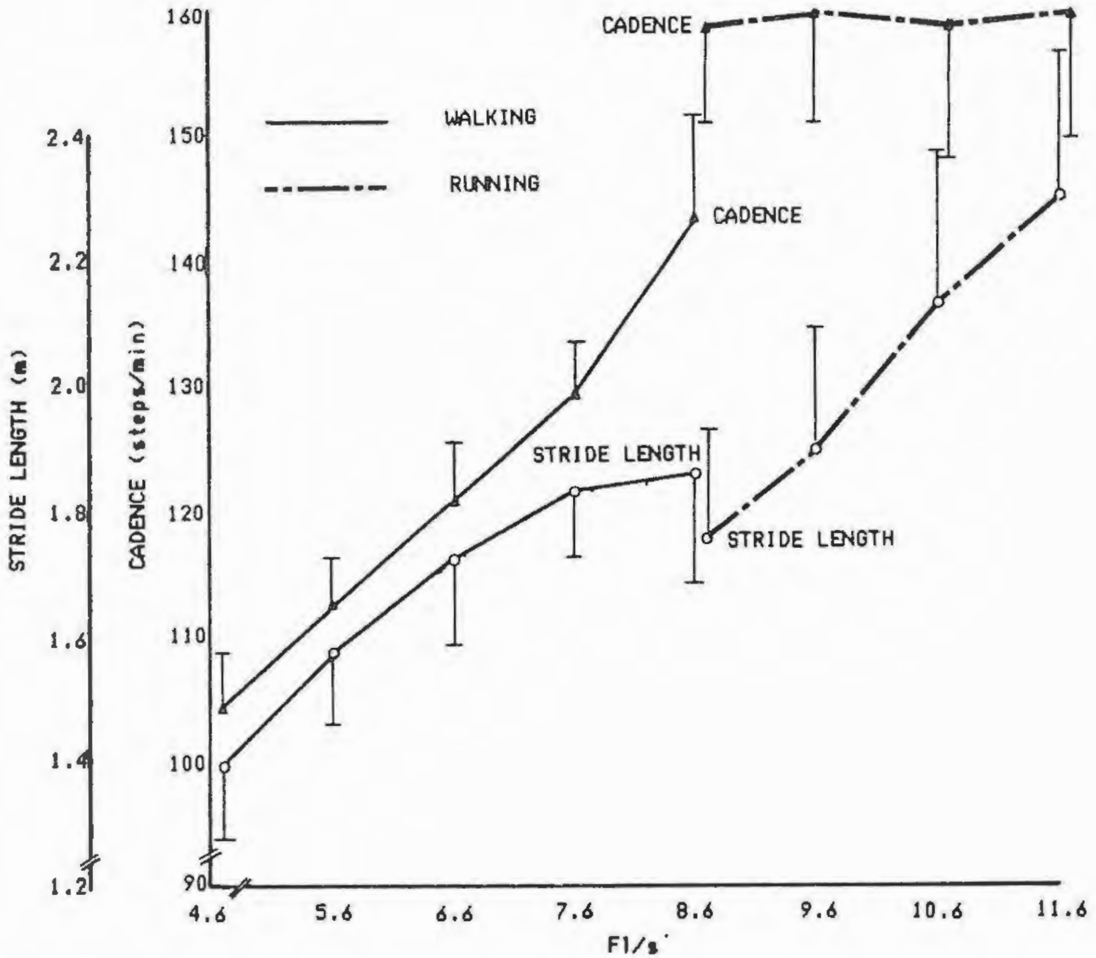


FIGURE 9: Mean cadence (steps/min) and stride length (m) for increasing relative speeds (St/s). Only cadence values for walking and running, when performed at the same speeds, were significantly different ($p < 0.05$).



<u>FIGURE 10:</u> Mean cadence (steps/min) and stride length (m) for increasing relative speeds ($v/\sqrt{gh}$). Cadence and stride length values for walking and running, when performed at the same speeds, were significantly different ($p < 0.05$).



<u>FIGURE 11:</u> Mean cadence (steps/min) and stride length (m) for increasing relative speeds (Fl/s). Cadence values for walking and running, when performed at the same speeds, were significantly different ($p < 0.05$).

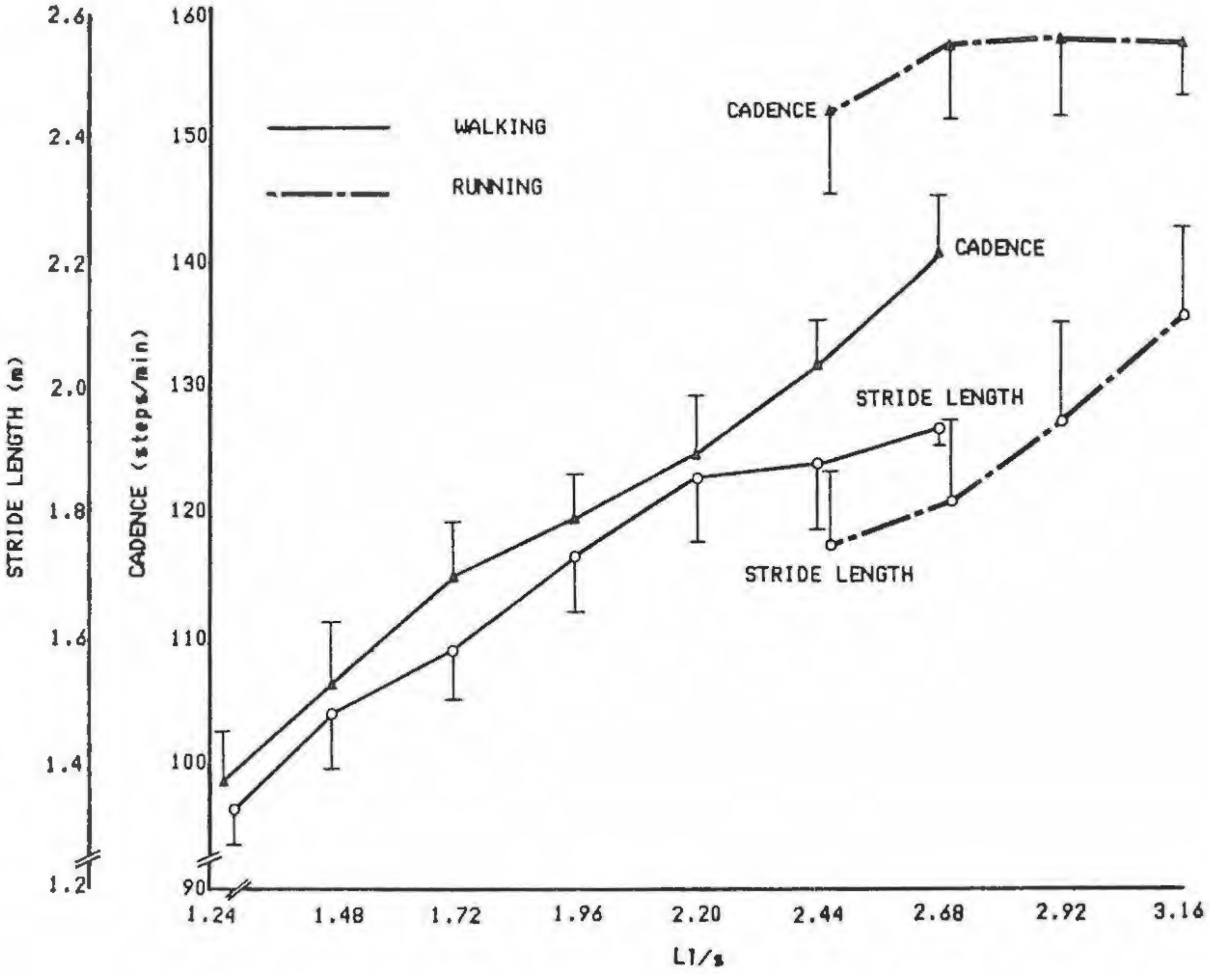


FIGURE 12: Mean cadence (steps/min) and stride length (m) for increasing relative speeds (Ll/s). Cadence and stride length values for walking and running, when performed at the same speeds, were significantly different ($p < 0.05$).

described by a log-log regression. The cadence-relative speed relationship, according to Grieve (1968) was best described by a power fit curvilinear regression and this relationship remained stable for an individual. The cadence and stride length-velocity relationships for the present study are summarised in Tables IX and X.

Increases in walking speed appear to have been achieved by increases in both stride length and cadence. However, at the faster speeds ($>$ 1.2 st/s, 0.47 $v/\sqrt{gh}$, 2.22 ll/s, 7.6 fl/s) an increase in speed appears to have been achieved by an increase in cadence which was disproportionate to the increase in stride length. For increases in running speed however, there were only small changes in cadence with relatively larger increases in stride length. These findings are supportive of those reported by McArdle et al. (1981) who showed that when running speed was increased, stride frequency increased by only 10%, whereas stride length increased by as much as 83%. Furthermore, these authors showed that by doubling the running speed from 2.77 m/s to 5.54 m/s, the stride length was increased by 85%, with only a 9% increase in stride frequency.

Changes in stride length and cadence have been reported to have profound effects on the energy cost of locomotion (Hogberg 1952). During walking, cadence and stride length changes both appear to cause an increase in the energy cost. At faster walking speeds, because of the limitations imposed on stride length by the morphology of the pelvis and length of leg primarily, the major means of accommodating the increase in velocity is to increase cadence. The combination of maximal, or almost maximal stride length, and increased cadence produce unnecessary muscular movements which in turn result in drastic increases in the energy cost.

Table IX: Cadence - velocity relationships for walking and running.

(Y) = cadence (steps/min); (X) = velocity (m/s).

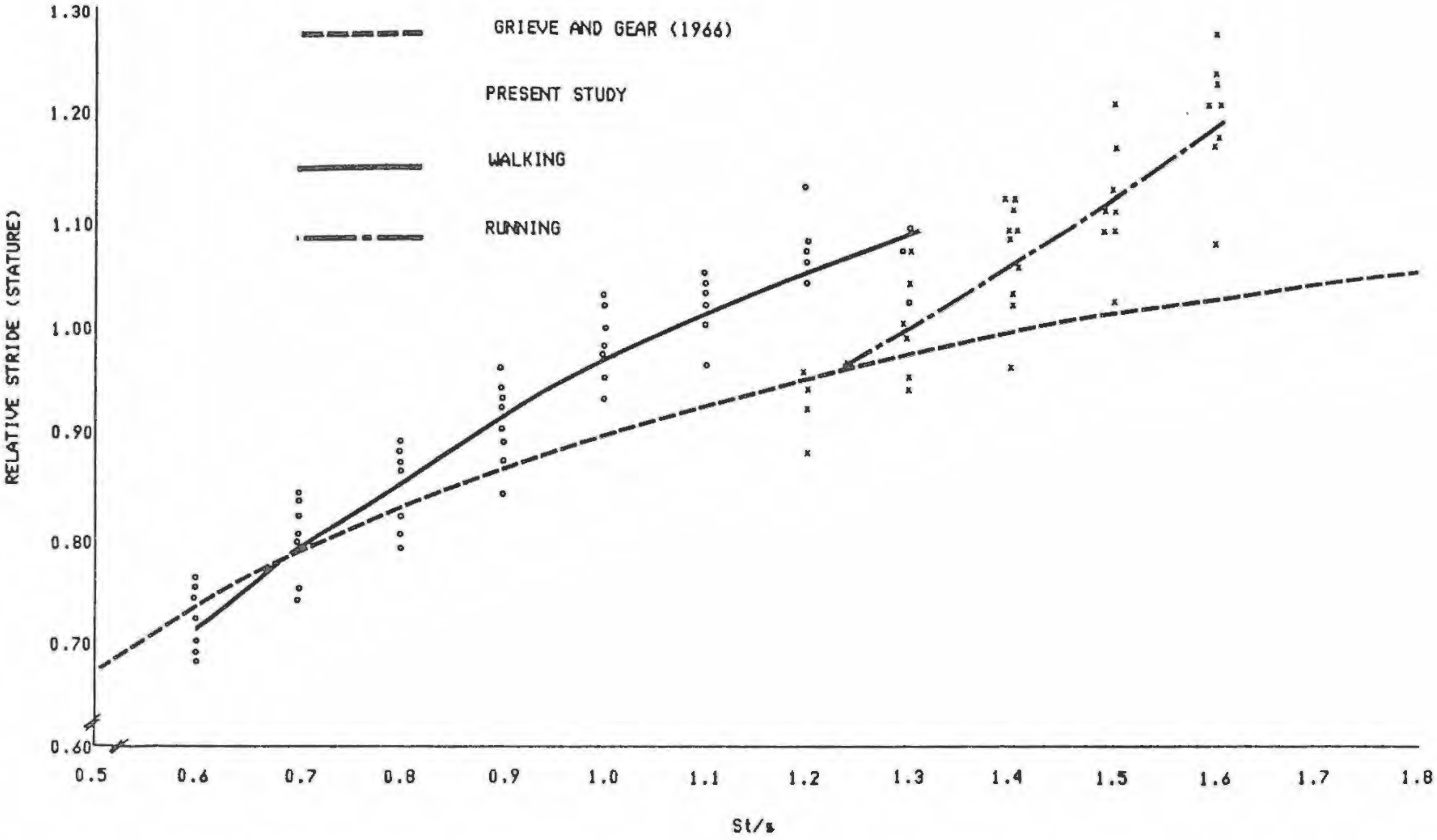
SPEED METHOD	BEST FIT	COEFFICIENTS		EQUATION FORM	r^2
		A	B		
WALKING CADENCE					
Absolute	Power	58.33	0.407	Y=A*X^B	97.20
st/s	Exp	73.63	0.518	Y=A*EXP(B*X)	98.72
$v/\sqrt{gh}$	Linear	65.90	134.7	Y=A+B*X	99.88
ll/s	Linear	64.71	28.04	Y=A+B*X	99.24
fl/s	Exp	72.68	0.078	Y=A*EXP(B*X)	99.38
RUNNING CADENCE					
Absolute	Linear	143.6	1.662	Y=A+B*X	70.11
st/s	Log	150.4	21.64	Y=A+B*LN(X)	94.63
$v/\sqrt{gh}$	Log	165.1	10.44	Y=A+B*LN(X)	97.97
ll/s	Log	136.4	19.53	Y=A+B*LN(X)	67.75
fl/s	Power	151.5	0.021	Y=A*X^B	51.80

Table X: Stride length - velocity relationships for walking and running. (Y) = stride length (m); (X) = velocity (m/s).

SPEED METHOD	BEST FIT	COEFFICIENTS A	B	EQUATION FORM	r^2
WALKING STRIDE LENGTH					
Absolute	Power	0.582	0.585	Y=A*X^B	99.36
st/s	Log	1.727	0.798	Y=A+B*LN(X)	96.28
$v/\sqrt{gh}$	Log	2.526	0.914	Y=A+B*LN(X)	99.88
ll/s	Log	1.158	0.823	Y=A+B*LN(X)	98.49
fl/s	Log	0.219	0.781	Y=A+B*LN(X)	97.71
RUNNING STRIDE LENGTH					
Absolute	Log	-1.794	1.683	Y=A+B*LN(X)	99.30
st/s	Exp	0.873	0.567	Y=A*EXP(B*X)	99.90
$v/\sqrt{gh}$	Power	3.081	0.946	Y=A*X^B	100.0
ll/s	Exp	0.898	0.269	Y=A*EXP(B*X)	97.63
fl/s	Linear	0.088	0.191	Y=A+B*X	99.52

During running however, the cadence and stride length-velocity relationships are essentially inverse (Goslin 1985); as cadence decreases stride length increases and oxygen consumption tends to increase. These trends are evident in this study and are supported by the findings from studies which have imposed variations in stride length on subjects (Hogberg 1952a, Cavanagh and Williams 1982). Deviations from the optimal (freely chosen) stride length tend to increase the energy cost of locomotion. Increased stride lengths (relative to optimal stride length) tend to raise oxygen uptake more than do decreases in stride length. Although the subjects freely chose their stride lengths, it is clear from Figures 8 to 12 that the change in stride length was greater than the change in cadence. Based on this logic it may be true to say that changes in stride length tended to drive the increase in oxygen consumption to a greater extent than did changes in cadence. Burke and Berger (1976) suggested that the increased energy cost associated with over-striding was due to greater hip rotation, an increase in the amount of shoulder movement and a greater vertical displacement of the centre of mass of the body. The increase in the energy cost mentioned above is obviously linked to a reduced economy. A reduced economy with a larger than optimal stride length has been attributed to the increase in vertical oscillation of the centre of gravity of the body (Hogberg 1952a).

Figure 13 indicates the relationship between relative stride (relative to stature) and relative speed (st/s) for the present study and from Grieve and Gear (1966). In relation to the relationship developed by the latter authors, the subjects in this study were using greater relative



<u>FIGURE 13:</u> Relative stride (stature) versus relative speed (St/s). A comparison between the results obtained by Grieve and Gear (1966), and the results obtained in the present study. For both walking and running subjects in the present study had greater relative strides for any given relative speed than those shown by Grieve and Gear.

strides at any given relative speed. Goslin (1985) suggests that the energetics of locomotion are related to absolute velocities, since the results of his work showed that the oxygen consumption was the same in males and females at equal absolute velocities, but the oxygen uptake of the males was greater than that of the females at the same relative velocities. The relationships between relative stride and relative speed (st/s) in the present study can be described by the following equations:

Walking:

$$\text{Rel stride} = 0.9657 + 0.4816 * \text{LOG (RS)} \qquad (r = 0.9918)$$

Running:

$$\text{Rel stride} = 0.4634 * \text{EXP} (0.5945 * \text{RS}) \qquad (r = 0.9984)$$

The efficiency of walking is greater than the efficiency of running (Figures 14 to 18). The use of relative speed does not appear to have any effect on the nature of the relationship between efficiency and movement velocity for walking. In all cases, with the exception of st/s which is described by an exponential equation, the efficiency-walking speed relationships are described by inverse linear equations. The nature of the relationship between efficiency and running speed is less clear-cut. These relationships are described by exponential, logarithmic and power fit curves. The efficiency of running tends to increase with increases in speed.

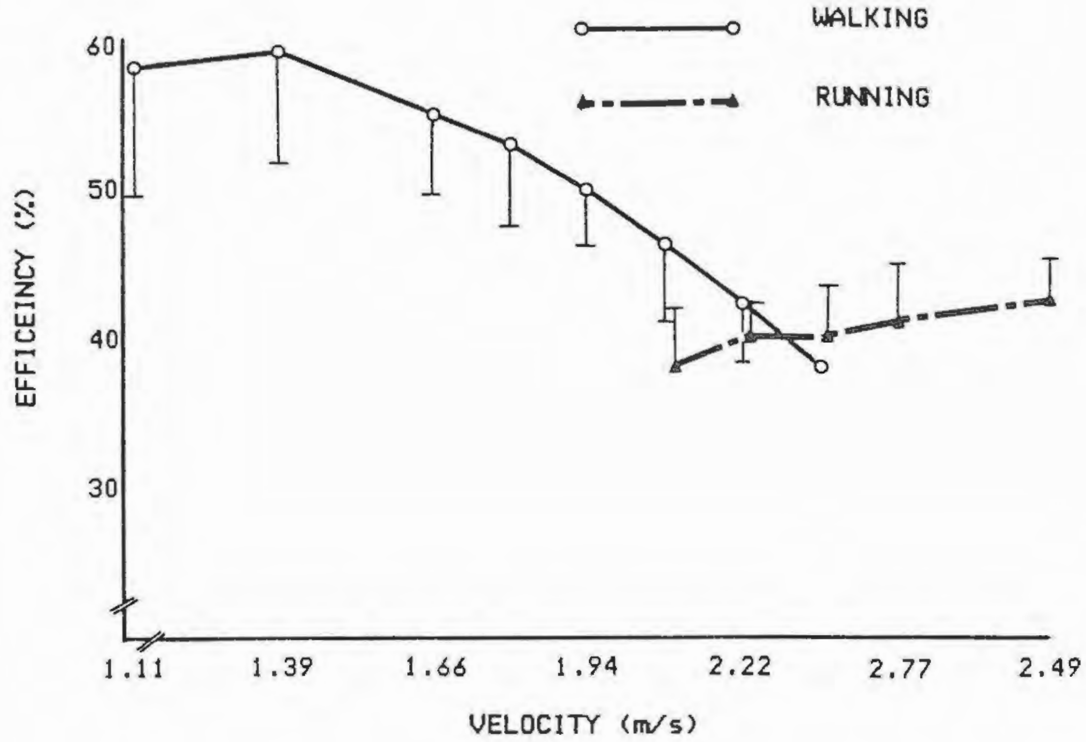


FIGURE 14: Mean efficiency values (%) for increasing walking and running speeds (m/s). Walking efficiency indicated the characteristic "inverted U" relationship with increasing speed while the running efficiency-speed relationship was more linear.

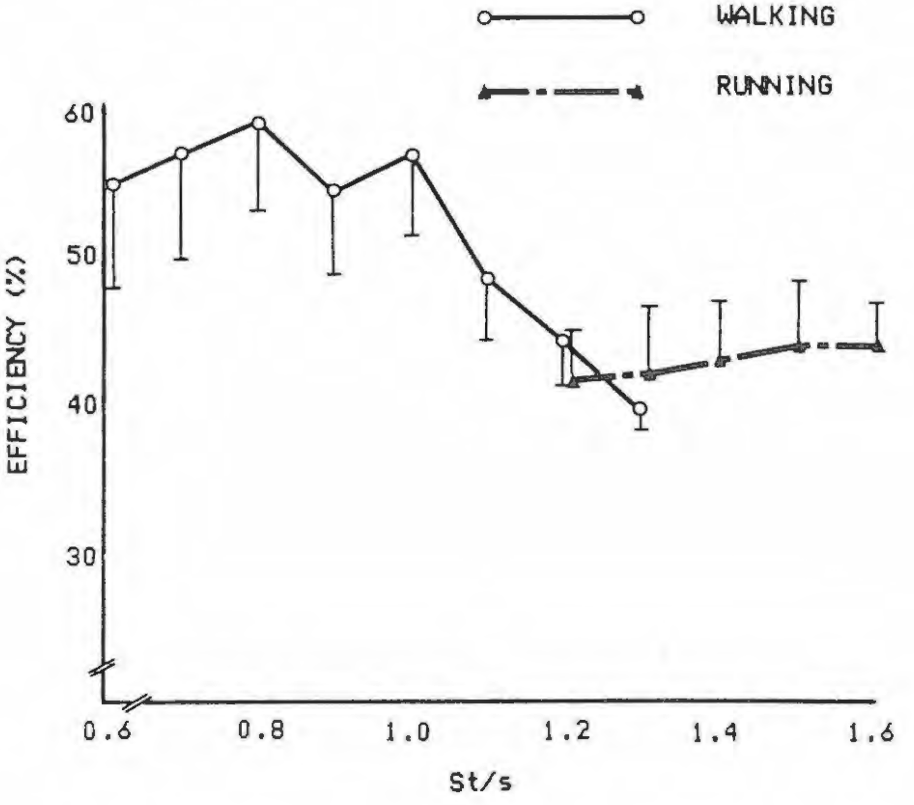


FIGURE 15: Mean efficiency values (%) for increasing relative speeds (St/s). The pattern of locomotion did not significantly effect efficiency ($p < 0.05$) when walking and running were performed at the same speeds.

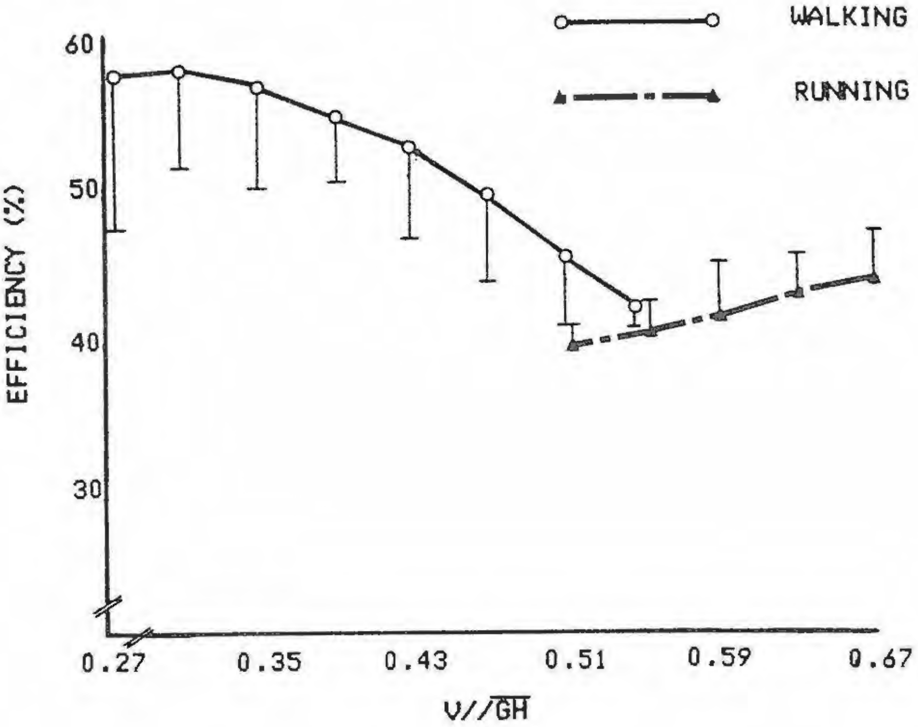


FIGURE 16: Mean efficiency values (%) for increasing relative speeds ($v/\sqrt{gh}$). The pattern of locomotion did not significantly effect efficiency ($p < 0.05$) when walking and running were performed at the same speeds.

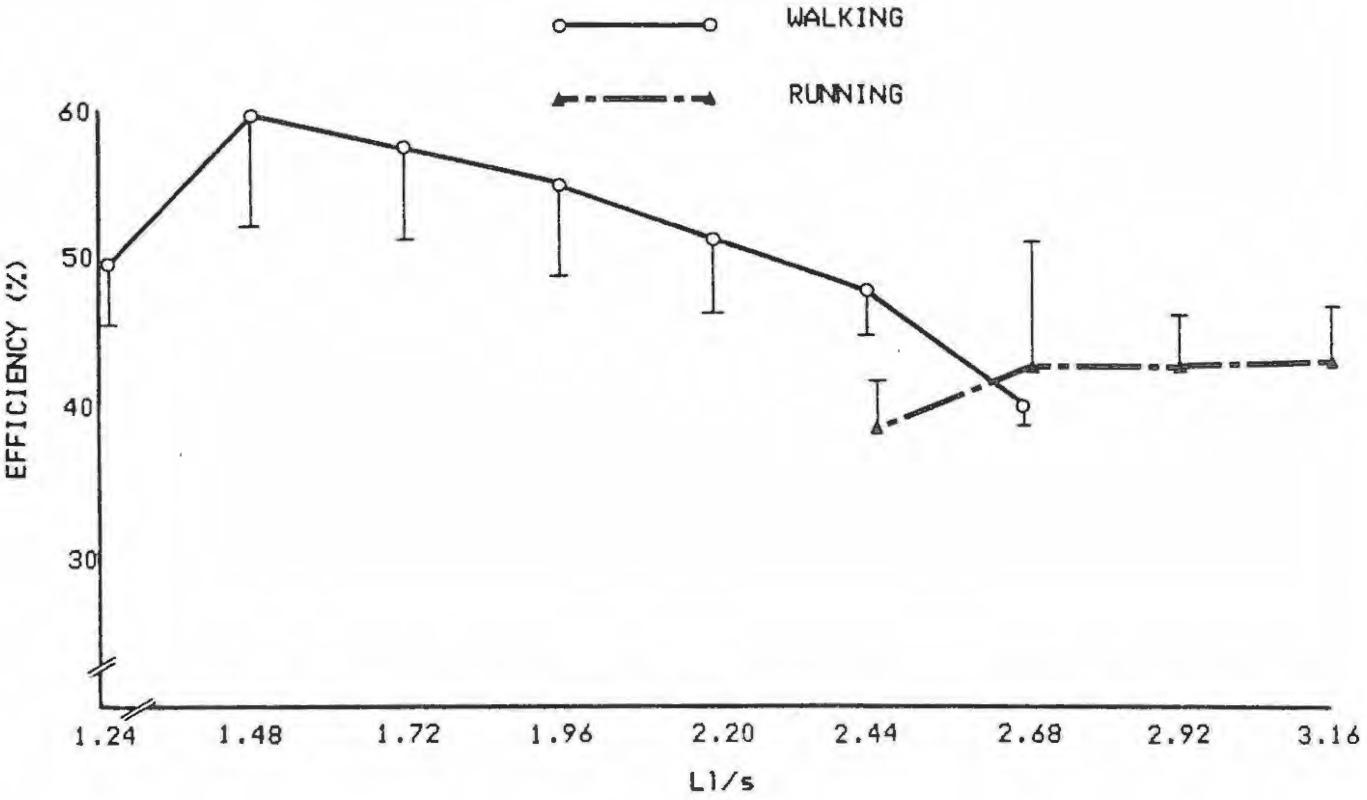


FIGURE 17: Mean efficiency values (%) for increasing relative speeds (Ll/s). The pattern of locomotion did not significantly effect efficiency ($p < 0.05$) when walking and running were performed at the same speeds.

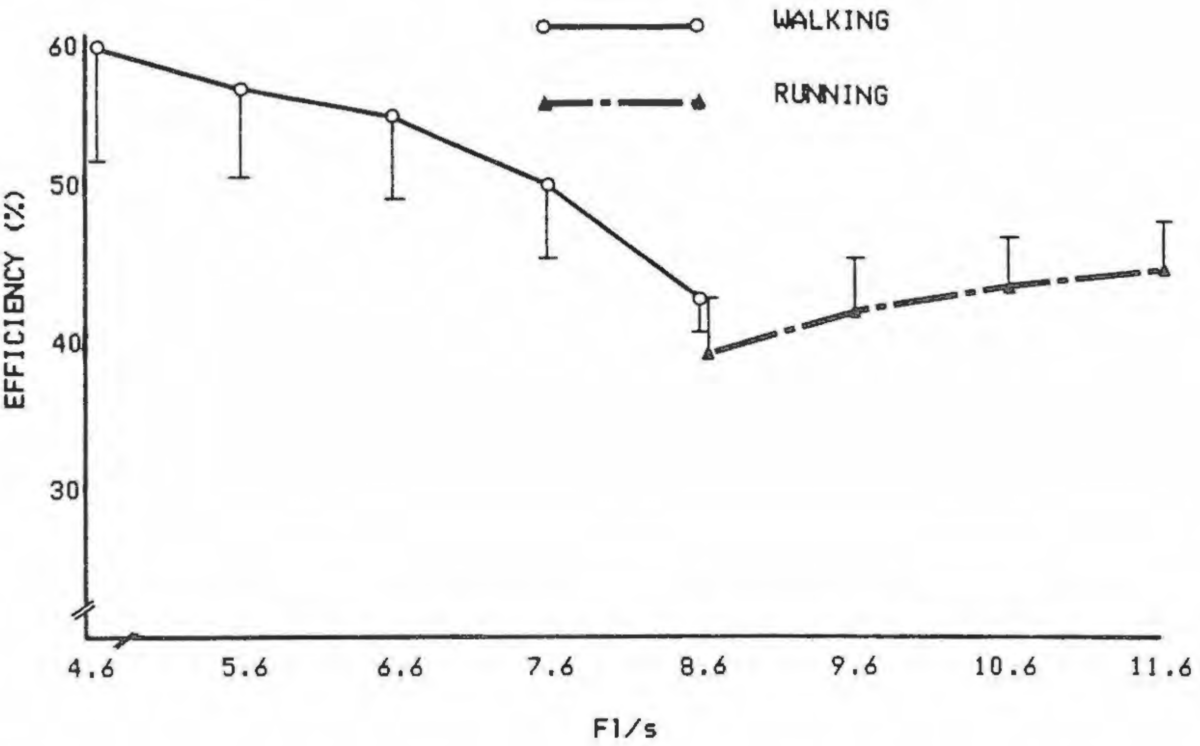


FIGURE 18: Mean efficiency values (%) for increasing relative speeds (Fl/s). At 8.6 Fl/s there was no significant difference ($p < 0.05$) between the efficiency of walking and the efficiency of running.

These trends are supported by the findings of other investigators (Cavagna and Kaneko 1977, Goslin 1985). There is however a great deal of conflicting evidence related to walking and running efficiencies. While most authors agree that the energy cost of walking displays an optimal point and the energy cost of running increases linearly with increases in velocity, there is substantial disagreement regarding the work done during locomotion. Most researchers agree, however, that there is considerably greater energy transfer between segments, and energy storage during negative work while running compared with the slower form of locomotion, walking (Cavagna et al. 1971, Thys et al. 1972, Fardy and Hellerstein 1978, Alexander 1980). This is particularly apparent in examining the efficiency of walking and running at the same velocity (Wyndham and Strydom 1971). This feature is demonstrated clearly in Figures 14 to 18 where, for walking and running at the same speeds, (2.35 m/s, 1.3 st/s, 2.68 ll/s) running is more efficient than walking. For speeds less than these, walking and running are either equally efficient, or walking is significantly more efficient ($p<0.05$) than running. In all cases in this study where subjects walked and ran at the same speeds, the efficiency of running was not significantly greater than the efficiency of walking ($p<0.05$).

Several factors interact to lower the efficiency of running. Most authors agree that the vertical power output during running remains constant or drops somewhat as velocity increases (Cavagna et al. 1963, Fukunaga et al. 1981), however, it still is twice that of walking. The major factors which affect efficiency with increases in velocity are; a less effective force-velocity relationship (Davies 1971), the involvement of less efficient fast-twitch muscle fibres increases (Donovan and Brooks 1977), and arm and leg rotational energy increases parabolically (Luhtanen and Komi 1978).

Ratings of perceived exertion (RPE) are related to the relative intensity of an activity (%$\dot{V}O_2$) (Robertson 1982). When local sensations of muscle or joint discomfort are significant, however, the RPE - %$\dot{V}O_2$ relationship can be significantly altered (Pandolf 1978, 1982). The RPE - velocity relationships for this study are depicted in Figures 19 to 23. It is clear that for all speed methods there is an almost linear increase in RPE with increases in speed. However, the increase in RPE for walking speeds appears to be greater than the increase in RPE for running speeds (ie. the slopes of the lines representing these data differ). These trends may be somewhat of an artifact of the experimental protocol in that several walking speeds (from slow to fast) were examined, whereas relatively fewer running speeds were examined. The fastest running speed was 2.77 m/s which, in terms of running speed, is relatively slow.

For walking and running at the same speeds, there are no significant differences ($p<0.05$) in the ratings of perceived exertion. This is not surprising if one considers that in other studies (Robertson 1982) RPE appear to be highly related to %$\dot{V}O_2$. For the speeds at which subjects both ran and walked there were no significant differences in submaximal $\dot{V}O_2$ (ml/kg/min). Therefore the relative intensities must also not have been significantly different ($p<0.05$). However, for the present study correlation coefficients for RPE and %$\dot{V}O_2$ varied between $r = 0.6307$ and

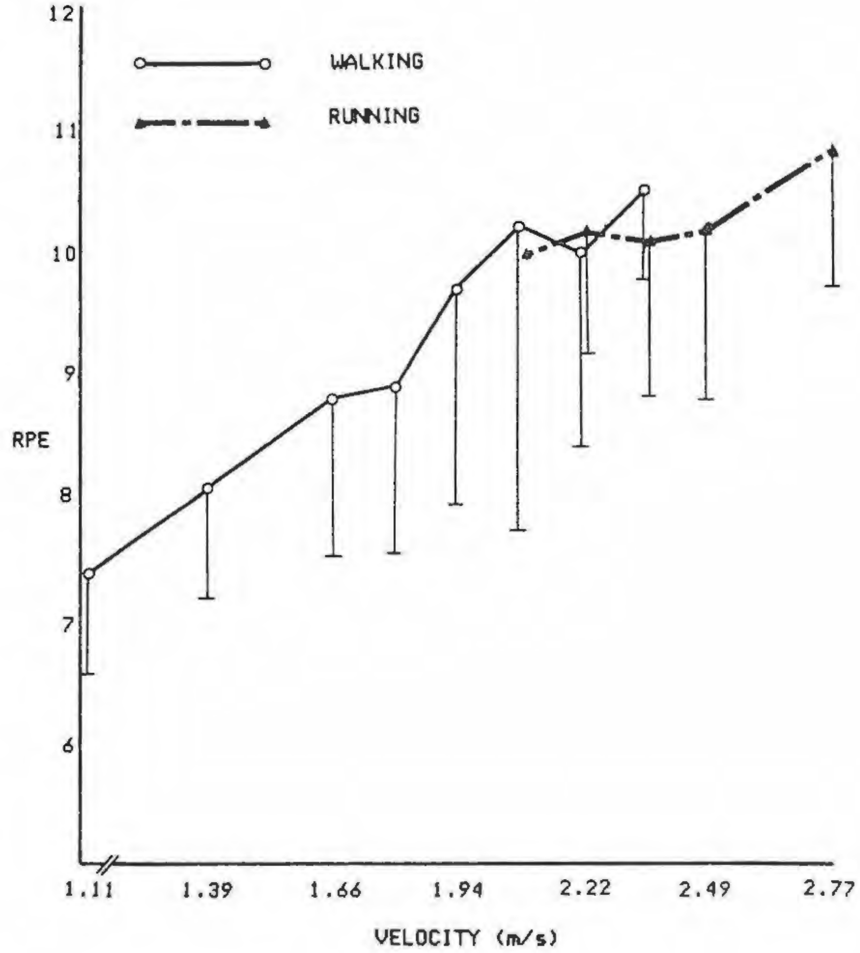
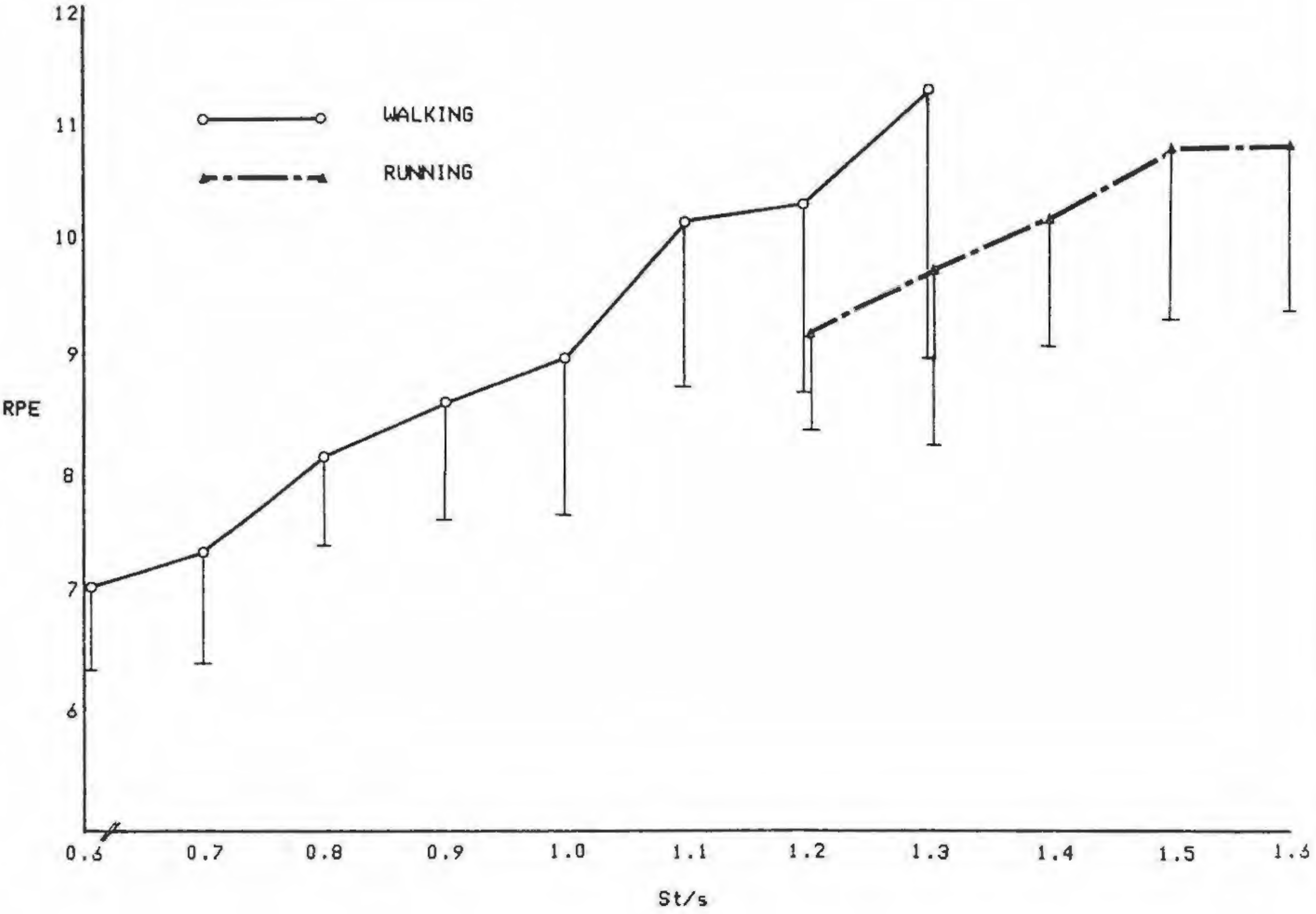


FIGURE 19: Mean Ratings of Perceived Exertion for increasing walking and running speeds. RPE was not significantly different ($p < 0.05$) when walking and running were performed at the same speeds.



<u>FIGURE 20:</u> Mean Ratings of Perceived Exertion for increasing relative speeds (St/s). At speeds where walking and running were performed, RPE was not significantly different ($p < 0.05$).

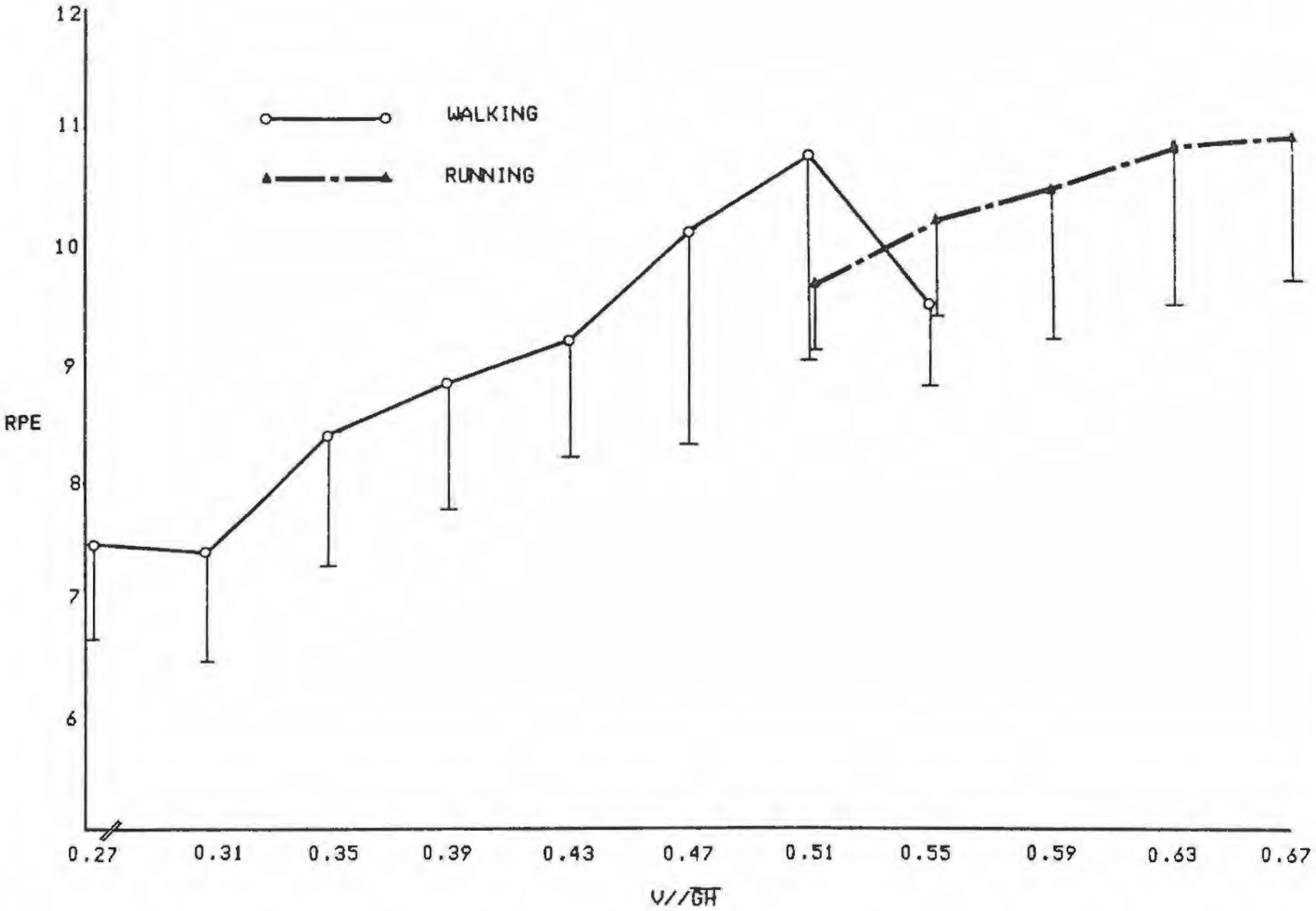


FIGURE 21: Mean Ratings of Perceived Exertion for increasing relative speeds ($v/\sqrt{gh}$). At speeds where walking and running were performed, RPE was not significantly different ($p < 0.05$).

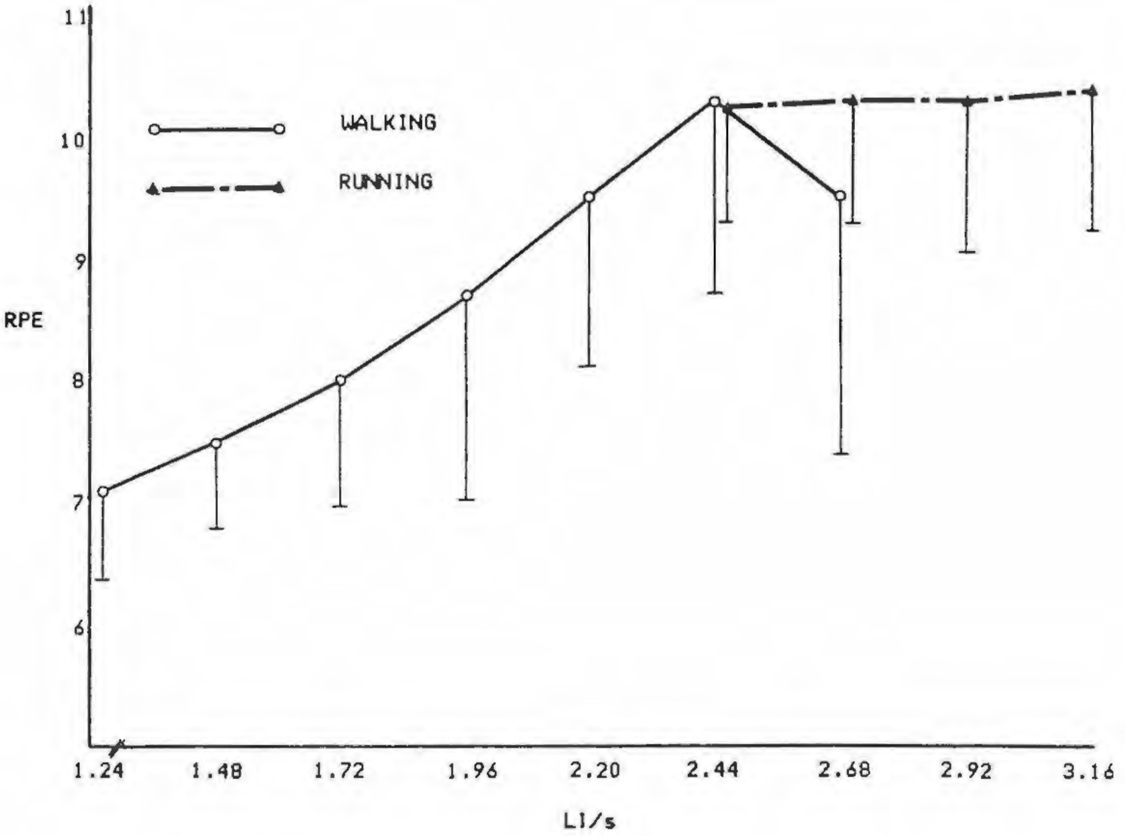


FIGURE 22: Mean Ratings of Perceived Exertion for increasing relative speeds (Ll/s). At speeds where walking and running were performed, RPE was not significantly different ($p < 0.05$).

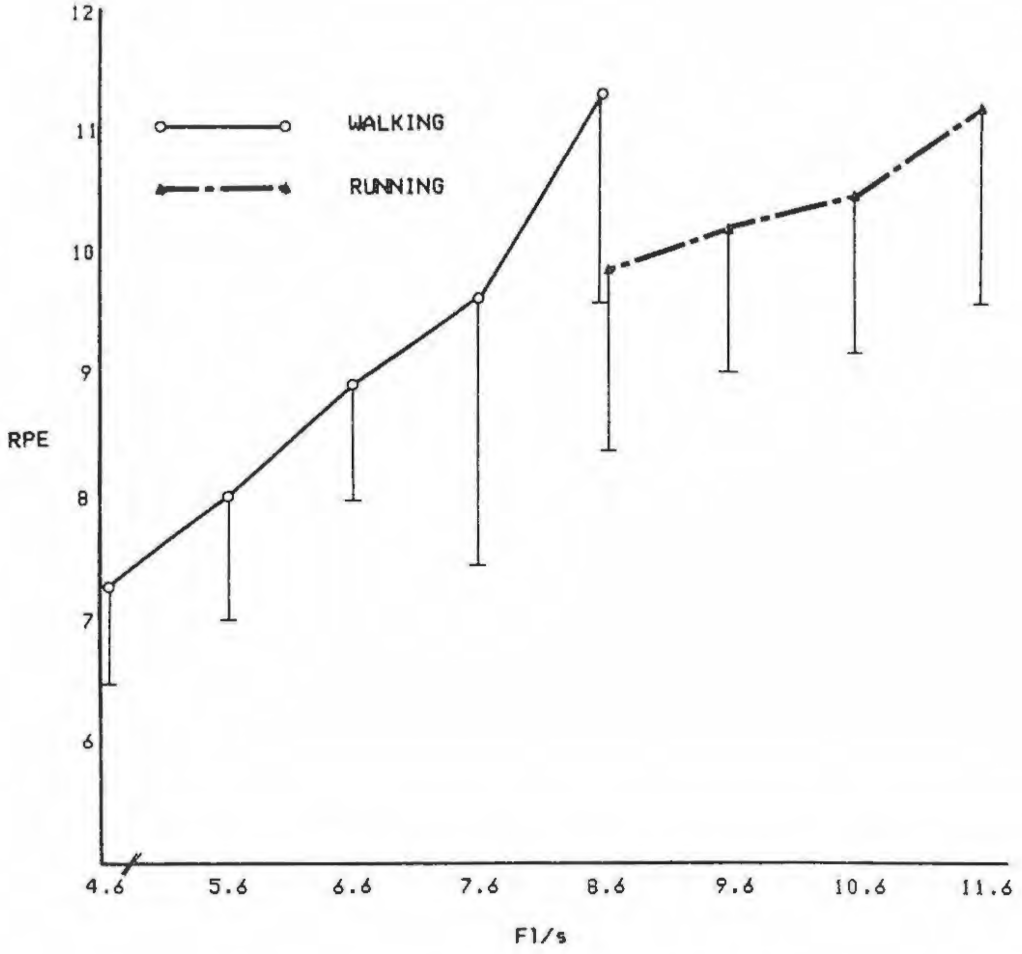


FIGURE 23: Mean Ratings of Perceived Exertion for increasing relative speeds (Fl/s). At speeds where walking and running were performed, RPE was not significantly different ($p < 0.05$).

$r = 0.6044$ for walking, and $r = 0.3966$ and $r = 0.4269$ for running, which, in both cases are only moderate correlations.

Studies which have focused upon the factors involved in the perception of effort during isometric muscular work have cited local factors such as mechanoreceptors and chemoreceptor activity (Cain and Stevens 1971) and tendon, skin and joint ligament receptors (Cain 1973) as affecting ratings of perceived exertion. These same factors have also been shown to exert significant input into perceptual response during aerobic work (Pandolf and Noble 1973, Stamford and Noble 1974, Ekblom et al. 1975). Support for the role of kinesthetic or proprioceptive feedback may also be inferred from the findings of a variety of comparative studies. In order to investigate the possibility that stride length and cadence variations, and the local factors associated with large stride lengths and high cadence at fast walking speeds were driving perceptions of effort, correlation coefficients for these gait parameters and RPE were calculated. The correlation coefficients for stride length and RPE at fast walking speeds varied from $r = -0.51$ to $r = -0.55$, and for cadence and RPE from $r = 0.54$ to $r = 0.60$. Although there appears to be a slightly stronger relationship between cadence and RPE than between stride length and RPE, the direction of these relationships is interesting.

It would appear that at any given fast walking speed (> 2.08 m/s) the stride length - cadence relationship is such that as the speed increases stride length decreases relatively and cadence increases to maintain the speed. At fast walking speeds stride length is limited primarily by the morphology of the pelvis and length of the legs. The stride length - RPE relationship is negative because of the relative reduction in the former while RPE values continue to increase, being mediated to a large extent by cadence. Although these trends may be of some significance in determining those factors driving the perceptions of effort during fast walking, the actual correlations are only moderate. These findings support the contention that it is not only physiological input that enables one to adequately describe perception of effort. Many non - physiological (psychological) factors such as sleep deprivation, anxiety, depression and fatigue all contribute in some way to influencing the perception of effort under different circumstances.

Goslin (1985) reported that it was felt that "local" sensations of discomfort accentuate the RPE response at fast walking speeds. He goes on to state that many subjects complained that the walk at 1.3 st/s was "too fast" and that they nursed tender anterior tibial musculature after this walk.

Several factors have been cited as being influencial in relation to RPE while running. These factors include lactate concentrations (Stamford and Noble 1974), $\dot{V}E$ (Sargeant and Davies 1973), $\dot{V}O_2$ (Edwards _et al._ 1972) and proprioceptive feedback (Ekblom _et al._ 1975). The correlation coefficients for the $\%\dot{V}O_2$ max and RPE while running were extremely low in the present study, as were these coefficients for stride length - RPE and cadence - RPE relationships (stride length: $r = 0.18$ to $r = 0.21$; cadence: $r = 0.22$ to $r = 0.25$). Blood lactate concentrations would probably not have been high enough during any of the running conditions to have had any significant effect on RPE. The mean $\%\dot{V}O_2$ max for all running speeds was 48.85%. Assuming that the ventilatory threshold is indicative of large increases in blood lactate, a mean ventilatory threshold of 74.47 $\%\dot{V}O_2$ max for the 11 subjects indicates that the intensity of the running conditions was substantially below the point at which lactate begins to accumulate and have significant effects on performance and perceptions of effort. Because of the apparent lack of clear evidence for a prominent physiological cue influencing RPE, it may be true to say that a number of factors together contributed to affect RPE during the running conditions, least of which may have been several psychological factors, such as motivation, mood state, fatigue and time of day.

THE LOCOMOTOR INTERFACES

It is generally and correctly understood that, as a means of locomotion, walking is suitable for slower speeds up to a certain limit which differs from individual to individual, whereas running is more suitable for high speeds (Ogasawara 1934). The exact speed at which this limit occurs has not been specifically identified but appears to be in the range of speeds 2.0 m/s to 2.33 m/s (Noble et al. 1973, Kagaya 1976).

The nature of the oxygen uptake - velocity relationships for walking and running create the impression that a) there is a single locomotor interface and, b) this interface occurs at the point at which the oxygen uptake - velocity curve for walking intersects the oxygen uptake - velocity curve for running. The data in Table XI indicate from the oxygen consumption - velocity relationships developed in this study

(Figures 3 to 7), the speeds at which the two curves intersect and the measured walk-to-run and run-to-walk interface speeds.

Table XI : The speeds in m/s and relative speed (st/s, $v/\sqrt{gh}$, ll/s, fl/s) at which the oxygen uptake - velocity curves for walking and running intersect. A comparison is drawn between these speeds and the speeds at which the walk-to-run and run-to-walk interfaces actually occurred.

SPEED METHOD	METABOLIC INTERSECTION SPEEDS		MEASURED INTERFACE SPEEDS			
	M/S	RS	WALK-TO-RUN		RUN-TO-WALK	
			M/S	RS	M/S	RS
Absolute	2.24	--	2.22	--	2.05	--
st/s	2.28	1.27	2.21	1.23	2.03	1.13
$v/\sqrt{gh}$	2.31	0.55	2.23	0.53	2.06	0.49
ll/s	2.33	2.68	2.24	2.57	2.07	2.38
fl/s	2.23	* 8.60	2.20	8.47	2.03	7.82
$\bar{X}$	2.28		2.22		2.05	

(* At this speed the energy cost curves did not intersect. This was the fastest speed at which subjects walked and ran).

It is clear from Table XI above that the average speed (2.28 m/s) at which the energy cost curves for walking and running intersect more closely reflects the measured walk-to-run interface speed (2.22 m/s) than the run-to-walk interface speed (2.05 m/s). Therefore, in general the use of the oxygen uptake - velocity curves for walking and running as a means of locating the locomotor interface speeds appears to be more useful for the walk-to-run interface speed than for the run-to-walk interface speed. The point of intersection between the energy cost curves for walking and running also creates the impression of a single locomotor interface as mentioned previously. This however is not the case as can be seen from Table XI. The measured run-to-walk interface speed is significantly slower ($p<0.05$) than the the measured walk-to-run interface speed, and the speed at which the energy cost curves intersect. It is clear therefore that there are two distinctly separate locomotor interface speeds and the run-to-walk interface speed is slower than both the measured walk-to-run interface speed, and the speed at which the energy cost curves intersect.

The results of a correlation and regression analysis of the data in Table XI reveals that, despite the small sample sizes, the "metabolic intersection speed" is more highly correlated with the measured walk-to-run interface speed than with the measured run-to-walk interface speed ($r = 0.841$ and $r = 0.7369$ respectively). The following equation best describes the relationship between the measured walk-to-run interface speed and the "metabolic intersection speed".

Walk/run interface speed = 1.5195 + 0.3075 * met. intersection speed.

(where speed is in m/s).

The coefficient of determination for this equation is moderately high ($r^2 = 0.7072$) and substantially higher than the coefficient of determination for the equation which best describes the relationship between the run-to-walk interface speed and the "metabolic intersection speed" ($r^2 = 0.543$).

Figure 24 indicates, as mentioned above, that the two locomotor interface speeds are significantly different ($p<0.05$). The walk-to-run interface speed occurs at a significantly faster speed than the run-to-walk interface speed. The kinematics of gait, as measured in this study, differ significantly ($p<0.05$) at the two identified locomotor interfaces. Data at the walk-to-run interface were collected while subjects were running, while data at the run-to-walk interface were collected on the same subjects while walking (Figures 25 and 26). At the former interface subjects accommodated increases in speed by using a relatively high cadence and a relatively small stride length. The opposite was observed at the run-to-walk interface where subjects used a relatively low cadence and a large stride length. Both cadence and stride length at the walk-to-run interface differed significantly ($p<0.05$) from cadence and stride length at the run-to-walk interface. These patterns are to be expected since running at 2.22 m/s is considered to be a slow pace. The natural kinematic adjustments while running at this speed would involve a relatively high cadence with a short stride length. Walking at 2.05 m/s (1.14 st/s), using the classification proposed by Charteris (1982) is considered to be a "medium fast" pace. Kinematic adjustments to walking at this speed would naturally involve a relatively large stride length and a low cadence.

In order to attempt to identify the significance of these locomotor interfaces in relation to the energy cost of locomotion further investigation involved establishing the consistency with which subjects

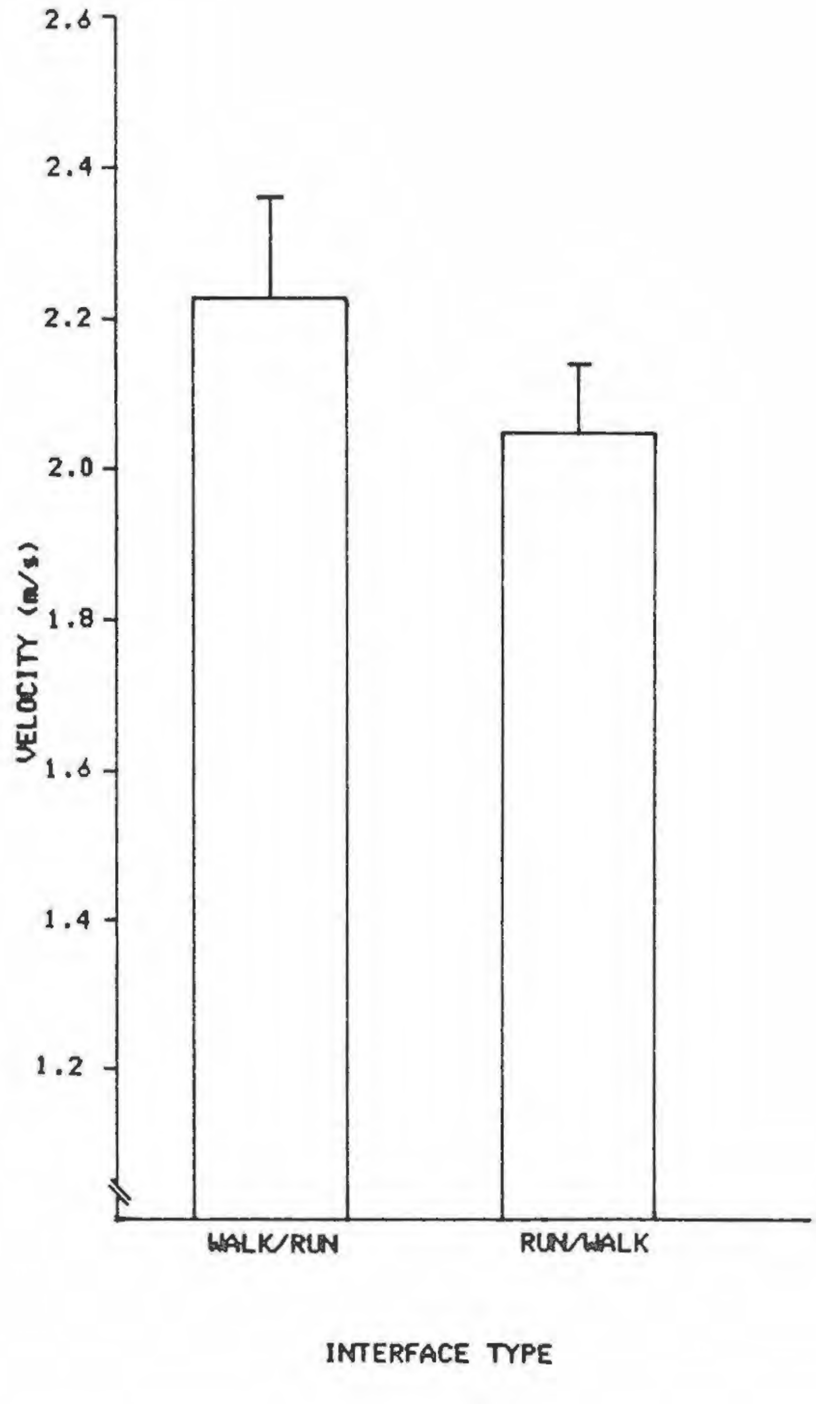


FIGURE 24: Mean walk-to-run and run-to-walk interface speeds (m/s). The former occurred at a significantly faster speed ($p < 0.05$) (2.22 m/s) than the latter interface, (2.05 m/s).

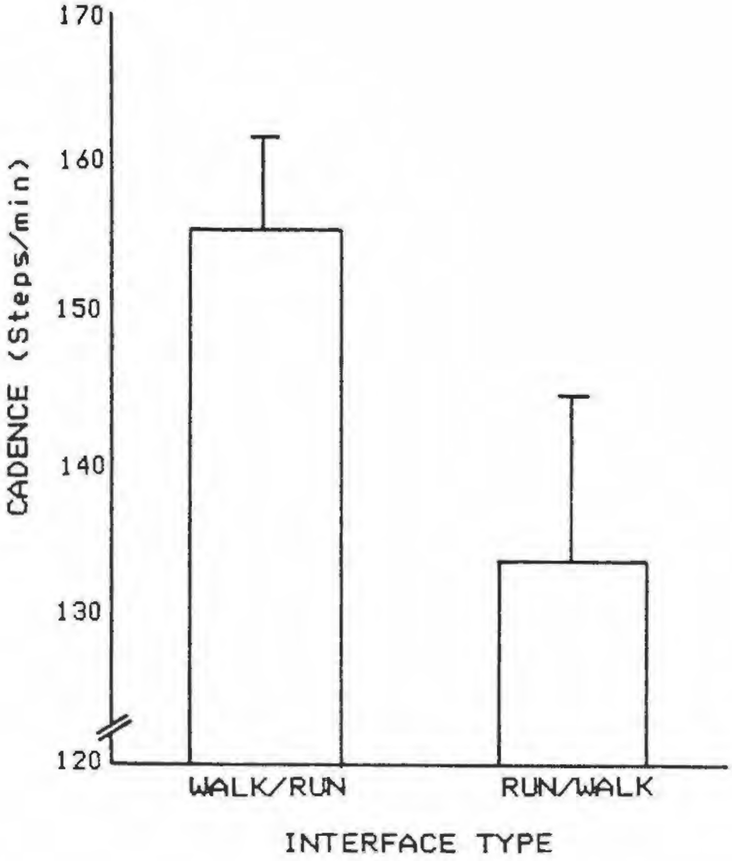


FIGURE 25: Cadence (steps/min) at the walk-to-run and run-to-walk interface speeds. Cadence at the former interface was significantly higher ($p < 0.05$) than that at the latter interface, however, these were running and walking cadence values respectively.

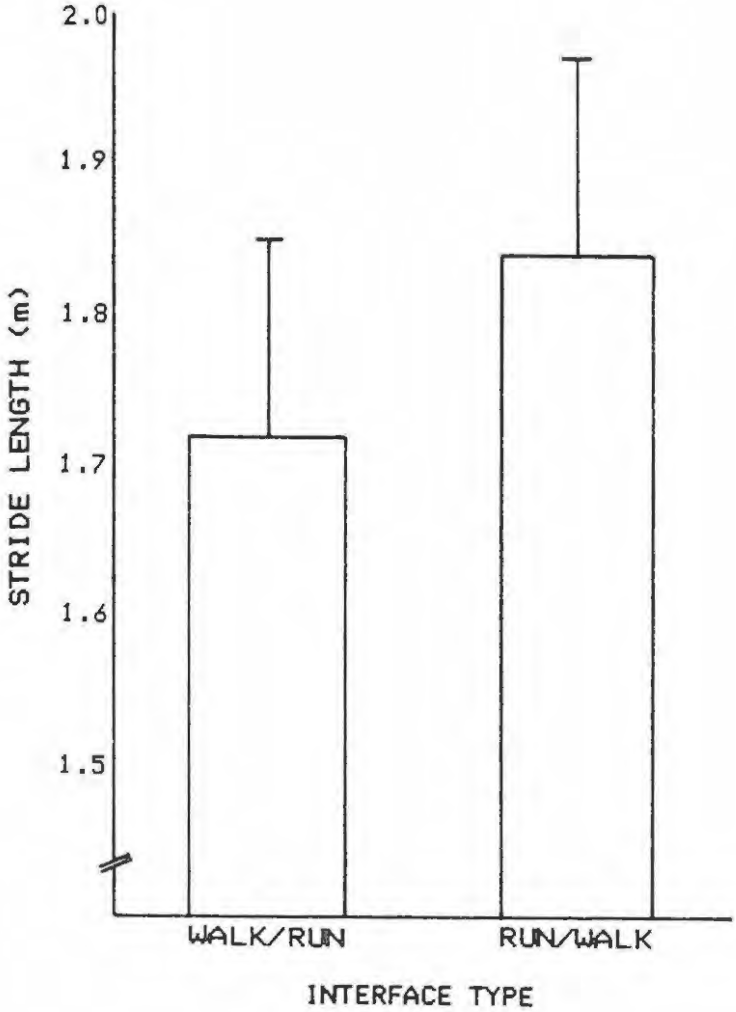


FIGURE 26: Stride length (m) at the walk-to-run and run-to-walk interface speeds. Stride lengths at the walk-to-run interface were significantly shorter than stride lengths at the run-to-walk interface. The former were measured during running and the latter during walking.

were able to locate the walk-to-run and run-to-walk interface speeds. Figure 27 indicates the mean coefficient of variation for speed with all speed methods combined. It is clear from this that the former interface was located with significantly more precision than the latter interface ($p<0.05$). Candler (1986) suggested that feedback from proprioceptive sources such as stretch receptors in the muscles and joints of the legs and hips, as well as the limitations imposed by the morphology of the pelvis and the legs on fast walking possibly contributed to the more consistent location of the walk-to-run interface speed. "These feedback mechanisms provided definite cues for a change from walking to running, which may have been associated with discomfort or even mild pain caused by stretching of the leg muscles and the increased discomfort associated with pelvic oscillations at high walking speeds". Furthermore, it is suggested that the change in the pattern of locomotion at the run-to-walk interface speed was not facilitated to the same extent by the same feedback mechanisms. In this case the subjects were moving at very slow running speeds before changing to a walk. There was no "painful discomfort" in running at these speeds and the change was probably mediated more by input from sensory cues such as the sound of the treadmill motor rather than by distinct proprioceptive feedback. Maintenance of balance becomes increasingly more difficult at slow running speeds because of the relatively long periods of time spent on one leg during the support phase of the running cycle. Control of balance may therefore have been another factor which mediated the change from running to walking at the run-to-walk interface.

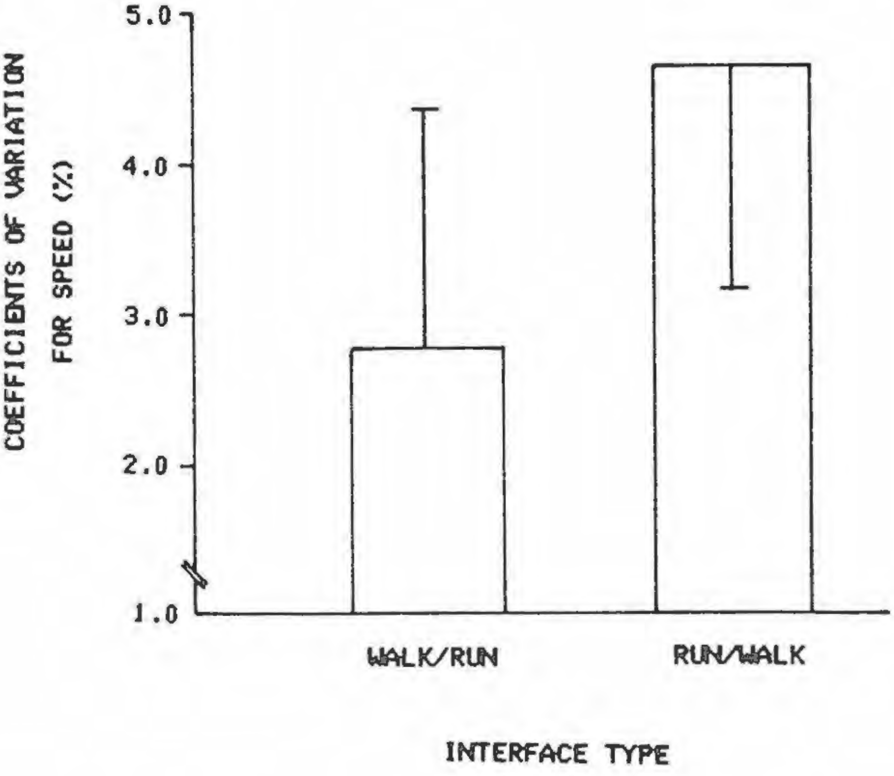


FIGURE 27: Mean coefficients of variation for speed (%) at the walk-to-run and run-to-walk interface speeds. Subjects located the walk-to-run interface with significantly greater precision ($p < 0.05$) than the run-to-walk interface.

From the relationships between the metabolic intersection speed and the two locomotor interface speeds previously discussed it is clear that the run-to-walk interface has little significance in terms of the energetics of locomotion. This interface, because of the lack of distinct feedback cues to facilitate a consistent change in the locomotor pattern at this speed, may simply be an "overshoot" of the walk-to-run interface. For these reasons further investigation of the run-to-walk interface was not carried out in this study. This does not, however, preclude its importance in further research related to the locomotor interfaces.

Additional investigation of the walk-to-run interface involved assessing movement responses to walking and running at a constant velocity (2.22 m/s). Table XII indicates selected physiological, kinematic and psychological parameters measured during walking and running at the walk-to-run interface speed and during running at the run-to-walk interface speed.

The energy cost ($mlO_2/kg/min$) of locomotion at the walk-to-run interface was not significantly different ($p<0.05$) for walking and running (Figure 28). On the basis of the previously presented information on the "metabolic intersection speed" and the walk-to-run interface speed (Table XII), this result could possibly have been expected, since the speed at which the latter occurred was not very different from the speed at which the energy cost curves for walking and running intersected (2.22 m/s compared with 2.28 m/s). Ogasawara (1934) suggests that when the speed of movement is essentially the same the differences in the energy cost for walking as compared to running range from approximately 4% at 2.01 m/s to 15% at 2.52 m/s and 20% at 2.88 m/s. These speeds fall

Table XII: Selected physiological, kinematic and psychological parameters at the walk-to-run and run-to-walk interfaces. At the walk-to-run interface data were collected on subjects walking and running.

MEASURED PARAMETER	INTERFACE TYPE		
	WALK-TO-RUN		RUN-TO-WALK
SPEED (m/s)	2.22		2.05
LOCOMOTOR PATTERN	WALK	RUN	RUN
$\dot{V}O_2$ (ml/kg/min)	26.7 (4.15)	28.1 (1.94)	
% $\dot{V}O_2$ max	44.9 (8.10)	46.9 (5.26)	
V.T. (% $\dot{V}O_2$ max)	61.2 (11.1)	61.8 (7.45)	
EFFICIENCY (%)	40.7 (5.79)	39.9 (3.82)	
CADENCE (steps/min)	138.1 (6.96)	155.5 (6.39)	133.6 (10.9)
STRIDE LENGTH (m)	1.93 (0.13)	1.72 (0.13)	1.84 (0.13)
RPE	11.2 (1.54)	9.5 (1.37)	
% RPE max	63.9 (9.82)	54.2 (10.3)	

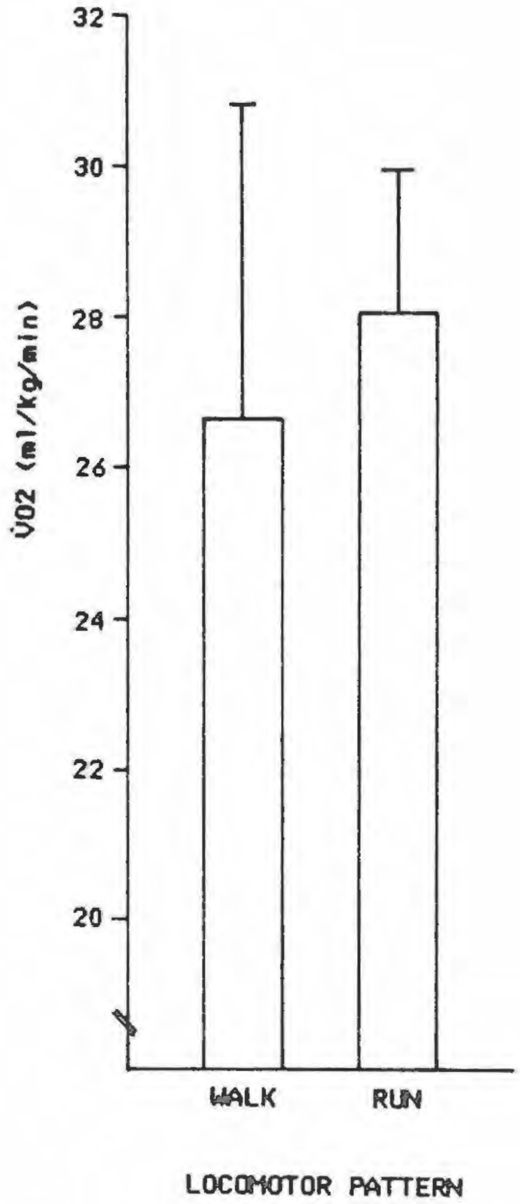


FIGURE 28: The energy cost (mlO_2/kg/min) of walking and running at the walk-to-run interface speed (2.22 m/s). The $\dot{V}O_2$ (ml/kg/min) was not significantly different ($p < 0.05$) despite the different locomotor patterns.

substantially below (2.01 m/s) and above (2.52 and 2.88 m/s) the walk-to-run interface speed identified in this study.

It is clear then, that the greater the difference in the speed of movement both above and below the walk-to-run interface speed, the greater the difference in the energy cost of walking and running at the same speeds. The common factor which appears to determine the differences in oxygen uptake between walking and running at the same speed when the speed is above or below the walk-to-run interface is the amount of the total musculature being utilized (Ogasawara 1934). The increased number of muscular movements are themselves a function of:

1) the shorter length of stride which necessitates a greater number of strides per unit of distance

2) the excessive compensatory arm movements across the chest during walking at high speeds

3) the exaggerated transverse plane rotation of the hips and corresponding counteraction of the shoulders, and

4) the sustained contraction of the muscles of the legs due to the straight - leg action; walking degenerates into running by virtue of a bent knee action at high speeds (Ogasawara 1934).

Cadence and stride length for walking and running at the walk-to-run interface differed significantly ($p<0.05$). Walking was characterised by a relatively slower cadence and larger stride length than running during which the opposite kinematic trends were observed (Figures 29 and 30).

Despite significant differences in these gait parameters there was no significant difference in the oxygen uptake values for walking and running at the walk-to-run interface speed ($p<0.05$). The gait pattern therefore had no effect on the energy cost of locomotion at this speed. Van der Walt and Wyndham (1973), in their attempt to produce prediction equations for the energy expenditure of walking and running, noted that pace length and leg length account for only 2% of the variance in $\dot{V}O_2$ during running and are therefore not considered important factors in relation to the prediction of energy costs. However, for a given locomotor pattern at any set velocity, variations in stride length relative to optimal stride length have a profound effect on the energy cost of locomotion. Lengthening the stride relative to the optimal stride length is reported to increase $\dot{V}O_2$ more than decreasing stride length relative to the optimal length.

Table XII shows that for walking and running at the walk-to-run interface speed, the efficiency of these locomotor patterns is not significantly different ($p<0.05$) (Figure 31). This finding does not support the finding of Lloyd and Zacks (1972) who suggest that running efficiency is higher than walking efficiency, particularly when walking and running are performed at the same velocity (Wyndham and Strydom 1971). Cavagna *et al.* (1964) cite the main reason for this difference in efficiency between these two forms of locomotion as being the beneficial effect of elastic recoil of running. Elastic recoil is lower at walking speeds because the energy is absorbed due to increased contraction time. Increases in the stretch of the muscle and speed of movement tend to increase elastic recoil (Fardy and Hellerstein 1978). Heglund *et al.*

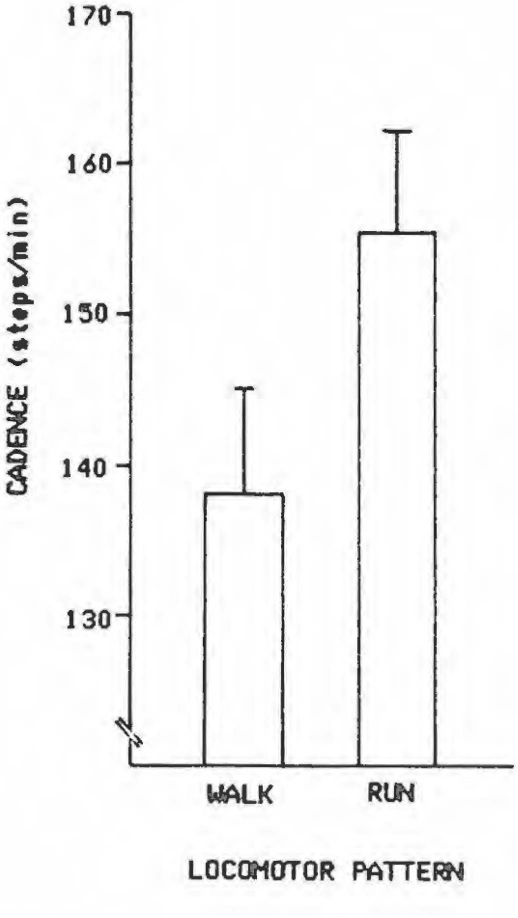


FIGURE 29: Cadence (steps/min) for walking and running at the walk-to-run interface speed (2.22 m/s). Walking cadence was significantly slower than running cadence ($p < 0.05$) at this speed.

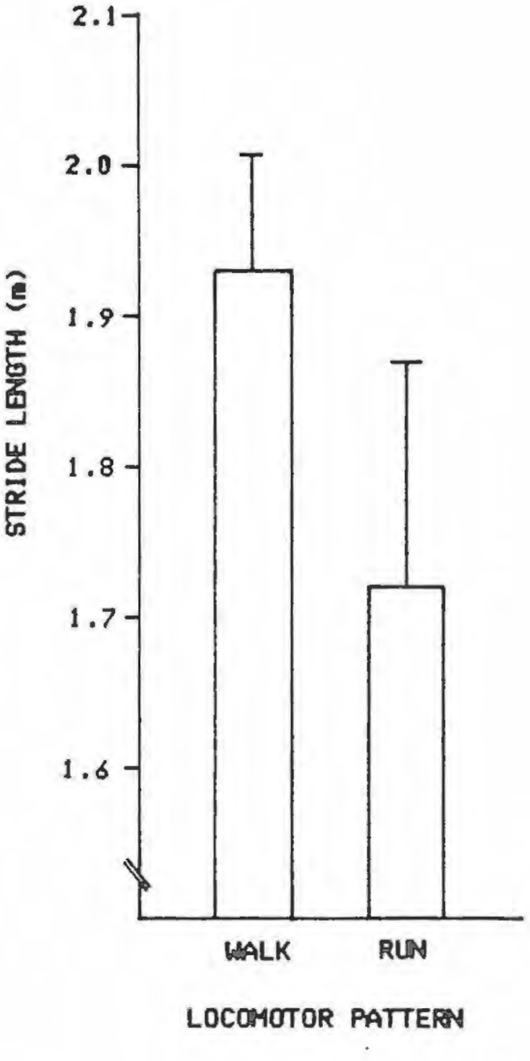


FIGURE 30: Stride length (m) for walking and running at the walk-to-run interface speed. Walking stride lengths were significantly longer ($p < 0.05$) than running stride lengths at this speed.

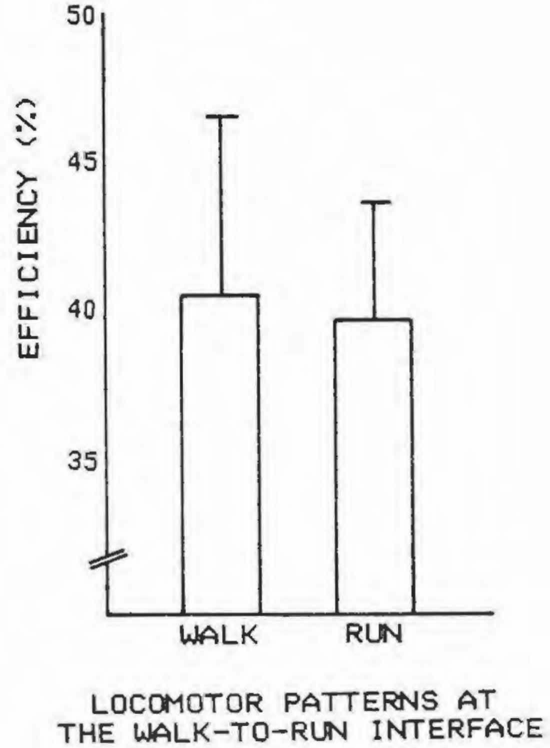


FIGURE 31: Efficiency (%) for walking and running at the walk-to-run interface speed. Despite the different locomotor patterns the efficiency of locomotion was not significantly different ($p < 0.05$) at this speed.

(1982) and Donovan and Brooks (1977) suggest that in normal walking it becomes more efficient once the speed exceeds 2.22 m/s.

Figure 14 depicts the efficiency of walking and running between 1.11 m/s and 2.77 m/s. As with the oxygen consumption curves, the efficiency curves for walking and running intersect at about 2.22 m/s. This therefore is the reason that despite the different locomotor patterns being used, there is no difference in efficiency. Since there is no difference in the oxygen consumption (ml/kg/min) for walking and running at the walk-to-run interface speed, the work done must also have been the same for walking and running since the efficiency values are not different.

The relative intensity of the work done at the walk-to-run interface was not significantly different for walking and running ($p<0.05$) (Table XII). However, the relative intensity for both locomotor patterns at 2.22 m/s in this study was substantially less than that reported by Kagaya (1976). He reported that at the "metabolic intersection speed" his subjects were working at 64.9% $\dot{V}O_2$ max, 19.95% harder than the subjects in the present study while walking at the walk-to-run interface speed and 17.95% harder than when running at this speed. Since Kagaya suggests that the "metabolic intersection speed" occurs at 2.14 m/s the subjects tested must have had somewhat lower maximal oxygen uptake values than the subjects used in this study. However, the relative intensities (% $\dot{V}O_2$max) cited in the study by Kagaya (1976) correspond with mean relative RPE values of 63.91% (± 9.82% RPE max) for walking and 54.18% (±10.31% RPE max) for running in the present study. Despite the large differences between these values, they are not significantly different because of the large standard deviations.

General ratings of perceived exertion were recorded for walking and running at the walk-to-run interface speed. The mean RPE value for walking was significantly higher ($p<0.05$) than the mean RPE value for running (Table XII) (Figure 32). Mihevic (1981) suggests that central and local RPE are related to the absolute and relative intensity of exercise respectively. In this study there was no significant difference in the relative intensity for walking and running and yet RPE values were significantly different. These data tend to indicate that other factors such as those associated with the physiological, kinematic and psychological parameters measured in this study as well as unmeasured factors, may have had a stronger influence on RPE than absolute or relative workloads. Lollgen et al. (1980) found that when cycling at zero load, 70% $\dot{V}O_2$ max, or maximal intensities, RPE was not always related to any of the central or local cues frequently mentioned. However, RPE was linked to central factors at high speeds of limb movement even during unloaded pedalling. A relationship between central RPE and speed of limb movement, independent of workload, has also been shown elsewhere (Croisant 1982).

The significantly higher RPE for walking was probably not related to speed of limb movement since cadence was higher while running at the same speed and the RPE was lower than the walking value. It was felt rather, that local factors associated with the relatively large stride length contributed more to the RPE values during walking. Factors such as proprioceptive feedback from muscle spindles, golgi tendon organs and

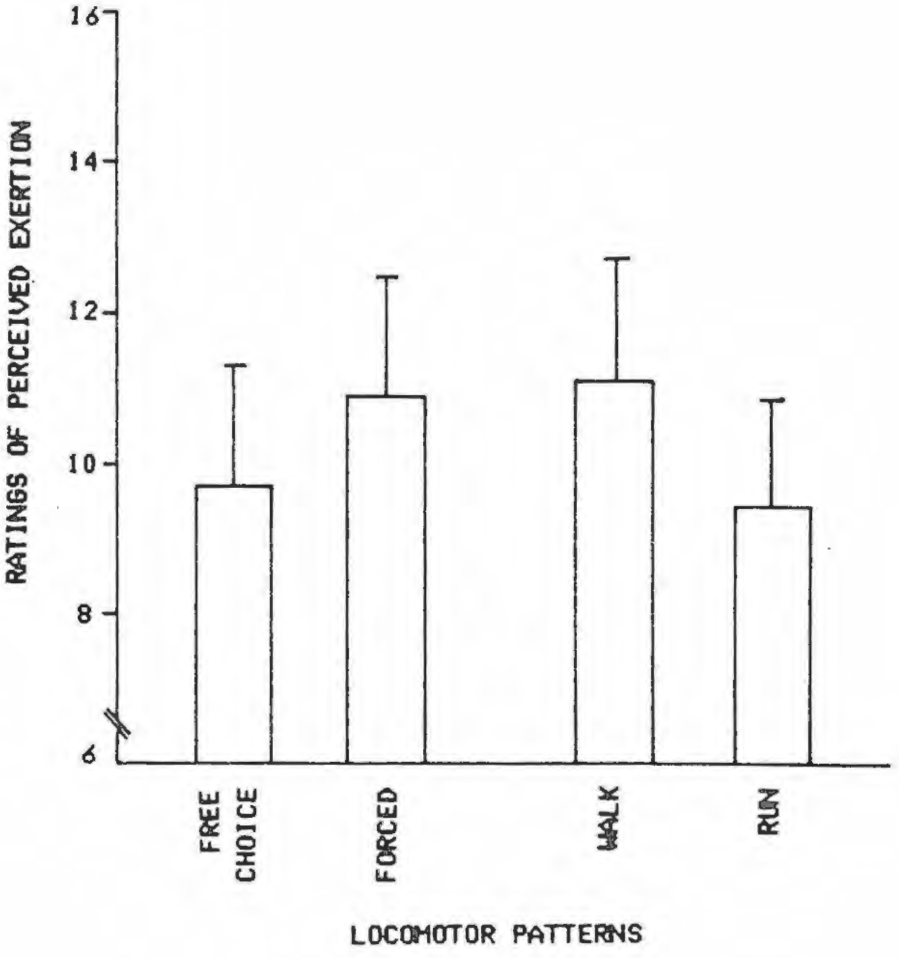


FIGURE 32: Ratings of Perceived Exertion for "free choice" and "forced" locomotor patterns, and walking and running at the walk-to-run interface speed (2.22m/s). RPE for "free choice" and "forced" locomotor patterns was not significantly different ($p < 0.05$), but the RPE for walking was significantly higher than the RPE for running ($p < 0.05$).

pacinian corpuscles, the stimulation of which resulted from stretching of the quadriceps and anterior tibialis muscles at the fast walking speeds. The discomfort of excessive pelvic oscillations and compensatory arm and shoulder movements may also have contributed to the significantly higher RPE values recorded for walking as opposed to running.

Despite the higher cadence during running relative to walking, in absolute terms the mean cadence (155.5 ± 6.39 steps/min) during running is not excessively high. Once again the speed of limb movement was probably not a major factor driving the RPE response during running. Because of the absence of distinct local discomforts during running, it was difficult to isolate specific factors mediating the RPE responses. In both cases the intensity of the locomotor tasks performed was less than 50% $\dot{V}O_2$ max and only 61.18% and 61.82% of the ventilatory threshold, for walking and running respectively. At no stage did the respiratory exchange ratio exceed 1.0. All these factors indicate that the walking and running tasks at the walk-to-run interface were essentially aerobic and the chances of the factors associated with anaerobiosis having any effect on the RPE responses was very slight.

These conclusions tend to illustrate the multi-faceted nature of perceived exertion, and the difficulties associated with identifying specific physiologic or psychologic factors influencing RPE in any given situation. Morgan (1973) suggests that "the important consideration is frequently not what the individual is doing, but rather what he thinks he is doing". In order to investigate this statement briefly, subjects were asked to choose either to walk or run at the interface speed (this was denoted the "free choice" locomotor pattern). Following this, if the "free choice" was a walk, the subjects were "forced" to run at the same speed on another occasion, and if the "free choice" was a run they were "forced" to walk at the same speed on another occasion. The RPE values for "free choice" and "forced" patterns of locomotion were not significantly different ($p<0.05$) (Figure 32). The fact that "forcing" the subjects to perform a particular locomotor task did not significantly effect the RPE in relation to the RPE for "free choice" locomotor tasks, coupled with the fact that it appears that the relative intensity had no effect on RPE at the walk-to-run interface, makes an explanation of these results, particularly for running, very difficult. Had "local" ratings of perceived exertion been collected significant differences may have become evident in each condition. Morgan (1973) suggests that a portion of the unexplained variance in ratings of perceived exertion may be dependent on factors of a psychometric nature. However, since none of these factors was measured in this study it is impossible to make statements relating to them, and their influence on RPE in this situation.

The lack of a statistically significant difference between the RPE values for "free choice" and "forced" locomotor patterns may however have been an artifact of the number of subjects who chose to walk and run in each category. These are illustrated in Table XIII.

Table XIII : The total number of subjects in this study was 11 (N = 11). This table indicates the number of subjects who chose to walk and/or run when given the "free choice" and "forced" conditions at the walk-to-run interface speed.

CATEGORY OF LOCOMOTOR PATTERN	NO. OF SUBJECTS CHOOSING TO WALK	NO. OF SUBJECTS CHOOSING TO RUN
"FREE CHOICE"	3	8
"FORCED"	8	3
TOTAL N	11	11

Because of the trend indicated in Table XIII above, and the fact that when analysed separately the walking and running RPE values are significantly different ($p<0.05$), when all these data are combined, the net result is that the RPE values for "free choice" and "forced" locomotor patterns are not significantly different.

THE USE OF RELATIVE SPEED

To date most of the research concerning relative speed has focused on the effects which relative speed have on the kinetics and kinematics of human gait. The use of absolute speed for the analysis of gait is somewhat invalid since tall and short people are taxed differently at the same absolute speeds. The use of speed made relative to some linear dimension of the body (stature, leg length, foot length) has the effect of factoring out inter-subject differences in linearity and thereby "normalizing" the gait patterns at any given relative speed.

Related to the fact that relative speed has the effect of reducing the inter-subject variability in certain gait parameters is the hint that it (relative speed) will have the same effect on the physiological responses during human locomotion (Goslin 1985). Katch et al. (1982) recognise two sources of variability in human responses, biological and technological. Out of a total variability of 5.6%, these authors suggest that biological sources account for 90% and technological sources less than 10%. If one considers the number of factors which contribute to biological variability, particularly in relation to oxygen consumption and economy of locomotion, finding a single factor which significantly influences variability in any given situation is a difficult task.

The two major issues considered in this study revolved around determining the effects of relative speed on the variability in the speed at which the two locomotor interfaces occurred, and secondly, the effects of relative speed on the energy cost of human locomotion.

The significant difference in the speeds at which the two locomotor interfaces occurred, and the possible reasons for these differences were discussed earlier. In computing the mean coefficient of variation for these speeds, all five speed methods were combined since it was felt that a larger sample would have resulted in a more conclusive statement being generated on the basis of the results of the statistical analysis. Figures 33 and 34 illustrate the inter-subject variability in speed for each speed method separately at the run-to-walk interface and walk-to-run interface respectively. Both figures indicate that the use of relative speed in attempting to reduce the variability with which subjects identify the locomotor interfaces has no significant influence ($p<0.05$). This implies that using absolute speed (m/s) is as good a means as any to use for identifying the walk-to-run and run-to-walk interface speeds. A comparison of the values given in these figures (Figures 33 and 34) from Table XIV reveals that for each speed method, the mean coefficient of variation for speed is greater at the run-to-walk interface than at the walk-to-run interface. These individual means clearly indicate why, when all these data are combined, there is significantly greater inter-subject variability in speed at the run-to-walk interface than at the walk-to-run interface. There is an extreme paucity of data regarding this issue in the literature therefore comparison with the findings of other researchers has been impossible.

Table XIV : Mean coefficients of variation for speed, both absolute (m/s), and relative (st/s, $v/\sqrt{gh}$, ll/s, fl/s) at the walk-to-run and run-to-walk interfaces.

SPEED METHOD	INTERFACE TYPE WALK-TO-RUN	RUN-TO-WALK
ALL COMBINED	2.79	4.66
ABSOLUTE (m/s)	2.78	4.60
st/s	2.77	4.70
$v/\sqrt{gh}$	2.84	4.64
ll/s	2.79	4.68
fl/s	2.77	4.68

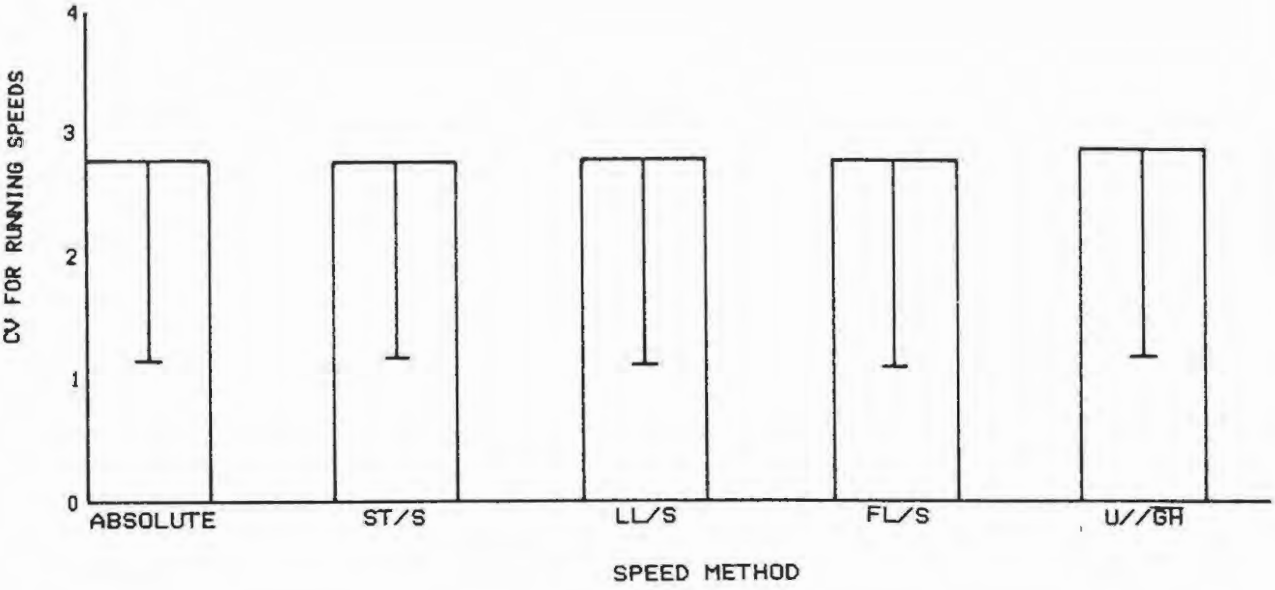


FIGURE 33: A comparison of the mean coefficients of variation (%) for walking speed at the run-to-walk interface using different speed methods, absolute (m/s) and relative (st/s, ll/s, fl/s, $v/\sqrt{gh}$). The use of relative speed had no significant effect ($p < 0.05$) on the variability in speed at this locomotor interface.

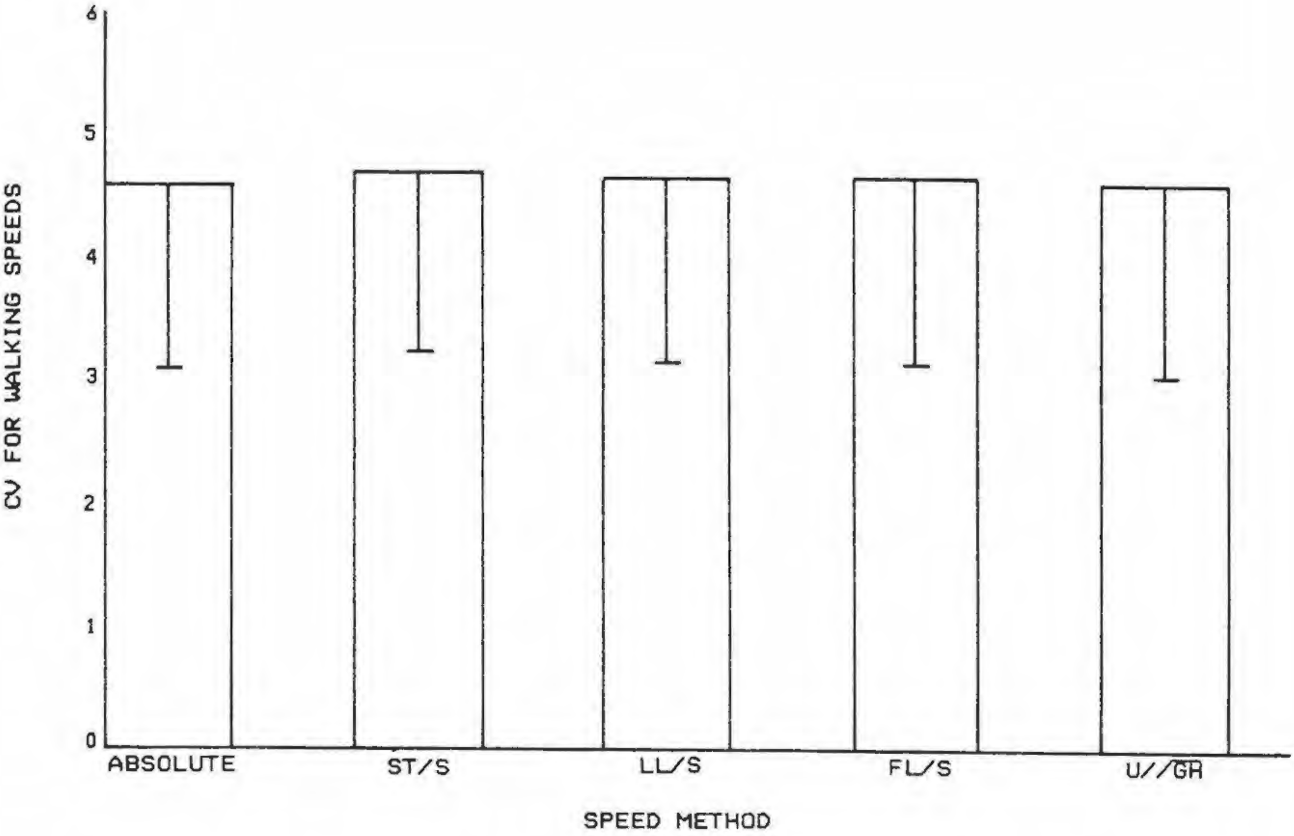
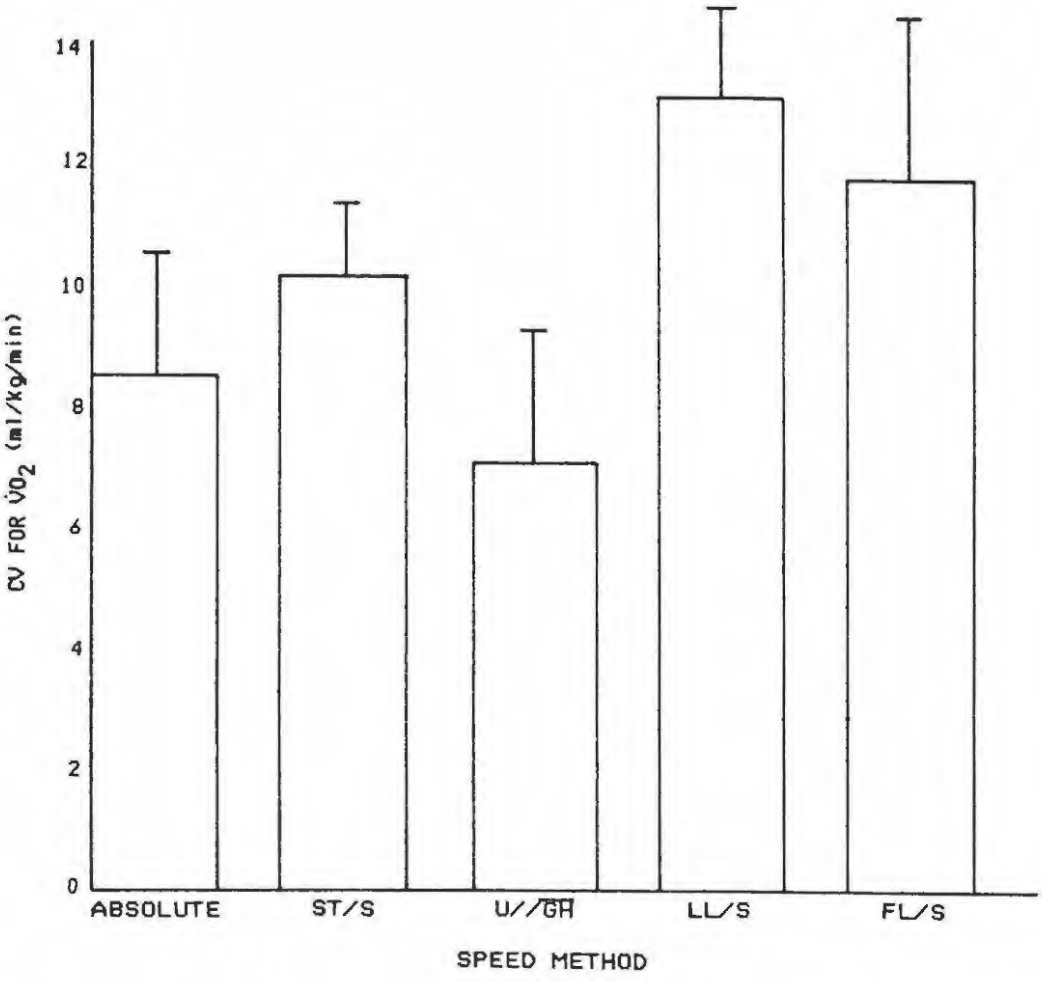


FIGURE 34: A comparison of the mean coefficients of variation (%) for running speed at the walk-to-run interface using different speed methods, absolute (m/s) and relative (st/s, ll/s, fl/s, $v/\sqrt{gh}$). The use of relative speed had no significant effect ($p < 0.05$) on the variability in speed at this locomotor interface.

Variations in submaximal oxygen consumption of as high as 50% have been reported when subjects are compared (Dill <u>et al.</u> 1930). Their data also reveal that a difference in excess of 30% still exists if the $\dot{V}O_2$ is expressed in relative terms (ml/kg/min). Several other researchers have reported inter-subject variations in oxygen uptake of similar magnitudes; 30% (Daniels 1974), 26% and 20% for trained female and male runners respectively (Farrel <u>et al.</u> 1979), 20% (Cureton and Sparling 1980). There are several factors which have been reported to influence the energy cost of locomotion and therefore produce quite drastic inter-subject variations, not least of which is the speed of locomotion. Costill <u>et al.</u> (1973) examined 16 trained distance runners running at 4.46 m/s and found a variation of 12% in submaximal $\dot{V}O_2$, while Williams (1980) reported a variation of 17% in a group of 31 recreational runners at 3.57 m/s.

The results of this study show that the use of relative speed in four different forms each using different measures of morphological linearity appears to have no significant effect ($p<0.05$) in reducing the inter-subject variability in $\dot{V}O_2$ when compared to absolute speed (m/s). Mean coefficients of variation for oxygen uptake (ml/kg/min) are presented for walking and running separately and walking and running combined in Table XIV (Figures 35 to 37). In all cases the variability is greater for the relative speed methods than for absolute speed. In several cases the variability in $\dot{V}O_2$ for relative speed is significantly greater ($p<0.05$) than that for absolute speed. One possible reason for inter-subject variations in $\dot{V}O_2$ not accounted for by using relative speed is differences in the distributions of mass amoung the limb



<u>FIGURE 35:</u> Coefficients of variation (%) for $\dot{V}O_2$ (ml/kg/min) for walking conditions only in each speed method. The use of relative speed had no significant effect ($p < 0.05$) on the inter-subject variability in $\dot{V}O_2$ (ml/kg/min) during walking.

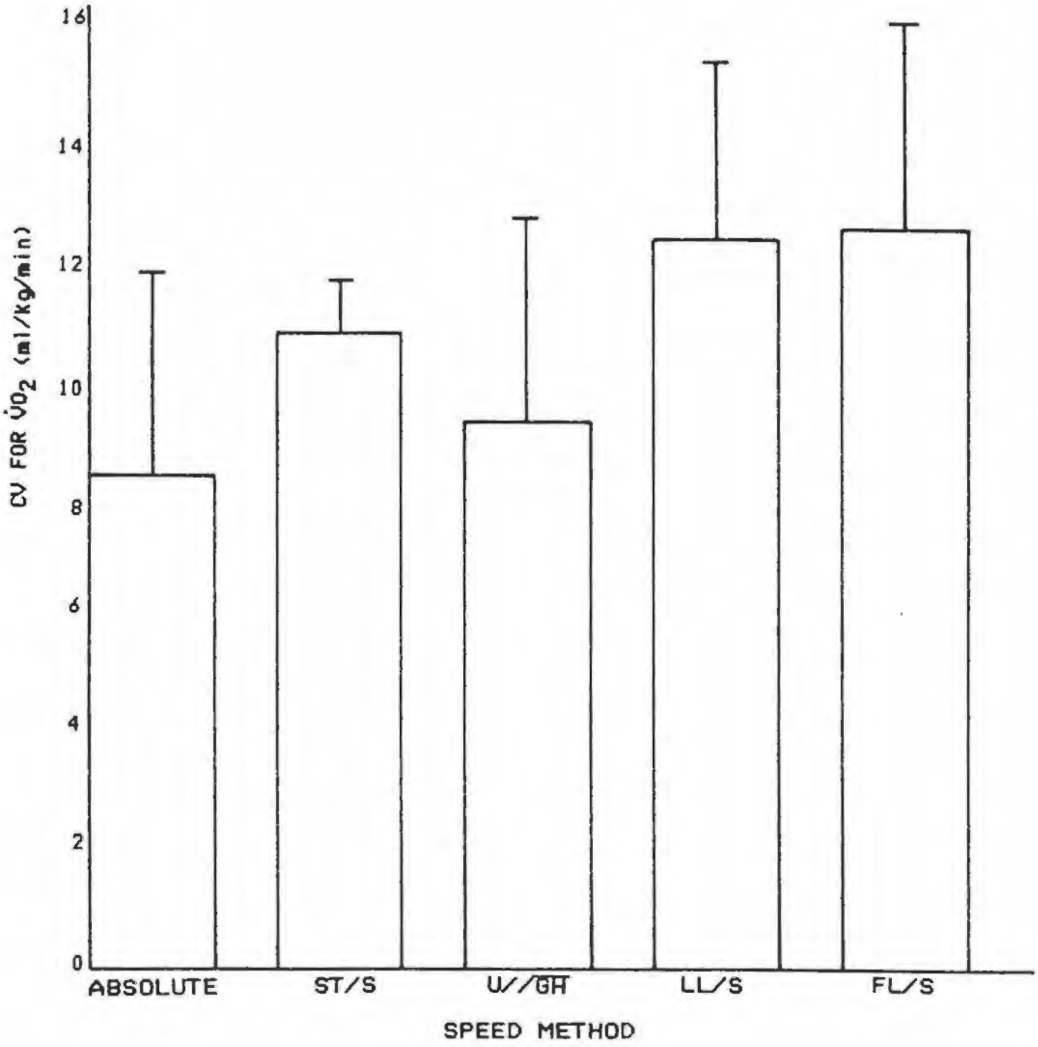


FIGURE 36: Coefficients of variation (%) for $\dot{V}O_2$ (ml/kg/min) for running conditions only in each speed method. The use of relative speed had no significant effect ($p < 0.05$) on the inter-subject variability in $\dot{V}O_2$ (ml/kg/min) during running.

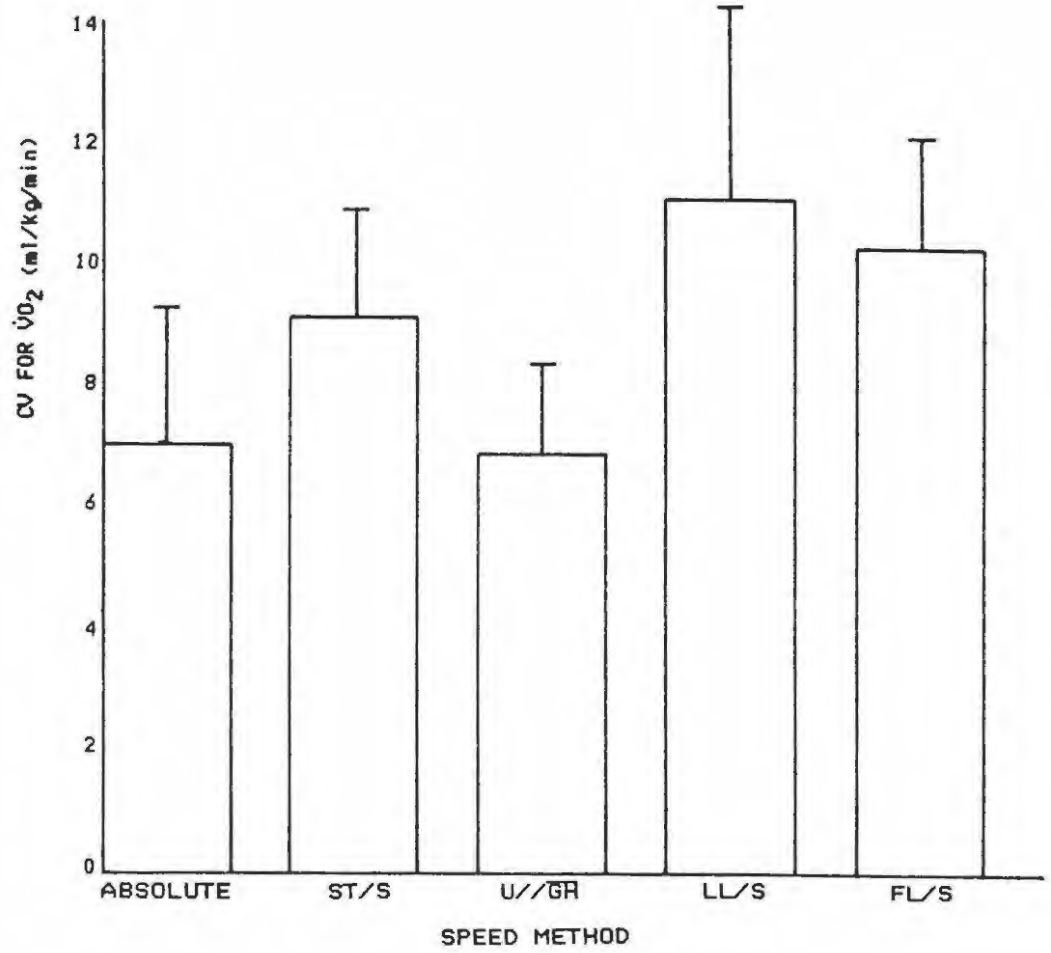


FIGURE 37: Coefficients of variation (%) for $\dot{V}O_2$ (ml/kg/min) for walking and running combined in each speed method. These results showed that for the speeds tested in this study, absolute speed is as effective as relative speed in accounting for inter-subject variability in $\dot{V}O_2$ (ml/kg/min).

segments. These differences can be marked between individuals with identical total body mass. Body mass appears to be an important factor related to the energy cost of locomotion (McArdle et al. 1981), to the extent that when using absolute speed (m/s) this is the only physical phenomenon commonly factored out (ie. $\dot{V}O_2$ was expressed relative to body mass). In the case of all the relative speed methods, differences in morphological linearity between subjects, as well as differences in body mass, were factored out and the variability in submaximal $\dot{V}O_2$ was greater using relative speed as opposed to absolute speed.

Other anatomical variations may also have a potential impact on between-individual variations in energy cost which are not accountable for using the methods employed in this study. Although there is a paucity of data on this, it is not unreasonable to suppose that there is a large variability between individuals of the same body size in the distance of the insertions of key muscles from joint centres (Cavanagh and Kram 1985). Other aspects of muscle architecture, such as fibre orientation, and fibre length in a given muscle could also have an effect on the energy cost of locomotion. For example substrate utilization, number and activity of mitochondria, effectiveness of aerobic enzymes, muscle and blood pH and muscle type. Individual differences in these factors may drive differences in oxygen consumption and not be influenced significantly by the effects of normalizing human gait by using relative speed (Goslin 1985).

Variability in efficiency is reported to differ according to the type of activity being performed as well as the method used to calculate mechanical energy. Different people are using different means of calculating efficiency and reporting different values of variability between subjects (Goslin 1985). For example variations in efficiency have been reported to range from 29.5% to 2.5% (Erickson et al. 1946, Williams et al. 1966) respectively. Variations in muscular efficiency when defined as the ratio of mechanical work to the metabolic energy expended (Stainsby et al. 1980), range from between -120% for downhill treadmill walking to +250% for level treadmill walking (Margaria 1968, Pierrynowski et al. 1980). The mean coefficient of variation for efficiency for walking and running across all five speed methods is 9.73%. This compares favourably with the value cited by Shephard (1976) for treadmill locomotion. Table XV indicates the coefficients of variation for efficiency in walking and running separately and walking and running combined for each speed method. Relative speed, in the forms used in this study, has no significant effect on the variability in efficiency between subjects.

Previous work done at Rhodes University (Williams 1985) on the effects of stature on oxygen uptake indicated that at absolute speeds between 0.875 m/s and 3.325 m/s short people (163.1 ± 4.9 cm) had a significantly higher $\dot{V}O_2$ (ml/kg/min) ($p<0.05$) than tall people (190.8 ± 3.7 cm). However, when these subjects performed the same walking and running tasks at relative speeds (st/s and $v/\sqrt{gh}$) there were no significant differences ($p<0.05$) in oxygen uptake between the two groups. These data suggest that the use of relative speed in reducing inter-subject variability in oxygen consumption is more effective than absolute speed when diverse ranges in stature are a feature of the subject pool. In this case the mean difference was 27.7 cm.

However, as the data from the present study suggests, when the variability in the measures of linearity used for each relative speed method is small, then the use of relative speed as a means of equalizing subjects on the basis of the energy cost of locomotion is somewhat worthless. Absolute speed may be used equally as effectively for groups of people with similar linear dimensions for the measurement of the energy cost of locomotion.

The effects of relative speed on the variability of the kinematic parameters measured in this study, namely cadence and stride length, appear to have produced similar trends as the previously discussed energy cost parameters (Table XV). Relative speed methods st/s and ll/s tend to reduce the variability in walking cadence, but for the most part the variability in cadence at relative speeds is no different from that at absolute speed. The use of relative speed (ll/s) significantly reduces stride length variability while walking at speeds between 1.24 ll/s and 2.68 ll/s ($p<0.05$). This may be due to the relationship between length of leg and length of stride. While running, on the other hand, the use of relative speed (fl/s) significantly increases the variability in stride length ($p<0.05$).

The lack of significant trends in the variability of the kinematic parameters in this study may also be due to the fact that the subjects only differed very slightly in measurements of stature, leg length and foot length. As a result, setting the movement velocity relative to these linear dimensions had little effect on the gait parameters measured. It is suggested that when more diverse ranges of linearity are

Table XV: Mean coefficients of variation for selected performance variables using different speed methods (m/s, st/s, $v/\sqrt{gh}$, ll/s, fl/s). Walking and running data are presented separately and as combined data.

PARAMETER	SPEED METHOD Absolute	st/s	$v/\sqrt{gh}$	ll/s	fl/s
$\dot{V}O_2$ (ml/kg/min)					
Walk	8.16	10.6	9.01	11.9	12.2
Run	7.06	9.20	6.92	11.1	10.3
Walk + Run	8.57	10.1	9.01	13.0	11.7
EFFICIENCY (%)					
Walk	9.51	9.13	10.6	10.4	9.91
Run	7.97	9.20	10.7	10.6	8.52
Walk + Run	9.28	9.47	10.6	10.7	9.29
CADENCE (steps/min)					
Walk	5.86	3.66	4.38	3.50	3.95
Run	5.30	5.09	5.11	4.45	6.04
Walk + Run	5.86	4.20	4.66	3.58	4.88
STRIDE LENGTH (m)					
Walk	5.12	7.14	5.66	4.88	8.02
Run	5.25	8.06	6.65	7.20	10.6
Walk + Run	5.36	7.46	6.04	5.81	9.14

a feature of the subject pool then relative speed becomes an effective means of factoring out these differences in linearity.

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

AIMS OF THE STUDY

This study sought to examine selected physiological, kinematic and psychological parameters related to human locomotion using absolute speed (m/s) and four relative speed methods based upon measures of morphological linearity (st/s, $v/\sqrt{gh}$, ll/s, fl/s). Particular attention was paid to the movement responses which occurred at the walk-to-run interface; a speed which differed from individual to individual, but below which people generally prefer to walk and above which people tend to prefer to run. The run-to-walk interface speed was also identified but was not investigated to the same extent as the walk-to-run interface since the former did not appear to have any metabolic significance.

The questions addressed aimed at attempting to explain the significance of relative speed as a means of reducing inter-subject variability in physiological responses during locomotion. Secondly, to determine whether or not there were two locomotor interfaces or a single interface for both forms of human locomotion, and finally, to establish the significance of these interfaces in relation to metabolic parameters.

The following hypotheses were developed in accordance with the above questions:

HYPOTHESIS ONE: That there is no difference in the speed at which subjects change from a walk to a run at the walk-to-run interface, and from a run to a walk at the run-to-walk interface.

HYPOTHESIS TWO: That the use of relative speed reduces the variability in the speeds at which subjects located the walk-to-run interface speed and the run-to-walk interface speed when compared with the variability in speed at the same interfaces for absolute speed.

HYPOTHESIS THREE: That there is no difference between the movement responses during walking and running at the walk-to-run interface in the following categories of variables:

a) kinematic
b) physiological
c) psychological (perceptual).

HYPOTHESIS FOUR: That the use of relative speed reduces inter-subject variability in the selected kinematic, physiological and psychological parameters during walking and running.

HYPOTHESIS FIVE: That the use of relative speed linearizes the oxygen consumption-velocity relationship across the locomotor interfaces.

METHODS

Eleven male caucasian subjects volunteered to participate in this study (mean age 21.55 ± 3.72 years; body mass 71.7 ± 6.49 kg; stature 180.3 ± 7.47 cm). They all performed a test of maximal aerobic power on a treadmill using a computer assisted on-line system to collect and analyse the data. This test yielded a mean maximal oxygen uptake value for the group of 60.15 ± 5.54 ml/kg/min. Several anthropometric measurements were performed, the mean values being: leg length 86.7 ± 6.29 cm, foot length 26.28 ± 1.54 cm, % body fat 8.39 ± 2.45, and body surface area 1.91 ± 0.12 m squared. Following these tests subjects were involved in a treadmill test during which the walk-to-run and run-to-walk interface speeds were located. Each subject performed 10 increasing speed trials and 10 decreasing speed trials.

During four subsequent visits to the laboratory each subject completed 49 walking and/or running conditions each of which were 4-minutes long. Absolute speed (m/s), and four relative speed methods were used (st/s, $v/\sqrt{gh}$, ll/s, fl/s). Furthermore, two 4-minute conditions at the walk-to-run interface speed were completed, one walking and one running. During each of these tests oxygen uptake, respiratory exchange ratio, cadence and ratings of perceived exertion (RPE) were measured. Measures of efficiency (%) and stride length were derived from the physiological and kinematic data respectively.

The results were analysed using single variable statistics, one-way analysis of variance and one independent regression analyses. A 0.05 level of probability was chosen.

RESULTS

1) The relationship between oxygen uptake and velocity for walking is curvilinear, whereas the same relationship for running is linear. These findings are consistent with those of several other authors (Åstrand and Rodahl 1977, McArdle *et al.* 1981).

   The nature of the oxygen uptake-velocity relationship for walking in this study was best described by an exponential equation. The use of relative speed has no apparent effect on this relationship. Most previous authors have found a least-squares power fit best describes this relationship. It is suggested that the reasons for this discrepancy may be twofold: 1) that in most of the previous work subjects have not walked at extremely fast speeds, and 2) the use of relative speed is a procedure sufficient to slightly alter the nature of this relationship.

   The oxygen uptake-running velocity relationships do not provide as clear a picture in terms of the nature of these relationships as the oxygen uptake-walking velocity relationships. For three of the five speed methods a power equation provided the best least-squares fit (absolute, st/s, $v/\sqrt{gh}$), while a linear equation and an exponential equation provided the best least-squares fit for relative speed methods ll/s and fl/s respectively. The significance of these trends was not clear.

2) Cadence and stride length were found to increase linearly with increases in movement velocity for walking and running. These findings are consistent with those of Charteris <u>et al.</u> (1982) and Hogberg (1952b), and Knuttgen (1961) respectively. The nature of the cadence and stride length-velocity relationships provided no clear trends. However, the coefficients of determination for all regression equations were relatively high (walking cadence: $r^2 =$ 97.2 t0 99.8; running cadence: $r^2 = 51.8$ to 97.97; walking stride length: $r^2 = 96.28$ to 99.88; running stride length: $r^2 = 97.63$ to 100).

Increases in walking speed appear to have been achieved by increases in both cadence and stride length. However, at the faster walking speeds (> 1.2 st/s, 0.47 $v/\sqrt{gh}$, 2.2 ll/s, 7.6 fl/s) an increase in speed appears to have been achieved by an increase in cadence which was disproportionate to the increase in stride length. For increases in running speed, however, there were only small changes in cadence with relatively larger increases in stride length.

The lack of specific trends for the cadence and stride length-velocity relationships indicated that relative speed had little effect on the nature of these relationships.

3) The efficiency of walking was found to be greater than the efficiency of running. The use of relative speed appeared not to have any significant effect on the nature of the relationship between efficiency and movement velocity for walking. In all cases, with the exception of st/s which is described by an exponential equation, the efficiency-walking speed relationships are described by linear equations.

The nature of the relationships between efficiency and running speed are less clear-cut in that these relationships are described by exponential, logarithmic and power fit equations. The efficiency of running tended to increase with increases in speed. This finding along with the finding of an inverted "U"- shaped curve for walking efficiencies is supportive of the findings in the literature.

4) With increases in movement velocity ratings of perceived exertion appeared to increase in an almost linear fashion. However, the increase in RPE for walking speeds appeared to be greater than the increase in RPE for running speeds. These trends may be an artifact of the experimental protocol in that fewer running speeds were examined. In addition to this the fastest running speed was only 2.77 m/s which is relatively slow.

For walking and running at the same speeds there were no significant differences in RPE ($p<0.05$). In previous work, Robertson (1982) noted that RPE was highly related to the relative intensity of the work done (% of maximal oxygen uptake). For walking and running at the same speeds in this study there were no significant differences in relative intensity ($p<0.05$) therefore on this basis it is not surprising that there were no significant differences in RPE.

Stride length and cadence appeared to have a moderate effect on RPE. For movement velocities at which both walking and running were performed the correlation coefficient for stride length and RPE varied from $r = -0.51$ to -0.55, and for cadence and RPE from $r = 0.54$ to 0.60.

These findings emphasised the multi-faceted nature of RPE and the difficulty of isolating single physiological or kinematic cues which drive perceptions of effort in any situation.

5) The nature of the oxygen uptake-velocity curves for walking and running creates the impression that there is a single locomotor interface. In this study it was found, firstly that there are two distinctly separate locomotor interfaces ($p<0.05$), and secondly that the "metabolic intersection point" more closely reflects the speed at which the walk-to-run interface occurs than the speed at which the run-to-walk interface occurs.

Furthermore it was found that the speed at which the walk-to-run interface occurred compared favourably with the "metabolic intersection speeds" cited in the literature.

WALK-TO-RUN INTERFACE SPEED: 2.22 m/s
RUN-TO-WALK INTERFACE SPEED: 2.05 m/s
METABOLIC INTERSECTION SPEED: 2.28 m/s

The correlation coefficient for the "metabolic intersection speed" and the walk-to-run interface speed in this study was r = 0.7369.

6) The two kinematic parameters investigated in this study (cadence and stride length) differed significantly ($p<0.05$) at the two locomotor interfaces. At the walk-to-run interface subjects accommodated increases in speed by using a relatively high cadence and a relatively short stride length. At the run-to-walk interface subjects used a relatively low cadence and longer stride length. These patterns were to be expected since running at 2.22 m/s is considered to be an extremely slow running pace. The natural kinematic adjustments for running at this speed would involve a high cadence and short stride length. While walking at 2.05 m/s is considered to be a "medium fast pace" (Charteris 1982). Kinematic adjustments to this speed would involve relatively longer stride lengths and a slower cadence.

7) The walk-to-run interface speed was located more precisely by all subjects than was the run-to-walk interface. The coefficient of variation for speed at the former was significantly less than that at the latter interface speed ($p<0.05$). It was suggested that distinct proprioceptive feedback provided cues for the more consistent location of the walk-to-run interface while these cues

were absent at the slower speeds and as a result there were no distinct cues which assisted subjects in locating the run-to-walk interface speed. Furthermore, the run-to-walk interface appeared to have little metabolic significance.

8) When the treadmill speed was kept constant at the speed at which the walk-to-run interface occurred (2.22 m/s) there was no significant difference in the oxygen uptake values for walking and running ($p<0.05$). This strongly confirmed that this speed was in fact very close to that speed at which the energy cost curves ($mlO_2/kg/min$) for walking and running intersected.

9) Cadence and stride length differed significantly at the walk-to-run interface for walking and running ($p<0.05$). Walking was characterised by a relatively slower cadence and longer stride length than running during which the opposite kinematic trends were observed. Despite significant differences in the kinematic parameters, there was no difference in the energy cost ($mlO_2/kg/min$) at the walk-to-run interface. It was concluded that the gait pattern had no significant effect on the energy cost of locomotion at the walk-to-run interface speed.

10) Efficiency was not significantly different for walking and running at the walk-to-run interface ($p<0.05$). This finding tends to contradict those in the literature particularly those of Wyndham and Strydom (1971) who suggest that running efficiency is higher

than that of walking particularly when these two locomotor patterns are performed at the same velocity.

The reason that efficiency is not significantly different for walking and running in this study is that the efficiency curves for these two locomotor patterns intersect at about 2.22 m/s, the speed at which the walk-to-run interface occurs. Since efficiency was essentially the same for walking and running and there was no difference in the oxygen uptake for these two locomotor patterns at the walk-to-run interface speed, it was concluded that the work done must have been the same for walking and running at this speed.

11) The mean RPE value for walking was significantly higher than the mean RPE value for running at the walk-to-run interface ($p<0.05$). Considering the results discussed up to now, factors other than the physiological parameters measured in this study must have been driving the perceived exertion responses. It was suggested that the kinematic parameters along with psychological factors of a psychometric nature may have been the primary mediators of RPE at the walk-to-run interface. During walking at this speed large pelvic oscillations and proprioceptive feedback associated with these movements may have influenced ratings of perceived exertion.

In order to investigate the premise "that the important consideration is frequently not what the individual is doing but rather what he thinks he is doing" which influences RPE (Morgan 1973), this parameter was examined during "free choice" and "forced" locomotor patterns. The RPE values for these two conditions were not significantly different ($p<0.05$). However, these results may have been an artifact of the number of subjects who chose to walk and run in each condition.

12) Relative speed, in the four forms used in this study, had no significant effect on the variability of any of the parameters measured ($p<0.05$). It is suggested that the reason for these results was the lack of diversity amongst the subjects chosen in the measures of morphological linearity used in the relative speed calculations (stature, leg length, and foot length). On the basis of these findings it was concluded that unless diverse morphological linearity is a feature of ones subject pool, absolute speed is as effective as relative speed in reducing inter-subject variability in the physiological, kinematic and psychological parameters measured in this study.

CONCLUSIONS

1) The two forms of human locomotion, walking and running, are distinctly different and in evaluating these gait patterns consideration must be given to this fact.

2) The impression created by the energy cost curves, that there is a single locomotor interface for both walking and running is a false one. There are two distinctly different locomotor interfaces, the

walk-to-run interface and the run-to-walk interface. The former appears to correspond with the "metabolic intersection point" and therefore has some metabolic significance. The latter appears to be merely an "overshoot" of the walk-to-run interface and presently has no apparent metabolic significance.

3) Because the walk-to-run interface speed corresponds with the intersection point of the energy cost curves, physiological responses to walking and running at this speed do not differ significantly. However, cadence and stride length patterns for these two locomotor patterns are distinctly different at this point.

4) The identification of single physiological or kinematic factors during perceptions of exertion in any given situation is an extremely difficult if not impossible task. Perceived exertion should therefore be considered a multi-factorial concept and should be evaluated as such.

5) The use of relative speed as a technique for reducing inter-subject variability in physiological and kinematic factors is worthless unless diverse ranges in morphological linearity are a characteristic of one's subject pool.

HYPOTHESIS ACCEPTANCE / REJECTION

HYPOTHESIS ONE: Tentative acceptance of the Alternate Hypothesis.

The findings of this study lead one to tentatively accept the Alternate Hypothesis ($p<0.05$) as follows:

That there is a difference in the speed at which subjects change from a walk to a run at the walk-to-run interface, and from a run to a walk at the run-to-walk interface.

HYPOTHESIS TWO: Tentative acceptance of the Alternate Hypothesis.

The findings of this study lead one to tentatively accept the Alternate Hypothesis ($p<0.05$) as follows:

That the use of relative speed does not reduce the variability in the speeds at which subjects locate the walk-to-run interface speed and the run-to-walk interface speed when compared to the variability in speed at the same interfaces for absolute speed.

HYPOTHESIS THREE:

a) Tentative acceptance of the Alternate Hypothesis

b) Tentative acceptance

c) Tentative acceptance of the Alternate Hypothesis

a) The findings of this study lead one to tentatively accept the Alternate Hypothesis ($p<0.05$) as follows:

That there are differences in the kinematic parameters as measured in this study during walking and running at the walk-to-run interface speed.

b) The findings of this study lead one to tentatively accept the Null Hypothesis ($p<0.05$) as follows:

That there are no differences in the physiological responses during walking and running at the walk-to-run interface speed

c) The findings of this study lead one to tentatively accept the Alternate Hypothesis ($p<0.05$) as follows:

That there are differences in ratings of perceived exertion during walking and running at the walk-to-run interface speed.

HYPOTHESIS FOUR: Tentative acceptance of the Alternate Hypothesis.

The findings of this study lead one to tentatively accept the Alternate Hypothesis ($p<0.05$) as follows:

That the use of relative speed does not reduce inter-subject variability in the selected physiological, kinematic and psychological parameters measured in this study during walking and running.

HYPOTHESIS FIVE: Tentative acceptance of the Alternate Hypothesis.

The findings of this study lead one to tentatively accept the Alternate Hypothesis ($p<0.05$) as follows:

That the use of relative speed does not linearize the oxygen consumption-velocity relationship across the locomotor interfaces.

RECOMMENDATIONS

1) That the run-to-walk interface be examined in the same way as the walk-to-run interface was in this study. This will enhance our understanding of the physiological, kinematic and psychological factors associated with human locomotion at this speed, and allow comparisons to be made with the data collectad at the walk-to-run interface.

2) Since there appears to be no significant difference in the physiological responses to walking and running at the walk-to-run interface speed, but the kinematic parameters measured differ significantly during walking and running at this speed, future researchers would be advised to undertake a detailed analysis of human gait at the walk-to-run interface. A similar analysis may also be performed at the run-to-walk interface.

3) It appears that relative speed is not effective in reducing inter-subject variability when the people being investigated are of similar linear dimensions. Future research may concentrate on examining the effects of using relative speed on inter-subject variability in physiological responses to human locomotion where there is a large diversity of linearity between people. In doing

so, a critical value for differences in linearity between subjects may be identified above which it would be beneficial to use relative speed as a means of reducing variability, and below which absolute speed would be the most effective procedure to use.

4) In this study a 15-point graded category Borg scale was used to assess general ratings of perceived exertion during walking and running. It is suggested that in future research local RPE values also be collected since these values may enhance the understanding of the factors driving RPE, particularly at fast walking speeds where local factors associated with long stride lengths may overide the cardiovascular factors thought to mediate general ratings of perceived exertion.

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APPENDIX 1

Informed consent form

Pre - test questionnaire

RPE information sheet

Borg Scale

RHODES UNIVERSITY

DEPARTMENT OF HUMAN MOVEMENT STUDIES AND PHYSICAL EDUCATION

SUBJECT CONSENT FORM

I, ______________________________ having been fully informed of the research entitled OXYGEN CONSUMPTION TRENDS AT THE WALK/ RUN INTERFACE do give my consent to act as a subject in the above named research.

PROCEDURES, RISKS AND BENEFITS

YOU will be asked to complete a test of maximal working capacity involving a progressively increasing speed run on the treadmill, during which your oxygen consumption will be continuously measured via inspired and expired air analysis. At the same testing session, prior to the V02 max test several anthropometric measurements will be obtained. These will include body mass, stature, sitting height, and two skinfolds.

In addition to the Vo2 max test you will be asked to report to the laboratory on another 5 occaisions. The first will be to establish your interface speed by means of 20 randomly assigned increasing and decreasing speed tests (10 of each). The interface speed will be established to determine at which speeds, during the actual data collection you will run at and which you will walk at.

The next 4 visits to the laboratory will involve you completing 12 randomly assigned walking and running conditions (48 conditions in all). Each condition will be 4 minutes; at minute 2 you will be asked to come on to the mouth piece. From minute 3 - 4 a one minute gas sample will be taken using the on - line system. Prior to each of the 4 sessions resting heart rate will be taken with you in the supine position (lying down). Between each of the 4 minute testing bouts you will be required to lie down until your heart rate is within 10 beats of the previously determined resting value. During each 4 minute bout, in addition to the data obtained from the on-line system cadence and ratings of perceived exertion and discomfort will be taken.

The risks you may encounter during this experiment are similar to those experienced during light to heavy exercise. During the VO2 max test there will be a safety person on hand at all times to protect your interests. The benefits you will accrue will include personal information about your maximal exercise capacity, at which absolute and relative speed in the chosen range you are most economical, an estimation of % body fat, lean body mass, ideal body mass. Apart from these benefits you will gain valuable experience pertaining to the use of equipment and data collection procedures in general. Furthermore, you will be providing a valuable service to the advancement of our knowledge in this area of human performance.

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

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

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

Subject (or legal representative)

(PRINT NAME)	(SIGNATURE)	(DATE)

****

Person Administering Informed Consent

(PRINT NAME)	(SIGNATURE)	(DATE)

****

Witness

(PRINT NAME)	(SIGNATURE)	(DATE)

****

Project Supervisor

(PRINT NAME)	(SIGNATURE)	(DATE)

****

WORK PHYSIOLOGY LABORATORY

PRE-TEST QUESTIONNAIRE

Experiment ____________________

Name: ____________________ Subject number: ____________

Date: ____________________ Time of Day: ____________

1) Hours of sleep last night?: ____________________

2) Do you feel well rested? YES NO

3) Any illnesses or injuries during the past two weeks? YES NO

____

____

____

4) Time of last meal? ____________ Normal, Big, Small?

____

____

____

5) Are you on any medication? YES NO ____________

____

____

6) Have you had anything to eat, drink or smoke during the last hour?
YES NO ____________________

____

7) Is there any reason why you should not participate in this test?
YES NO ____________________

____

____

Signature of Subject ____________________

Signature of investigator ____________________

"We want you to estimate how hard you <u>feel</u> the work is: that is we want you to rate the degree of perceived exertion you feel. By perceived exertion we mean the total amount of exertion and physical fatigue, combining all sensations and feelings of physical stress, effort and fatigue. Don't concern yourself with any one factor such as leg discomfort or shortness of breath, but try to concentrate on your <u>total inner</u> feeling of exertion. Try to estimate as honestly and objectively as possible. Don't underestimate the degree of exertion you feel, but don't overestimate it either. Just try to estimate as accurately as possible. When you are asked to rate your work, you should do so by giving the numerical value on the scale in front of you which indicates your evaluation of your perceived exertion at that moment. A rating of 6 corresponds with feelings of exertion while standing quietly on the treadmill. A rating of 20 reflects maximal exertion."

RATINGS OF PERCEIVED EXERTION

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

(After Borg 1970)

APPENDIX 2

On-Line Computer-Aided Data Acquisition System

Computer program "CONT30"

Computer program "MANUAL"

With the advent of electronic gas analysers and accurate, reliable volumeters coupled with powerful, dedicated microprocessors the open-circuit method of metabolic assessment has become substantially less cumbersome (Goslin *et al.* 1985). This combination of high technology allows continuous analysis of respiratory gas exchange, in addition to which a hard copy of subjects responses is immediately available following each sample period.

The following equations comprise the "computational package" used in the on-line computer-aided data acquisition system (Goslin 1985).

1) Partial Pressure of Water Vapour (PH_2O) (mmHg):

PH_2O = EXP(2.303*(8.10765-(1750.286/(235+T))))

Where T = gas temperature (degrees C)

2) Correction factor to reduce ambient conditions to standard temperature and pressure, dry (STPD):

STPD FACTOR = (273/(273+T))*((PB-(FRH*PH_2O))/760)

Where PB = barometric pressure (mm Hg)

FRH = fractional relative humidity of inspired air

3) Correction of Inspired ambient volume ($\dot{V}I$) for sample duration and STPD:

$\dot{V}$ISTPD($l.min^{-1}$) = $\dot{V}$I(l)*STPD FACTOR*(60/Time)

Where Time = sample duration (s)

4) Fractional nitrogen inspired (FIN_2) and expired (FEN_2):

$FIN_2 = 1-(FIO_2+FICO_2)$

$FEN_2 = 1-(FEO_2+FECO_2)$

5) Oxygen Consumption ($\dot{V}O_2$):

$\dot{V}O_2(l.min^{-1}) = \dot{V}ISTPD*(FIO_2-((FIN_2/FEN_2)*FEO_2))$

6) Carbon Dioxide Production ($\dot{V}CO_2$):

$\dot{V}CO_2(l.min^{-1}) = \dot{V}ISTPD*(((FIN_2/FEN_2)*FECO_2)-FICO_2)$

7) Respiratory exchange ratio (R):

$R = \dot{V}CO_2/\dot{V}O_2$

8) Oxygen consumption per kilogram of body mass ($\dot{V}O_2$):

$\dot{V}O_2(ml.kg^{-1}.min^{-1}) = (1000*\dot{V}O_2(l.min^{-1}))/\text{Body mass (kg)}$

9) Breathing frequency (f):

$f(br.min^{-1}) = f(br)*(60/\text{sample duration(s)})$

10) Average tidal volume ($\overline{V}t$):

$\overline{V}t(l.br^{-1}) = \dot{V}ISTPD(l.min^{-1})/f(br.min^{-1})$

11) Ventilatory Equivalent (V.E.) for oxygen:

V.E. for $O_2 = (\dot{V}ISTPD(l.min^{-1})/\dot{V}O_2(l.min^{-1}))/10$
$(l.100mlO_2^{-1})$

12) Ventilatory Equivalent (V.E.) for carbon dioxide:

V.E. for $CO_2 = (\dot{V}ISTPD(l.min^{-1})/\dot{V}CO_2(l.min^{-1}))/10$
$(l.100mlCO_2^{-1})$

13) Oxygen pulse (O_2 Pulse):

O_2 Pulse = $(1000*\dot{V}O_2(l.min^{-1}))/\text{heart rate}(b.min^{-1})$
$(mlO_2.bt^{-1})$

14) Estimated cardiac output ($\dot{Q}$):

$\dot{Q}(l.min^{-1})=(ZZ+(5.2*\dot{V}O_2(ml.kg^{-1}.min^{-1})))*(BM/1000)$

Where ZZ = 66 if male subject

ZZ = 75 if female subject

BM = Body mass (kg)

15) Stroke volume (S.V.):

S.V.$(ml.bt^{-1})$ = $(1000*\dot{Q}(l.min^{-1}))/\text{heart rate }(b.min^{-1})$

```
80 REM "CONT30"
90 REM ON-LINE PHYSIOLOGICAL DATA COLLECTION
95 REM CONTINUOUS AUTOMATIC SAMPLES EVERY 30 SECONDS WITH SAMPLE DURATION 25 SEC
ONDS
100 REM FIRST SAMPLE STARTS AT 0 MIN 30 SECONDS - LAST SAMPLE IS AT 25 MINUTES
110 POKE HEX("20"),HEX("7E"):REM - CHANGE MEMEND
120 DIM CL$(50),O(50),C(50),HR(50),T(50),IV(50),PW(50),SF(50)
125 DIM A(21),PV(50)
130 DIM N(50),VS(50),VO(50),R(50),EO(50),EC(50),OP(50),FI(3)
140 DIM SD(50),SV(50),RV(50),Q(50),VC(50),F(50),TV(50)
145 DIM SP(50)
150 DATA 0.2093,0.0004,0.7903
160 DATA 0.9376
170 FOR I=1 TO 3:READ FI(I):NEXT I
180 READ VF
190 EXEC,"GET TIMER":REM - LOAD TIMING ROUTINE
200 POKE HEX("24"),HEX("7F"):POKE HEX("25"),HEX("00")
210 PRINT"THIS IS A PROGRAM TO ENABLE YOU TO COLLECT PHYSIOLOGICAL DATA"
220 PRINT"ON-LINE.  YOU WILL BE ASKED TO ENTER CERTAIN INFORMATION."
230 PRINT"THE COMPUTER WILL ASK YOU TO ENTER FIRST AND LAST SAMPLE TIMES"
235 PRINT"AS WELL AS THE REPEATING SAMPLING SEQUENCE YOU WANT FOR EACH 10 MINUTE
S"
240 PRINT" ":PRINT" "
245 PRINT"YOU MUST LEAVE AT LEAST 5 SECONDS BETWEEN THE END OF ONE SAMPLE"
247 PRINT"AND THE BEGINNING OF THE NEXT FOR PRINTER OUTPUT."
250 PRINT" ":PRINT" "
260 PRINT:PRINT"PLEASE ENTER THE FOLLOWING INFORMATION:-"
270 INPUT"SUBJECT NAME: ",NM$
280 INPUT"SUBJECT SEX(M/F): ",SX$
285 IF SX$<>"M" AND SX$<>"F" GOTO 280
290 INPUT"SUBJECT MASS(KG): ",WT
295 IF WT<20 GOTO 290
296 IF WT>120 GOTO 290
300 INPUT"SUBJECT AGE(YRS): ",AG
304 PRINT"NOW ENTER THE MAXIMAL OXYGEN UPTAKE OF YOUR SUBJECT (ENTER 0 IF UNKNOW
N)-"
305 INPUT"SUBJECT MAX VO2 (ML/KG/MIN): ";MV
310 INPUT"EXPERIMENT: ",E$
320 INPUT"CONDITION: ",C$
330 INPUT"DATE: ",DA$
340 INPUT"TIME OF DAY: ",TI$
350 INPUT"BAROMETRIC PRESSURE(MM HG): ",BP
355 IF BP<670 GOTO 350
356 IF BP>760 GOTO 350
360 INPUT"RELATIVE HUMIDITY(%): ",RH
365 IF RH<0 GOTO 360
366 IF RH>100 GOTO 360
370 DEF FNR1(X)=INT(10*X+0.5)/10
380 DEF FNR2(X)=INT(100*X+0.5)/100
390 DEF FNR3(X)=INT(1000*X+0.5)/1000
395 DEF FNR4(X)=INT(10000*X+0.5)/10000
400 FH=RH/100
410 K=0:G=0
420 REM - SET UP TO READ INSPIRED VOLUME (16 BIT NUMBER ON PORT 0)
430 POKE HEX("8001"),0:POKE HEX("8000"),0:POKE HEX("8001"),4
440 POKE HEX("8003"),0:POKE HEX("8002"),0:POKE HEX("8003"),4
450 REM - SET UP A/D (CHANNELS 0-3)
460 POKE 32777,0:POKE 32776,0:POKE 32777,4
470 POKE 32779,0:POKE 32778,0:POKE 32779,4
480 POKE 32799,0:POKE 32798,255:POKE 32799,4
490 OPEN"0.PRINT.SYS" AS 0
500 PRINT #0, TAB(20);"ON-LINE PHYSIOLOGICAL DATA"
510 PRINT #0, TAB(20);"=========================="
520 PRINT #0, " "
560 PRINT #0, "EXPERIMENT: ";E$
570 PRINT #0, "CONDITION: ";C$
580 PRINT #0, " "
590 PRINT #0,"SUBJECT NAME: ";NM$;"  (";SX$;")";TAB(50);"AGE: ";AG;TAB(65);"MASS
 (KG): ";WT
```

```
595 PRINT #0, " "
597 IF MV=0 GOTO 600
598 PRINT #0, "MAXIMAL OXYGEN UPTAKE (ML/KG/MIN): ";MV
599 PRINT #0,""
600 PRINT #0,"DATE: ";DA$;TAB(50);"TIME OF DAY: ";TI$
605 PRINT #0, " "
610 PRINT #0,"BAROMETRIC PRESSURE (MM HG): ";BP;TAB(50);"RELATIVE HUMIDITY (%):
";RH
620 PRINT #0, " "
630 PRINT #0, "THE COLUMN HEADED 'TIME' SHOWS THE ELAPSED TIME FROM THE START ";
640 PRINT #0, "OF THE EXPERIMENT TO THE START OF THE CURRENT SAMPLE PERIOD."
650 PRINT #0, "THE NUMBER IN BRACKETS IS THE SAMPLE DURATION IN SECONDS."
660 PRINT #0, " ":PRINT #0, " "
665 PRINT #0, "-----------------------------------------------------------------";
666 PRINT #0, "-----------------------------------------------------------------"
670 PRINT #0, "NO       TIME        R VO2   VO2  VCO2   R   VI(STPD) HR    F   TEM
P  FEO2   FECO2";
680 PRINT #0, "  VE-O2 VE-CO2   Q     SV    O2 PU   VT     SPEED"
690 PRINT #0, "                             ML/KG   L/M   L/M           L/M    B/M  BR/M";
700 PRINT #0,TAB(84);"L/100ML      L/M  ML/B  ML/B   L/BR   KM/HR"
710 PRINT #0, "-----------------------------------------------------------------";
712 PRINT #0, "-----------------------------------------------------------------"
731 FS=30
741 LS=1500
745 SD(K+1)=25
750 H=20
760 A(0)=0
770 FOR G=1 TO H
775 A(G)=A(G-1)+30
785 NEXT G
820 PRINT:PRINT:INPUT"PRESS S, THEN PRESS RETURN TO START THE EXPERIMENT",B$
825 IF B$<>"S" GOTO 820
830 X=USR(X):REM - START THE CLOCK
840 GOSUB 3700
845 GOSUB 3400
850 IF U>=FS-1 GOTO 960
855 IF U>=(T3+1) THEN GOTO 840
860 GOTO 845
865 SD(K+1)=SD(K)
866 IF K>1 GOTO 877
868 G=1
870 D=A(G):L=SD(K)
871 IF D>(FS+L+4)THEN GOTO 905
872 G=G+1
874 IF G<>H THEN GOTO 870
875 G=0
877 G=G+1
878 IF G<>(H+1) THEN GOTO 905
880 FOR G=1 TO H
885 A(G)=A(G)+600
900 NEXT G
903 G=1
905 GOSUB 3700
910 GOSUB 3400
915 IF U>=LS-1 THEN GOTO 960
920 IF U>=A(G)-1 THEN GOTO 960
925 IF U>=(T3+1) THEN GOTO 905
930 GOTO 910
960 K=K+1:REM - INITIALIZE
965 N=0:OT=0:TC=0:TH=0:TT=0:BB=500:CC=600:F(K+1)=0:DD=0:EE=0:GG=0
966 HH=0:SP=0
970 REM START SAMPLE TIMER
980 S1$=CHR$(PEEK(HEX("7F97"))):S2$=CHR$(PEEK(HEX("7F98")))
990 T1=10*VAL(S1$)+VAL(S2$)
1000 S1$=CHR$(PEEK(HEX("7F97"))):S2$=CHR$(PEEK(HEX("7F98")))
1010 T2=10*VAL(S1$)+VAL(S2$)
1020 IF T1<>T2 GOTO 1040
1030 GOTO 1000
1040 V1=(PEEK(HEX("8002"))*256+PEEK(HEX("8000")))/10
1050 PRINT:PRINT"############"
```

```
1060 REM - READ THE CLOCK
1070 H1$=CHR$(PEEK(HEX("7F93"))):H2$=CHR$(PEEK(HEX("7F94")))
1080 M1$=CHR$(PEEK(HEX("7F95"))):M2$=CHR$(PEEK(HEX("7F96")))
1090 S1$=CHR$(PEEK(HEX("7F97"))):S2$=CHR$(PEEK(HEX("7F98")))
1100 CL$(K)=H1$+H2$+":"+M1$+M2$+":"+S1$+S2$
1110 REM - DETERMINE SAMPLE END
1120 FT=60*(10*VAL(M1$)+VAL(M2$))+10*VAL(S1$)+VAL(S2$)+SD(K)
1140 POKE 32799,0
1160 GOSUB 3000
1165 IF CK>(FT-1) GOTO 1370
1170 O2=(PEEK(32778)*256+PEEK(32776))/100
1175 N=N+1
1180 OT=OT+O2
1200 POKE 32799,1
1210 GOSUB 3000
1215 IF CK>(FT-1) GOTO 1370
1220 CO=(PEEK(32778)*256+PEEK(32776))/100
1225 DD=DD+1
1230 TC=TC+CO
1240 GOSUB 3200
1260 POKE 32799,2
1270 GOSUB 3000
1275 IF CK>(FT-1) GOTO 1370
1280 HR=((PEEK(32778)*256+PEEK(32776))/10)+10
1285 EE=EE+1
1290 TH=TH+HR
1300 IF GG<20 GOTO 1328
1305 IF (GG-20)=HH GOTO 1328
1310 POKE 32799,4
1311 GOSUB 3200
1312 GOSUB 3000
1314 IF CK>(FT-1) GOTO 1370
1316 S=((PEEK(32778)*256+PEEK(32776))*0.0054226)-0.05997
1318 HH=HH+1
1320 SP=SP+S
1322 GOTO 1140
1328 POKE 32799,3
1330 GOSUB 3000
1332 GOSUB 3200
1335 IF CK>(FT-1) GOTO 1370
1340 T=(PEEK(32778)*256+PEEK(32776)-2731)/10
1345 GG=GG+1
1350 TT=TT+T
1360 GOTO 1140
1370 V2=(PEEK(HEX("8002"))*256+PEEK(HEX("8000")))/10
1380 IF V2<V1 THEN V2=V2+409.5
1390 IV(K)=(V2-V1)*VF
1400 O(K)=OT/N:C(K)=TC/DD:HR(K)=TH/EE:T(K)=TT/GG
1405 SP(K)=SP/HH
1410 O(K)=O(K)/100:C(K)=C(K)/100
1420 PW(K)=EXP(2.303*(8.10765-(1750.286/(235+T(K)))))
1430 SF(K)=(273/(273+T(K)))*((BP-(FH*PW(K)))/760)
1440 N(K)=1-(O(K)+C(K))
1450 VS(K)=IV(K)*SF(K)*(60/SD(K))
1460 VO(K)=VS(K)*(FI(1)-((FI(3)/N(K))*O(K)))
1470 VC(K)=VS(K)*(((FI(3)/N(K))*C(K))-FI(2))
1480 R(K)=VC(K)/VO(K)
1490 RV(K)=VO(K)*1000/WT
1493 IF MV=0 GOTO 1500
1495 PV(K)=(RV(K)/MV)*100
1500 F(K)=F(K)*60/SD(K)
1510 TV(K)= VS(K)/F(K)
1520 PRINT:PRINT"SAMPLE ";K;" -    REL VO2=";FNR1(RV(K));"     R=";FNR2(R(K));"
 SPEED(KM/H)=";FNR2(SP(K))
1530 IF K<3 GOTO 1560
1540 PRINT:PRINT"%MAX VO2=";FNR1(PV(K));"     LAST DVO2=";INT((VO(K-1)-VO(K-2))*1
000);"     THIS DVO2=";INT((VO(K)-VO(K-1))*1000)
1560 PRINT:ZZ=66:IF SX$="F" THEN ZZ=75
1570 I=K
1580 EO(I)=(VS(I)/VO(I))/10
1590 EC(I)=(VS(I)/VC(I))/10
```

```
1595 IF HR(I) = 0 GOTO 1610
1600 OP(I)=VO(I)*1000/HR(I)
1610 RV(I)=VO(I)*1000/WT
1620 Q(I)=ZZ+(5.2*RV(I))
1630 Q(I)=Q(I)*WT/1000
1640 IF HR(I)=0 GOTO 1670
1650 SV(I)=(Q(I)*1000)/HR(I)
1660 PRINT #0," "
1670 PRINT #0, I;TAB(3);CL$(I);"(";SD(I);")";TAB(18);FNR1(RV(I));TAB(25);FNR2(VO
(I));TAB(31);FNR2(VC(I));TAB(37);FNR2(R(I));
1680 PRINT #0, TAB(43);FNR2(VS(I));TAB(51);INT(HR(I));TAB(57);INT(F(I));
1685 PRINT #0, TAB(61);FNR1(T(I));TAB(66);FNR4(O(I));TAB(74);FNR4(C(I));
1690 PRINT #0, TAB(82);FNR2(EO(I));TAB(88);FNR2(EC(I));TAB(95);FNR1(Q(I));
1695 PRINT #0, TAB(101);INT(SV(I));TAB(106);FNR2(OP(I));TAB(113);FNR2(TV(I));
1700 PRINT #0, TAB(120);FNR2(SP(I))
1740 IF U>=LS-1 THEN GOTO 1750
1745 GOTO 865
1750 POKE HEX("8013"),0:POKE HEX("8012"),HEX("80"):REM - STOP CLOCK
1760 END
3000 M1$=CHR$(PEEK(HEX("7F95"))):M2$=CHR$(PEEK(HEX("7F96")))
3010 S1$=CHR$(PEEK(HEX("7F97"))):S2$=CHR$(PEEK(HEX("7F98")))
3020 CK=60*(10*VAL(M1$)+VAL(M2$))+10*VAL(S1$)+VAL(S2$)
3040 RETURN
3200 AA=(PEEK(HEX("B002"))*256+PEEK(HEX("8000")))/10
3210 IF BB=CC AND AA<>B8 THEN F(K)=F(K)+1
3220 CC=BB:BB=AA
3230 RETURN
3400 H1$=CHR$(PEEK(HEX("7F93"))):H2$=CHR$(PEEK(HEX("7F94")))
3410 M1$=CHR$(PEEK(HEX("7F95"))):M2$=CHR$(PEEK(HEX("7F96")))
3420 S1$=CHR$(PEEK(HEX("7F97"))):S2$=CHR$(PEEK(HEX("7F98")))
3430 U=3600*(10*VAL(H1$)+VAL(H2$))+60*(10*VAL(M1$)+VAL(M2$))+10*VAL(S1$)+VAL(S2$
)
3440 CK$=H1$+H2$+":"+M1$+M2$+":"+S1$+S2$
3450 IF U>=(T3+1) THEN PRINT CK$,
3460 RETURN
3700 H1$=CHR$(PEEK(HEX("7F93"))):H2$=CHR$(PEEK(HEX("7F94")))
3710 M1$=CHR$(PEEK(HEX("7F95"))):M2$=CHR$(PEEK(HEX("7F96")))
3720 S1$=CHR$(PEEK(HEX("7F97"))):S2$=CHR$(PEEK(HEX("7F98")))
3730 T3=3600*(10*VAL(H1$)+VAL(H2$))+60*(10*VAL(M1$)+VAL(M2$))+10*VAL(S1$)+VAL(S2
$)
3740 RETURN
```

```
80 REM "MANUAL"
90 REM ON-LINE PHYSIOLOGICAL DATA COLLECTION
100 REM IRREGULAR SAMPLING INTERVALS - MANUAL
110 POKE HEX("20"),HEX("7E"):REM - CHANGE MEMEND
120 DIM CL$(50),O(50),C(50),HR(50),T(50),IV(50),PW(50),SF(50)
125 DIM A(21), PV(50)
130 DIM N(50),VS(50),VO(50),R(50),EO(50),EC(50),OP(50),FI(3)
140 DIM SD(50),SV(50),RV(50),Q(50),VC(50),F(50),TV(50)
145 DIM SP(50)
150 DATA 0.2093,0.0004,0.7903
160 DATA 0.9876
170 FOR I=1 TO 3:READ FI(I):NEXT I
180 READ VF
190 EXEC,"GET TIMER":REM - LOAD TIMING ROUTINE
200 POKE HEX("24"),HEX("7F"):POKE HEX("25"),HEX("00")
210 PRINT"THIS IS A PROGRAM TO ENABLE YOU TO COLLECT PHYSIOLOGICAL DATA"
220 PRINT"ON-LINE.  YOU WILL BE ASKED TO ENTER CERTAIN INFORMATION."
230 PRINT"THE COMPUTER WILL THEN WAIT FOR YOU TO PRESS A CERTAIN KEY"
240 PRINT"BEFORE SAMPLING FOR A GIVEN PERIOD. THIS PROCESS MAY BE REPEATED"
250 PRINT"UNTIL THE EXPERIMENT IS TERMINATED BY PRESSING ANOTHER KEY."
260 PRINT:PRINT"PLEASE ENTER THE FOLLOWING INFORMATION:-"
270 INPUT"SUBJECT NAME: ",NM$
280 INPUT"SUBJECT SEX(M/F): ",SX$
285 IF SX$<>"M" AND SX$<>"F" GOTO 280
290 INPUT"SUBJECT MASS(KG): ",WT
295 IF WT<20 GOTO 290
296 IF WT>120 GOTO 290
300 INPUT"SUBJECT AGE(YRS): ",AG
304 PRINT"NOW ENTER THE MAXIMUM OXYGEN UPTAKE OF YOUR SUBJECT (ENTER 0 IF UNKNOW
N)-"
305 INPUT"SUBJECT MAX VO2 (ML/KG/MIN): ";MV
310 INPUT"EXPERIMENT: ",E$
320 INPUT"CONDITION: ",C$
330 INPUT"DATE: ",DA$
340 INPUT"TIME OF DAY: ",TI$
350 INPUT"BAROMETRIC PRESSURE(MM HG): ";BP
355 IF BP<670 GOTO 350
356 IF BP>760 GOTO 350
360 INPUT"RELATIVE HUMIDITY(%): ",RH
365 IF RH<0 GOTO 360
366 IF RH>100 GOTO 360
370 DEF FNR1(X)=INT(10*X+0.5)/10
380 DEF FNR2(X)=INT(100*X+0.5)/100
390 DEF FNR3(X)=INT(1000*X+0.5)/1000
395 DEF FNR4(X)=INT(10000*X+0.5)/10000
400 FH=RH/100
410 K=0
420 REM - SET UP TO READ INSPIRED VOLUME (16 BIT NUMBER ON PORT 0)
430 POKE HEX("8001"),0:POKE HEX("8000"),0:POKE HEX("8001"),4
440 POKE HEX("8003"),0:POKE HEX("8002"),0:POKE HEX("8003"),4
450 REM - SET UP A/D (CHANNELS 0-3)
460 POKE 32777,0:POKE 32776,0:POKE 32777,4
470 POKE 32779,0:POKE 32778,0:POKE 32779,4
480 POKE 32799,0:POKE 32798,255:POKE 32799,4
490 OPEN"0.PRINT.SYS" AS 0
500 PRINT #0, TAB(20);"ON-LINE PHYSIOLOGICAL DATA"
510 PRINT #0, TAB(20);"=========================="
520 PRINT #0, " "
560 PRINT #0, "EXPERIMENT: ";E$
570 PRINT #0, "CONDITION: ";C$
580 PRINT #0, " "
590 PRINT #0, "SUBJECT NAME: ";NM$;"  (";SX$;")";TAB(50);"AGE: ";AG;TAB(65);"MAS
S (KG): ";WT
595 PRINT #0, " "
597 IF MV=0 GOTO 600
598 PRINT #0,"MAXIMAL OXYGEN UPTAKE (ML/KG/MIN): ";MV
599 PRINT #0,""
600 PRINT #0, "DATE: ";DA$;TAB(50);"TIME OF DAY: ";TI$
605 PRINT #0, " "
610 PRINT #0, "BAROMETRIC PRESSURE (MM HG): ";BP;TAB(50);"RELATIVE HUMIDITY (%):
 ";RH
```

```
620 PRINT #0, " "
630 PRINT #0, "THE COLUMN HEADED 'TIME' SHOWS THE ELAPSED TIME FROM THE START"
640 PRINT #0, "OF THE EXPERIMENT TO THE START OF THE CURRENT SAMPLE PERIOD."
650 PRINT #0, "THE NUMBER IN BRACKETS IS THE SAMPLE DURATION IN SECONDS."
660 PRINT #0,  " ":PRINT #0, " "
665 PRINT #0, "----------------------------------------------------------------";
666 PRINT #0, "----------------------------------------------------------------"
670 PRINT #0, "NO      TIME       R VO2   VO2  VCO2   R   VI(STPD) HR    F   TEM
P  FEO2   FECO2";
680 PRINT #0, "  VE-O2 VE-CO2   Q     SV    O2 PU   VT     SPEED"
690 PRINT #0, "                   ML/KG   L/M   L/M         L/M    B/M  BR/M";
700 PRINT #0, TAB(84);"L/100ML     L/M  ML/B  ML/B   L/BR   KM/HR"
710 PRINT #0, "----------------------------------------------------------------";
712 PRINT #0, "----------------------------------------------------------------"
850 PRINT:PRINT:INPUT"PRESS S, THEN PRESS RETURN TO START THE EXPERIMENT",B$
860 IF B$<>"S" GOTO 850
870 X=USR(X):REM - START THE CLOCK AND INITIALIZE
880 N=0:OT=0:TC=0:TH=0:TT=0:BB=500:CC=600:F(K+1)=0
890 DD=0:EE=0:GG=0:HH=0:SP=0
900 PRINT:INPUT"ENTER NEW SAMPLE DURATION?(Y/N) ",AN$
910 IF AN$="N" THEN SD(K+1)=SD(K):GOTO 925
920 PRINT:INPUT"ENTER DURATION IN SECONDS: ",SD(K+1)
925 PRINT:INPUT"CHECK TREADMILL SPEED?(Y/N) ",TS$
926 IF TS$="Y" THEN GOSUB 3500
930 PRINT:INPUT"TO SAMPLE: PRESS S (RETURN) ",K$
940 IF K$<>"S" AND K$<>"T" GOTO 930
950 IF K$="T" GOTO 1750
960 K=K+1
970 REM START SAMPLE TIMER
980 S1$=CHR$(PEEK(HEX("7F97"))):S2$=CHR$(PEEK(HEX("7F98")))
990 T1=10*VAL(S1$)+VAL(S2$)
1000 S1$=CHR$(PEEK(HEX("7F97"))):S2$=CHR$(PEEK(HEX("7F98")))
1010 T2=10*VAL(S1$)+VAL(S2$)
1020 IF T1<>T2 GOTO 1040
1030 GOTO 1000
1040 V1=(PEEK(HEX("8002"))*256+PEEK(HEX("8000")))/10
1050 PRINT"############"
1060 REM - READ THE CLOCK
1070 H1$=CHR$(PEEK(HEX("7F93"))):H2$=CHR$(PEEK(HEX("7F94")))
1080 M1$=CHR$(PEEK(HEX("7F95"))):M2$=CHR$(PEEK(HEX("7F96")))
1090 S1$=CHR$(PEEK(HEX("7F97"))):S2$=CHR$(PEEK(HEX("7F98")))
1100 CL$(K)=H1$+H2$+":"+M1$+M2$+":"+S1$+S2$
1110 REM - DETERMINE SAMPLE END
1120 FT=3600*(10*VAL(H1$)+VAL(H2$))+60*(10*VAL(M1$)+VAL(M2$))+10*VAL(S1$)+VAL(S2
$)
1125 FT=FT+SD(K)
1140 POKE 32798,0
1160 GOSUB 3000
1165 IF CK>(FT-1) GOTO 1370
1170 O2=(PEEK(32778)*256+PEEK(32776))/100
1175 N=N+1
1180 OT=OT+O2
1200 POKE 32798,1
1210 GOSUB 3000
1215 IF CK>(FT-1) GOTO 1370
1220 CO=(PEEK(32778)*256+PEEK(32776))/100
1225 DD=DD+1
1230 TC=TC+CO
1240 GOSUB 3200
1260 POKE 32798,2
1270 GOSUB 3000
1275 IF CK>(FT-1) GOTO 1370
1280 HR=((PEEK(32778)*256+PEEK(32776))/10)+10
1285 EE=EE+1
1290 TH=TH+HR
1300 IF GG<20 GOTO 1328
1305 IF (GG-20)=HH GOTO 1328
1310 POKE 32798,4
1311 GOSUB 3200
1312 GOSUB 3000
1314 IF CK>(FT-1) GOTO 1370
```

```
1316 S=((PEEK(32778)*256+PEEK(32776))*0.0054226)-0.05997
1318 HH=HH+1
1320 SP=SP+S
1322 GOTO 1140
1328 POKE 32793,3
1330 GOSUB 3000
1332 GOSUB 3200
1335 IF CK>(FT-1) GOTO 1370
1340 T=(PEEK(32778)*256+PEEK(32776)-2731)/10
1345 GG=GG+1
1350 TT=TT+T
1360 GOTO 1140
1370 V2=(PEEK(HEX("8002"))*256+PEEK(HEX("8000")))/10
1380 IF V2<V1 THEN V2=V2+409.5
1390 IV(K)=(V2-V1)*VF
1400 O(K)=OT/N:C(K)=TC/DD:HR(K)=TH/EE:T(K)=TT/GG
1405 SP(K)=SP/HH
1410 O(K)=O(K)/100:C(K)=C(K)/100
1420 PW(K)=EXP(2.303*(8.10765-(1750.286/(235+T(K)))))
1430 SF(K)=(273/(273+T(K)))*((BP-(FH*PW(K)))/760)
1440 N(K)=1-(O(K)+C(K))
1450 VS(K)=IV(K)*SF(K)*(60/SD(K))
1460 VO(K)=VS(K)*(FI(1)-((FI(3)/N(K))*O(K)))
1470 VC(K)=VS(K)*(((FI(3)/N(K))*C(K))-FI(2))
1480 R(K)=VC(K)/VO(K)
1490 RV(K)=VO(K)*1000/WT
1493 IF MV=0 GOTO 1500
1495 PV(K)=(RV(K)/MV)*100
1500 F(K)=F(K)*60/SD(K)
1510 TV(K)= VS(K)/F(K)
1520 PRINT:PRINT"SAMPLE ";K;" -   REL VO2=";FNR1(RV(K));"     R=";FNR2(R(K));"
 SPEED(KM/H)=";FNR2(SP(K))
1525 IF MV=0 GOTO 1530
1527 PRINT:PRINT"PERCENT OF MAX VO2=";FNR1(PV(K))
1530 IF K<3 GOTO 1560
1540 PRINT:PRINT"SAMPLE ";K;"  LAST DVO2=";INT((VO(K-1)-VO(K-2))*1000);"  THIS D
VO2=";INT((VO(K)-VO(K-1))*1000)
1560 ZZ=66:IF SX$="F" THEN ZZ=75
1570 I=K
1580 EO(I)=(VS(I)/VO(I))/10
1590 EC(I)=(VS(I)/VC(I))/10
1595 IF HR(I) = 0 GOTO 1610
1600 OP(I)=VO(I)*1000/HR(I)
1610 RV(I)=VO(I)*1000/WT
1620 Q(I)=ZZ+(5.2*RV(I))
1630 Q(I)=Q(I)*WT/1000
1640 IF HR(I)=0 GOTO 1670
1650 SV(I)=(Q(I)*1000)/HR(I)
1660 PRINT #0," "
1670 PRINT #0, I;TAB(3);CL$(I);"(";SD(I);")";TAB(18);FNR1(RV(I));TAB(25);FNR2(VO
(I));TAB(31);FNR2(VC(I));TAB(37);FNR2(R(I));
1680 PRINT #0, TAB(43);FNR2(VS(I));TAB(51);INT(HR(I));TAB(57);INT(F(I));
1685 PRINT #0, TAB(61);FNR1(T(I));TAB(66);FNR4(O(I));TAB(74);FNR4(C(I));
1690 PRINT #0, TAB(82);FNR2(EO(I));TAB(88);FNR2(EC(I));TAB(95);FNR1(Q(I));
1695 PRINT #0, TAB(101);INT(SV(I));TAB(106);FNR2(OP(I));TAB(113);FNR2(TV(I));
1700 PRINT #0, TAB(120);FNR2(SP(I))
1710 IF MV=0 GOTO 1740
1715 PRINT #0, ""
1720 PRINT #0, TAB(3);"%VO2 MAX= ";FNR1(PV(I))
1740 GOTO 330
1750 POKE HEX("8013"),0:POKE HEX("8012"),HEX("80"):REM - STOP CLOCK
1760 END
3000 M1$=CHR$(PEEK(HEX("7F95"))):M2$=CHR$(PEEK(HEX("7F96")))
3005 H1$=CHR$(PEEK(HEX("7F93"))):H2$=CHR$(PEEK(HEX("7F94")))
3010 S1$=CHR$(PEEK(HEX("7F97"))):S2$=CHR$(PEEK(HEX("7F98")))
3020 CK=3600*(10*VAL(H1$)+VAL(H2$))+60*(10*VAL(M1$)+VAL(M2$))+10*VAL(S1$)+VAL(S2
$)
```

```
3040 RETURN
3200 AA=(PEEK(HEX("8002"))*256+PEEK(HEX("8000")))/10
3210 IF BB=CC AND AA<>BB THEN F(K)=F(K)+1
3220 CC=BB:BB=AA
3230 RETURN
3500 FOR MM=1 TO 10: REM SPEED CHECK SUBROUTINE
3510 PP=0:SP=0
3520 POKE 32798,4
3530 FOR KK=1 TO 15:NEXT KK
3540 S=((PEEK(32778)*256+PEEK(32776))*0.0054226)-0.05997
3550 PP=PP+1
3560 SP=SP+S
3570 IF PP<16 GOTO 3520
3580 SP=SP/PP
3590 PRINT"SPEED(KM/H)= ";SP
3600 NEXT MM
3610 SP=0
3620 RETURN
```

APPENDIX 3

Equations and relationships used for computed data

Computer program "WALK/RUN"

EQUATIONS AND RELATIONSHIPS USED FOR COMPUTED DATA

1. PERCENT FAT

Body density = 1.1043 - (0.001327 * TS) - (0.00131 * SS)

where TS = Thigh skinfold
SS = Subscapular skinfold.

% Fat = ((4.95/body density) - 4.5) * 100

2. LEAN BODY MASS = body mass - (body mass * (% fat/100)
(kg) (kg) (kg)

3. IDEAL BODY MASS = lean body mass / (1 - (ideal % fat/100))
(kg) (kg)

where Ideal % Fat for males is 12%.

4. BSA = (body mass $^{0.425}$) * (stature * $^{0.725}$) * 0.007184
(m^2) (kg) (cm)

5. LEG LENGTH = stature - sitting height
(cm) (cm) (cm)

6. STRIDE LENGTH = 2 * (velocity/cadence)
(m) (m/min) (steps/min)

7. RELATIVE STRIDE = stride length/stature
(st/stride) (m) (m)

8. RELATIVE SPEED = velocity/stature
(st/s) (m/s) (m)

9. RELATIVE SPEED = velocity/$\sqrt{\text{gravity} * \text{stature}}$

(v/$\sqrt{gh}$) (m/s) (9.18) (m)

10. RELATIVE SPEED = velocity/leg length

(ll/s) (m/s) (m)

11. RELATIVE SPEED = velocity/foot length

(fl/s) (m/s) (m)

12. GROSS ENERGY COST = VO_2 * EE

(kJ/min) (l/min) (kJ/l)

where EE = 19.616 + (((R - 0.707) / 0.293) * 1.511)

(kJ/l)

and R = respiratory exchange ratio

13. NET ENERGY COST = gross energy cost - rest energy cost

(kJ/min) (kJ/min) (kJ/min)

14. ECONOMY

$\dot{V}O_2$ per absolute speed = $\dot{V}O_2$ / velocity

(ml/kg/min per km/hr) (km/hr)

$\dot{V}O_2$ per relative speed (st/s) = $\dot{V}O_2$ / RS

(ml/kg/min per st/s) (st/s)

$\dot{V}O_2$ per relative speed (v/$\sqrt{gh}$) = $\dot{V}O_2$ / RS

(ml/kg/min per v/$\sqrt{gh}$) (v/$\sqrt{gh}$)

$\dot{V}O_2$ per relative speed (ll/s) = $\dot{V}O_2$ / RS

(ml/kg/min per ll/s) (ll/s)

$\dot{V}O_2$ per relative speed (fl/s) = $\dot{V}O_2$ / RS

(ml/kg/min per fl/s)   (fl/s)

15. Power Output (Heglund *et al.* 1982)

Power = (((0.478 * $V^{1.53}$) + (0.685 * V) + 0.072) * BM + GW

(W)   (kg) (W)

where V = velocity (m/s)

GW = grade work

grade work = (body mass * 9.8) * (grade fraction) * V

(W)   (kg)

16. EFFICIENCY

NET EFFICIENCY = ((power * 0.06) / net energy cost) * 100

(%)   (W)   (kJ/min)

NOTE: See attached computer program - "WALK/RUN".

```
100  REM  WALKRUN
110  REM    CALCULATES A NUMBER OF VARIABLES
120  REM   RELATED TO EFFICIENCY AND ECONOMY OF LOCOMOTION
130  HOME
140  DEF  FN R0(X) =  INT (X + 0.5)
150  DEF  FN R1(X) =  INT (10 * X + 0.5) / 10
160  DEF  FN R2(X) =  INT (100 * X + 0.5) / 100
170  DEF  FN R3(X) =  INT (1000 * X + 0.5) / 1000
180 D$ =  CHR$ (4)
190 W$ = ""
200  PRINT : INPUT "SUBJECT NAME? ";NAME$
300  PRINT : INPUT "CALCULATE ANTHROPOMETRIC RESULTS (Y/N)? ";A$
310  IF A$ = "Y" THEN  GOSUB 3000
320  PRINT : INPUT "CALCULATE INTERFACE TEST DATA (Y/N)? ";B$
330  IF B$ = "Y" THEN  GOSUB 4000
340  PRINT : INPUT "CALCULATE WALK/RUN TEST DATA (Y/N)? ";C$
350  IF C$ = "Y" THEN  GOSUB 4500
380  PRINT : INPUT "CALCULATE MORE DATA FOR THIS SUBJECT (Y/N)? ";F$
390  IF F$ = "Y" THEN  GOTO 300
395  CLEAR
400  PRINT : INPUT "CALCULATE RESULTS FOR ANOTHER SUBJECT (Y/N)? ";G$
410  IF G$ = "Y" THEN  GOTO 130
420  HOME
430  PRINT "THANK YOU AND CHEERS!"
440  END
3000  REM  ANTHROPOMETRY SUBROUTINE
3010  HOME
3020  PRINT "INPUT THE FOLLOWING DATA:"
3030  PRINT : INPUT "STATURE (CM)? ";ST
3040  PRINT : INPUT "SITTING HEIGHT (CM)? ";SH
3050  PRINT : INPUT "FOOT LENGTH (CM)? ";FL
3060  PRINT : INPUT "BODY MASS (KG)? ";BM
3080  PRINT : INPUT "SUBSCAPULAR SKINFOLD (MM)? ";SS
3090  PRINT : INPUT "THIGH SKINFOLD (MM)? ";TS
3100 D = 1.1043 - (0.001327 * TS) - (0.00131 * SS)
3290 PF = ((4.95 / D) - 4.5)
3295 BL = BM * PF
3300 LBM = BM - BL
3330 IBM = (BM - BL) / (1 - (12 / 100))
3340 SA = (BM ^ 0.425) * (ST ^ 0.725) * 0.007184
3350 LL = ST - SH
3360 LS = (LL / ST) * 100
3370 FR = (FL / LL) * 100
3380  PRINT D$;"PR#1"
3390  PRINT : PRINT "ANTHROPOMETRY FOR: ";NAME$
3400  PRINT : PRINT "PERCENT FAT= "; FN R1(PF * 100)
3410  PRINT "LEAN BODY MASS (KG)= "; FN R1(LBM)
3420  PRINT "IDEAL BODY MASS (KG)= "; FN R1(IBM - 1);" TO "; FN R1(IBM +
     1)
3430  PRINT "BODY SURFACE AREA (SQ.M.)= "; FN R2(SA)
3440  PRINT "LEG LENGTH (CM)= "; FN R1(LL)
3450  PRINT "LEG LENGTH AS % OF STATURE = "; FN R1(LS)
3460  PRINT "FOOT LENGTH AS % OF LEG LENGTH = "; FN R1(FR)
3465  PRINT : PRINT
3470  PRINT D$;"PR#0"
3480  HOME
3490  RETURN
4000  REM  INTERFACE SPEED TEST SUBROUTINE
4010  REM  CALCULATES VARIABLES OF MECHANICAL
```

```
4020  REM  NATURE AT THE WALK/RUN OR
4030  REM  RUN/WALK INTERFACE SPEED
4040  PRINT : PRINT "INPUT THE FOLLOWING INFORMATION:"
4050  PRINT : INPUT "ACTUAL SPEED - THIS SAMPLE (KM/H)? ";SP
4060  PRINT : INPUT "CADENCE (STEPS/MIN)? ";CA
4070  GOSUB 7000
4080  PRINT D$;"PR#1"
4090  PRINT : PRINT "INTERFACE SPEED RESULTS FOR: ";NAMES$
4100  PRINT
4105  PRINT "STRIDE LENGTH (M) = "; FN R2(SL)
4110  PRINT "STEP LENGTH/CADENCE RATIO (M/ST/S) = "; FN R2(SC)
4120  PRINT "REL. SP. (ST/S) = "; FN R2(RS)
4130  PRINT "REL. SP. (LEG LENGTHS/S) = "; FN R2(RL)
4140  PRINT "REL. SP. (FOOT LENGTHS/S) = "; FN R2(RF)
4150  PRINT "REL.SP.(FROUDE) = "; FN R2(RG)
4160  PRINT D$;"PR#0"
4170  PRINT : PRINT : PRINT : INPUT "ANOTHER INTERFACE TEST SAMPLE FOR TH
     IS SUBJECT (Y/N)? ";H$
4180  IF H$ = "Y" THEN  GOTO 4050
4190  IF H$ <  > "N" GOTO 4170
4200  HOME
4210  RETURN
4500  REM  WALK/RUN TEST SUBROUTINE
4503  PRINT : INPUT "VENT.THRESHOLD(ML/KG/MIN)? ";VT
4505  PRINT : INPUT "THIS SUBJECT'S MAX RPE IS? ";MR
4510  PRINT : PRINT "INPUT THE FOLLOWING INFORMATION:"
4520  PRINT : INPUT "ACTUAL SPEED FOR THIS SAMPLE (KM/H)? ";SP
4530  PRINT : INPUT "RELATIVE SPEED FOR THIS SAMPLE? ";RS
4550  PRINT D$;"PR#1"
4560  PRINT : PRINT "WALK/RUN TEST RESULTS FOR: ";NAME$
4570  PRINT : PRINT "AT A RELATIVE SPEED OF ";RS
4590  PRINT D$;"PR#0"
4600  GOSUB 6000
4640  PRINT : PRINT : PRINT : INPUT "ANOTHER WALK/RUN SAMPLE FOR THIS SUB
     JECT (Y/N)? ";I$
4650  IF I$ = "Y" THEN  GOTO 4510
4660  IF I$ <  > "N" THEN  GOTO 4640
4670  HOME
4680  RETURN
6000  REM  CALCULATION SUBROUTINE FOR
6010  REM  ECONOMY AND EFFICIENCY
6100  PRINT : PRINT "INPUT THE FOLLOWING DATA:"
6120  PRINT : INPUT "CADENCE (STEPS/MIN)? ";CA
6130  IF MR = 0 THEN  GOTO 6150
6140  PRINT : INPUT "RPE SCALE SCORE? ";RPE
6150  PRINT : INPUT "VO2 (L/MIN)? ";VO2
6160  PRINT : INPUT "RESP. EXCH. RATIO (R)? ";R
6170  IF R > 1 THEN R = 1
6180  IF R < 0.707 THEN R = 0.707
6190 EE = 19.616 + (((R - 0.707) / 0.293) * 1.511)
6200 EC = VO2 * EE
6210 CS = ((EC / BM) / CA) * 1000
6230  GOSUB 7000
6240 VM = SP / 0.06
6260 E1 = ((VO2 * 1000) / BM) / SP
6270 SL = 2 * (VM / CA)
6290 SC = (SL * 30) / CA
6300 RL = (VM / 60) / (LL / 100)
6310 RF = (VM / 60) / (FL / 100)
6320 RS = (SP / 3.6) / (ST / 100)
6325 E2 = ((VO2 * 1000) / BM) / RL
6330 E3 = ((VO2 * 1000) / BM) / RS
6340 CM = ((EC / BM) / VM) * 1000
6400 GW = (BM * 9.8) * (GD / 100) * (SP / 3.6)
6410 V = SP / 3.6
6420 P1 = (((0.478 * V ^ 1.53) + (0.685 * V) + 0.072) * BM) + GW
```

```
6430 E5 = ((VO2 * 1000))/█(█
6435 PR = (RPE / MR) * 100
6440 PVT = (((VO2 * 1000) / BM) / VT) * 100
6442 PR = (RPE / MR) * 100
6445 NC = EC - ((BM * 0.0035) * EE)
6450 E4 = ((VO2 * 1000) / BM) / RF
6455 N1E = ((P1 * 0.06) / NC) * 100
6460  REM   OUTPUT OF E AND E DATA
6470  PRINT D$;"PR#1"
6480  PRINT : PRINT : PRINT "%VENT.THRESHOLD(%) = "; FN R0(PVT)
6490  PRINT "%MAX RPE(%) = "; FN R0(PR)
6500  PRINT "STRIDE LENGTH (M) = "; FN R2(SL)
6510  PRINT "STEP LENGTH/CADENCE RATIO(M/ST/S) = "; FN R2(SC)
6690  PRINT : PRINT : PRINT "ENERGY COST DATA:"
6700  PRINT : PRINT "GROSS ENERGY COST (KJ/MIN) = "; FN R2(EC)
6720  PRINT "ENERGY COST PER STEP(J/KG) = "; FN R2(CS)
6750  PRINT "ENERGY COST PER DISTANCE (J/KG/M) = "; FN R2(CM)
6760  PRINT : PRINT : PRINT : PRINT "LOCOMOTION ECONOMY:"
6770  PRINT "VO2 PER REL. SPEED (ML/KG PER ST/S) = "; FN R2(E3)
6780  PRINT "VO2 PER REL. SPEED (ML/KG PER LL/S) = "; FN R2(E2)
6785  PRINT "VO2 PER REL. SPEED (ML/KG PER FL/S) = "; FN R2(E4)
6790  PRINT "VO2 PER REL. SPEED(ML/KG PER FROUDE) = "; FN R2(E5)
6795  PRINT "VO2 PER ABS. SPEED (ML/KG PER KM/H) = "; FN R2(E1)
6850  PRINT : PRINT : PRINT "POWER OUTPUT(W) = "; FN R1(P1)
6860  PRINT "EFFICIENCY (%) = "; FN R1(N1E)
6900  PRINT D$;"PR#0"
6910  RETURN
7000  REM  CALCULATES SPEED INFORMATION
7010 VM = SP / 0.06
7020 SL = 2 * (VM / CA)
7030 SC = (SL * 30) / CA
7040 RS = (SP / 3.6) / (ST / 100)
7050 RL = (VM / 60) / (LL / 100)
7060 RF = (VM / 60) / (FL / 100)
7070 RG = (SP / 3.6) / (9.8 * (ST / 100)) ^ 0.5
7080  RETURN
```

APPENDIX 4

Data collection sheets

WALK/RUN PROJECT

MAX TEST DATA SHEET

NAME: ____________________

DATE: ___/___/___ TIME: ____________

BAROMETRIC PRESSURE: _______mmHg RELATIVE HUMIDITY: ________%

BODY MASS: ____________kg

Check

_____ Administer pre-test questionnaire

_____ Load "Cont30"

_____ Start clock and computer together

TIME (min)	SPEED (km/h)	CADENCE (steps/min)	TIME (min)	SPEED (km/h)	CADENCE (steps/min)
0	8	________	8	16	________
1	9	________	9	17	________
2	10	________	10	17+1%	________
3	11	________	11	17+2%	________
4	12	________	12	17+3%	________
5	13	________	13	17+4%	________
6	14	________	14	17+5%	________
7	15	________			

MAX R.P.E. ____________ MAX VO_2 (ml/kg/min) ____________

WALK/RUN PROJECT

ANTHROPOMETERY AND INTERFACE SPEED TEST DATA SHEET

NAME____________________ AGE________________

TIME______________ DATE____/____/____

ANTHROPOMETRY

Stature______________

Sitting Height____________

Foot Length____________

Body Mass______________

SKINFOLDS

Subscapular____________

Thigh______________

INTERFACE TEST

TRIAL NO.	METHOD	INTERFACE SPEED	CADENCE/ MIN.	TRIAL NO.	METHOD	INTERFACE SPEED	CADENCE/ MIN.
1				11			
2				12			
3				13			
4				14			
5				15			
6				16			
7				17			
8				18			
9				19			
10				20			

INTERFACE SPEED__________________

WALK/RUN

WALK/RUN DATA SHEET

NAME____________________ WALK/RUN SESSION 1 2 3 4

DATE____/____/____ TIME OF DAY______________

BODY MASS____________ BAROMETRIC PRESSURE__________

MAX VO2 ____________ RELATIVE HUMIDITY ___________

STATURE_____________ LEG LENGTH_____________

FOOT LENGHT__________

INTERFACE SPEED___________ RESTING HEART RATE__________

TRIAL NO.	SPEED METHOD	SPEED		WALK RUN	CADENCE/ MIN.	RPE	CSR	REC HEART RATE
		REL	KM					
1				WALK RUN				
2				WALK RUN				
3				WALK RUN				
4				WALK RUN				
5				WALK RUN				
6				WALK RUN				
7				WALK RUN				
8				WALK RUN				
9				WALK RUN				
10				WALK RUN				
11				WALK RUN				
12				WALK RUN				
13				WALK RUN				

WALK RUN PROJECT

INTERFACE V02

NAME:____________________ DATE:____/____/____

TIME:__________

BARROMETRIC PRESSURE:__________mmHg

RELATIVE HUMIDITY:__________%

TEMPERATURE:_________ C

INTERFACE SPEED:__________KM/HR

RESTING HEART RATE:________

	METHOD	WALK	RUN	SPEED	CADENCE	RPE	REC HR
1)	PREFERRED	WALK	RUN	______	________	_____	______
2)	FORCED	WALK	RUN	______	________	_____	______
3)	FORCED	WALK	RUN	______	________	_____	______

APPENDIX 5

Tables of statistical summaries of data for 11 male subjects

Table XVI : Statistical summary of general information for 11 male subjects.

PARAMETER	MEAN	S.D.
AGE (YRS)	21.55	3.72
STATURE (cm)	180.30	7.47
SITTING HEIGHT (cm)	93.62	4.12
BODY MASS (kg)	71.70	6.49
FOOT LENGTH (cm)	26.28	1.54
% BODY FAT	8.39	2.45
LEAN BODY MASS (kg)	65.66	6.18
BODY SURFACE AREA (m^2)	1.91	0.12
LEG LENGTH (cm)	86.70	6.29
LEG LENGTH/STATURE (%)	48.05	2.18
FOOT LENGTH/LEG LENGTH (%)	30.39	1.75
MAX RPE	17.64	1.63
MAX $\dot{V}O_2$ (ml/kg/min)	60.15	5.54
V.T. (% max $\dot{V}O_2$)	74.74	3.94
V.T. (ml/kg/min)	44.82	5.02
V.T. (velocity m/s)	4.04	0.036

Table XVII : Statistical summary of absolute (m/s) and relative speeds (st/s, $v/\sqrt{gh}$, ll/s, fl/s) at which the walk-to-run interface speed occurred. Mean data are presented for each subject.

SUBJECT	WALK-TO-RUN INTERFACE SPEEDS				
	m/s	st/s	$v/\sqrt{gh}$	ll/s	fl/s
SR	2.13	1.32	0.53	2.94	8.78
MW	2.03	1.17	0.49	2.56	8.47
TR	2.48	1.37	0.59	2.85	9.44
PC	2.20	1.20	0.52	2.48	8.55
RC	2.28	1.26	0.54	2.43	8.36
NM	2.41	1.35	0.58	2.86	8.86
GP	2.29	1.22	0.53	2.58	8.18
BA	2.18	1.17	0.57	2.41	8.19
JR	2.03	1.13	0.48	2.38	8.21
PM	2.20	1.16	0.51	2.46	7.62
PD	2.24	1.23	0.53	2.39	8.55
$\overline{X}$	2.22	1.23	0.53	2.58	8.47
SD	0.14	0.08	.035	0.21	0.47

Table XVIII: Statistical summary of absolute (m/s) and relative speeds (st/s, $v/\sqrt{gh}$, ll/s, fl/s) at which the run-to-walk interface speed occurred. Mean data are presented for each subject.

SUBJECT	RUN-TO-WALK INTERFACE SPEEDS				
	m/s	st/s	$v/\sqrt{gh}$	ll/s	fl/s
SR	2.10	1.30	0.53	2.89	8.66
MW	2.00	1.15	0.49	2.53	8.35
TR	2.03	1.11	0.48	2.30	7.62
PC	1.97	1.07	0.46	2.22	7.66
RC	2.09	1.16	0.50	2.22	7.66
NM	2.04	1.15	0.49	2.42	7.50
GP	2.13	1.14	0.50	2.40	7.60
BA	2.21	1.19	0.52	2.45	8.33
JR	2.08	1.16	0.49	2.44	8.41
PM	2.05	1.08	0.48	2.29	7.09
PD	1.86	1.02	0.44	1.98	7.09
$\bar{X}$	2.05	1.13	0.49	2.38	7.82
SD	.091	.073	.025	0.54	0.54

Table XIX : Statistical summary of cadence (steps/min) and stride length (m) at the walk-to-run and run-to-walk interfaces respectively. Mean data are presented for each subject.

SUBJECT	W-R INTERFACE		R-W INTERFACE	
	CADENCE	STRIDE LENGTH	CADENCE	STRIDE LENGTH
SR	167	1.54	164	1.54
MW	161	1.52	136	1.77
TR	159	1.87	132	1.83
PC	149	1.77	127	1.86
RC	156	1.76	133	1.89
NM	156	1.85	130	1.87
GP	157	1.75	132	1.94
BA	146	1.79	130	2.04
JR	160	1.52	137	1.81
PM	147	1.81	124	1.98
PD	153	1.76	125	1.79
$\bar{X}$	155.5	1.72	134	1.85
SD	6.39	0.13	10.87	0.13

Table XX : Statistical summary of general information for walking at the walk-to-run interface speed. Mean data are presented for each subject.

SUBJECT	CADENCE (steps/min)	STRIDE LENGTH (m)	$\dot{V}O_2$ (ml/kg/min)	EFFICIENCY (%)	RPE	%$\dot{V}O_2$max (ml/kg/min)
SR	148	2.01	32.6	36.8	12	50.6
MW	134	1.81	19.9	52.5	10	36.8
TR	132	1.97	23.4	46.8	12	37.9
PC	152	1.68	26.1	39.6	13	45.8
RC	138	1.76	21.2	47.3	11	31.3
GP	136	1.94	23.9	35.6	13	40.7
NM	138	1.98	29.6	36.6	11	49.5
PD	134	2.05	27.0	42.4	9	45.8
PM	142	2.04	30.1	38.9	9	43.9
JR	137	1.95	30.8	34.9	13	60.2
BA	128	2.07	29.0	36.7	10	51.9
$\overline{X}$	138.1	1.93	20.69	40.74	11.18	44.95
SD	6.96	0.13	4.15	5.79	1.54	8.10

Table XXI : Statistical summary of general information for running at the run-to-walk interface speed. Mean data are presented for each subject.

SUBJECT	CADENCE (steps/min)	STRIDE LENGTH (m)	$\dot{V}O_2$ (ml/kg/min)	EFFICIENCY (%)	RPE	%$\dot{V}O_2$max (ml/kg/min)
SR	172	1.48	26.7	39.1	9	46.9
MW	160	1.53	25.9	37.7	10	38.2
TR	150	1.76	29.3	45.2	10	49.8
PC	158	1.74	31.4	34.7	10	49.5
RC	156	1.77	27.6	41.7	8	46.7
GP	150	1.92	26.5	45.9	7	38.7
NM	148	1.82	28.1	39.5	11	54.9
PD	154	1.72	30.0	36.0	8	53.8
PM	156	1.90	28.7	43.5	9	44.5
JR	158	1.53	24.9	39.9	11	45.8
BA	148	1.76	29.4	35.9	11	47.6
$\bar{X}$	155.5	1.72	28.05	39.92	9.45	46.95
SD	6.93	0.15	1.94	3.80	1.37	5.26

Table XXII : Statistical summary of absolute speed (km/hr) at various relative speeds (st/s). The following conversion factor was used to convert km/hr to m/s:

m/s = km/hr * 0.277.

SPEED (st/s)	ABSOLUTE SPEED (km/hr) MEAN	SD
0.6	3.89	0.16
0.7	4.55	0.19
0.8	5.19	0.21
0.9	5.84	0.24
1.0	6.49	0.27
1.1	7.14	0.29
1.2	7.79	0.32
1.3	8.44	0.35
1.4	9.08	0.38
1.5	9.74	0.40
1.6	10.39	0.43

Table XXIII: Statistical summary of absolute speed at various speeds ($v/\sqrt{gh}$).

SPEED ($v/\sqrt{gh}$)	ABSOLUTE SPEED (km/hr) MEAN	SD
0.27	4.08	0.08
0.31	4.69	0.09
0.35	5.29	0.11
0.39	5.90	0.12
0.43	6.51	0.14
0.47	7.11	0.15
0.51	7.72	0.16
0.55	8.33	0.17
0.59	8.93	0.19
0.63	9.53	0.19
0.67	10.14	0.21

Table XXIV: Statistical summary of absolute speed at various relative speeds (ll/s).

SPEED (ll/s)	ABSOLUTE SPEED (km/hr) MEAN	SD
1.24	3.93	0.21
1.48	4.69	0.25
1.72	5.45	0.29
1.96	6.22	0.32
2.20	6.98	0.36
2.44	7.74	0.40
2.68	8.50	0.45
2.92	9.26	0.48
3.16	10.02	0.52

Table XXV : Statistical summary of absolute speed at various relative speeds (fl/s).

SPEED (fl/s)	ABSOLUTE SPEED (km/hr) MEAN	SD
4.6	4.35	0.26
5.6	5.29	0.31
6.6	6.24	0.37
7.6	7.19	0.42
8.6	8.14	0.48
9.6	9.08	0.54
10.6	10.10	0.52
11.6	10.97	0.65

Table XXVI: Summary of the number of subjects who chose to walk and/or run at various velocities.

SPEED	LOCOMOTOR PATTERN	
	WALK	RUN
Absolute (km/hr)		
4	11	
5	11	
6	11	
6.5	11	
7	11	
7.5	9	2
8	5	6
8.5	2	9
9		11
10		11
Relative (st/s)		
0.6	11	
0.7	11	
0.8	11	
0.9	11	
1.0	11	
1.1	11	
1.2	6	5
1.3	3	8
1.4		11
1.5		11
1.6		11
Relative ($v/\sqrt{gh}$)		
0.27	11	
0.31	11	
0.35	11	
0.39	11	
0.43	11	
0.47	11	
0.51	8	3
0.55	2	9
0.59		11
0.63		11
0.67		11

Table XXVI continued:

Relative (ll/s)		
1.24	10	
1.48	10	
1.72	10	
1.96	10	
2.2	10	
2.44	6	4
2.68	2	8
2.92		10
3.16		10
Relative (fl/s)		
4.6	11	
5.6	11	
6.6	11	
7.6	10	1
8.6	4	7
9.6		11
10.6		11
11.6		11

Table XXVII: Statistical summary of cadence (steps/min) at various velocities.

SPEED	CADENCE			
	WALK		RUN	
Absolute (km/hr)	MEAN	SD	MEAN	SD
4	101	5.09		
5	116.5	16.3		
6	120	6.29		
6.5	123	5.39		
7	128.1	7.01		
7.5	133.1	13.89	157	4.24
8	134.8	1.79	155.3	12.75
8.5	141	1.41	157.7	9.4
9			159.5	6.75
10			160	8.63
Relative (st/s)				
0.6	99.18	3.71		
0.7	106	5.14		
0.8	113	5.09		
0.9	118.9	4.50		
1.0	122.7	4.67		
1.1	128	3.03		
1.2	134.6	3.72	153.6	9.93
1.3	146.7	5.03	156.7	6.67
1.4			158	7.85
1.5			159.3	8.54
1.6			160	7.04
Relative ($v/\sqrt{gh}$)				
0.27	101.8	5.33		
0.31	108	5.58		
0.35	112.9	6.02		
0.39	118.7	4.20		
0.43	124.5	5.94		
0.47	128.5	6.00		
0.51	134.5	5.83	158	10.6
0.55	140	2.83	158.8	4.81
0.59			159.5	6.93
0.63			160.5	8.63
0.67			160.7	9.77

Table XXVII continued:

SPEED	CADENCE			
	WALK		RUN	
	MEAN	SD	MEAN	SD
Relative (ll/s)				
1.24	98.6	4.00		
1.48	106.4	4.70		
1.72	115	4.14		
1.96	119.6	3.50		
2.20	125	4.74		
2.44	132	3.58	152.5	7.19
2.68	141	4.24	157.5	5.73
2.92			158	6.05
3.16			157.8	4.05

SPEED	WALK MEAN	WALK SD	RUN MEAN	RUN SD
Relative (fl/s)				
4.6	104.4	4.08		
5.6	112.4	3.67		
6.6	120.9	4.41		
7.6	129.4	4.00		
8.6	143.5	8.39	158.3	9.85
9.6			159.5	8.63
10.6			158.9	11.00
11.6			159.6	10.54

Table XXVIII: Statistical summary of stride length (m) at various velocities.

SPEED	STRIDE LENGTH			
	WALK		RUN	
	MEAN	SD	MEAN	SD
Absolute (km/hr)				
4	1.32	0.07		
5	1.46	0.17		
6	1.67	0.08		
6.5	1.76	0.08		
7	1.83	0.09		
7.5	1.89	0.16	1.59	0.04
8	1.98	0.02	1.73	0.15
8.5	2.01	0.01	1.80	0.11
9			1.89	0.07
10			2.09	0.11
Relative (st/s)				
0.6	1.31	0.08		
0.7	1.43	0.11		
0.8	1.54	0.12		
0.9	1.64	0.12		
1.0	1.76	0.12		
1.1	1.85	0.12		
1.2	1.91	0.12	1.73	0.16
1.3	1.85	0.16	1.82	0.12
1.4			1.93	0.16
1.5			2.04	0.18
1.6			2.17	0.16
Relative ($v/\sqrt{gh}$)				
0.27	1.34	0.09		
0.31	1.45	0.09		
0.35	1.56	0.11		
0.39	1.66	0.09		
0.43	1.75	0.11		
0.47	1.85	0.11		
0.51	1.91	0.11	1.63	0.14
0.55	1.98	0.03	1.75	0.09
0.59			1.87	0.11
0.63			1.99	0.13
0.67			2.11	0.15

Table XXVIII continued:

SPEED	STRIDE LENGTH			
	WALK		RUN	
	MEAN	SD	MEAN	SD
Relative (ll/s)				
1.24	1.33	0.06		
1.48	1.48	0.09		
1.72	1.58	0.08		
1.96	1.73	0.09		
2.20	1.86	0.11		
2.44	1.88	0.11	1.75	0.12
2.68	1.94	0.03	1.82	0.13
2.92			1.95	0.16
3.16			2.12	0.14
Relative (fl/s)				
4.6	1.39	0.12		
5.6	1.57	0.12		
6.6	1.72	0.14		
7.6	1.83	0.11		
8.6	1.86	0.18	1.74	0.19
9.6			1.90	0.19
10.6			2.13	0.24
11.6			2.30	0.23

Table XXIX: Statistical summary of relative $\dot{V}O_2$ (per kg) at various velocities.

SPEED	RELATIVE $\dot{V}O_2$ (ml/kg/min)			
	WALK		RUN	
	MEAN	SD	MEAN	SD
Absolute (km/hr)				
4	10.71	1.21		
5	12.71	1.33		
6	15.79	1.42		
6.5	17.55	1.55		
7	19.75	1.49		
7.5	22.61	2.17	25.90	2.12
8	26.38	2.14	26.97	1.17
8.5	30.4	0.14	28.88	2.61
9			30.38	2.69
10			33.00	1.61
Relative (st/s)				
0.6	11.05	1.25		
0.7	12.13	1.45		
0.8	13.18	1.28		
0.9	15.62	1.70		
1.0	16.70	1.63		
1.1	20.53	2.21		
1.2	24.30	2.41	26.12	1.89
1.3	27.96	2.86	28.45	3.16
1.4			29.79	3.13
1.5			31.20	3.02
1.6			33.31	2.48
Relative ($v/\sqrt{gh}$)				
0.27	11.09	1.40		
0.31	12.16	0.97		
0.35	13.77	1.52		
0.39	15.70	1.26		
0.43	17.79	1.96		
0.47	20.42	2.34		
0.51	23.68	1.86	25.97	1.39
0.55	27.30	0.56	28.04	1.71
0.59			30.13	2.66
0.63			31.09	1.92
0.67			32.18	2.67

Table XXIX continued:

SPEED	RELATIVE $\dot{V}O_2$ (ml/kg/min)			
	WALK		RUN	
	MEAN	SD	MEAN	SD
Relative (ll/s)				
1.24	11.12	1.51		
1.48	12.01	1.73		
1.72	14.19	1.83		
1.96	16.42	2.22		
2.20	19.40	2.56		
2.44	22.32	2.34	27.95	2.17
2.68	27.75	1.63	28.28	4.35
2.92			30.47	3.04
3.16			32.68	3.63
Relative (fl/s)				
4.6	11.32	1.12		
5.6	13.86	1.74		
6.6	16.56	2.21		
7.6	20.79	3.53		
8.6	25.83	2.09	28.98	3.66
9.6			30.31	3.22
10.6			32.74	2.75
11.6			35.19	3.41

Table XXX : Statistical summary of efficiency (%) at various velocities.

SPEED	EFFICIENCY (%)			
	WALK		RUN	
	MEAN	SD	MEAN	SD
Absolute (km/hr)				
4	58.2	8.29		
5	59.4	7.5		
6	55.10	5.17		
6.5	53.1	5.37		
7	50.1	4.06		
7.5	46.5	5.02	38.2	3.89
8	42.5	4.13	40.2	2.22
8.5	38.4	0.42	40.3	3.56
9			41.4	3.65
10			42.6	2.76
Relative (st/s)				
0.6	54.7	6.73		
0.7	56.6	7.06		
0.8	58.7	5.74		
0.9	54.2	5.54		
1.0	56.6	5.43		
1.1	48.5	4.36		
1.2	44.10	2.96	41.20	3.45
1.3	39.5	1.22	41.70	4.80
1.4			42.70	4.29
1.5			43.90	4.29
1.6			43.90	2.77
Relative ($v/\sqrt{gh}$)				
0.27	51.4	10.31		
0.31	57.70	6.46		
0.35	56.90	6.91		
0.39	54.50	3.75		
0.43	52.70	6.32		
0.47	49.30	5.71		
0.51	45.30	4.61	39.30	1.00
0.55	41.90	1.13	40.10	2.38
0.59			41.10	3.72
0.63			42.70	2.41
0.67			43.7	3.28

Table XXX continued:

SPEED	EFFICIENCY (%)			
	WALK		RUN	
	MEAN	SD	MEAN	SD
Relative (ll/s)				
1.24	54.5	8.56		
1.48	59.8	7.68		
1.72	57.5	6.28		
1.96	55	6.33		
2.20	51.4	5.08		
2.44	47.8	3.01	38.6	3.14
2.68	40.4	2.33	42.7	7.42
2.92			42.6	3.57
3.16			43.1	3.72
Relative (fl/s)				
4.6	59.48	7.54		
5.6	56.55	5.95		
6.6	54.69	5.53		
7.6	50.35	5.16		
8.6	42.98	2.56	38.8	3.90
9.6			41.84	3.44
10.6			43.40	3.33
11.6			44.29	3.60

Table XXXI: Statistical summary of Ratings of Perceived Exertion (RPE) at various velocities.

SPEED	RPE			
	WALK		RUN	
	MEAN	SD	MEAN	SD
Absolute (km/hr)				
4	7.36	0.81		
5	8.09	0.94		
6	8.82	1.33		
6.5	8.91	1.38		
7	9.82	1.89		
7.5	10.22	2.49	10.0	
8	10.0	1.58	10.16	0.98
8.5	10.5	0.71	10.1	1.27
9			10.18	1.4
10			10.81	1.08
Relative (st/s)				
0.6	7.09	0.7		
0.7	7.36	0.92		
0.8	8.18	0.75		
0.9	8.64	1.03		
1.0	9.00	1.34		
1.1	10.18	1.4		
1.2	10.33	1.63	9.20	0.84
1.3	11.3	2.31	9.75	1.49
1.4			10.18	1.08
1.5			10.8	1.47
1.6			10.8	1.40
Relative ($v/\sqrt{gh}$)				
0.27	7.45	0.82		
0.31	7.36	0.92		
0.35	8.36	1.12		
0.39	8.82	1.08		
0.43	9.18	0.98		
0.47	10.1	1.81		
0.51	10.75	1.75	9.67	0.58
0.55	9.5	0.71	10.2	0.83
0.59			10.45	1.29
0.63			10.82	1.33
0.67			10.91	1.22

Table XXXI continued:

SPEED	RPE			
	WALK		RUN	
	MEAN	SD	MEAN	SD
Relative (ll/s)				
1.24	7.1	0.74		
1.48	7.5	0.71		
1.72	8.0	1.05		
1.96	8.7	1.7		
2.20	9.5	1.4		
2.44	10.33	1.63	10.25	0.95
2.68	9.5	2.12	10.3	1.04
2.92			10.3	1.25
3.16			10.4	1.17
Relative (fl/s)				
4.6	7.27	0.79		
5.6	8.0	1.0		
6.6	8.91	0.94		
7.6	9.6	2.17		
8.6	11.3	1.71	9.85	1.46
9.6			10.2	1.17
10.6			10.45	1.29
11.6			11.18	1.6

Table XXXII: Statistical summary of the respiratory exchange ratio (R) at various velocities.

SPEED	RESPIRATORY EXCHANGE RATIO			
	WALK		RUN	
	MEAN	SD	MEAN	SD
Absolute (km/hr)				
4	.85	.06		
5	.84	.06		
6	.83	.06		
6.5	.84	.04		
7	.84	.02		
7.5	.87	.07	.88	.04
8	.84	.05	.87	.05
8.5	.89		.87	.05
9			.85	.07
10			.86	.05
Relative (st/s)				
0.6	.82	.06		
0.7	.84	.06		
0.8	.85	.05		
0.9	.83	.05		
1.0	.84	.04		
1.1	.87	.05		
1.2	.87	.06	.88	.06
1.3	.91	.07	.85	.06
1.4			.87	.05
1.5			.87	.04
1.6			.89	.05
Relative ($v/\sqrt{gh}$)				
0.27	.85	.03		
0.31	.87	.05		
0.35	.83	.03		
0.39	.82	.06		
0.43	.82	.04		
0.47	.85	.04		
0.51	.87	.02	.88	.05
0.55	.91	.007	.89	.05
0.59			.87	.05
0.63			.89	.04
0.67			.86	.05

Table XXXII continued:

SPEED	RESPIRATORY EXCHANGE RATIO			
	WALK		RUN	
	MEAN	SD	MEAN	SD
Relative (ll/s)				
1.24	.86	.06		
1.48	.86	.07		
1.72	.82	.05		
1.96	.85	.05		
2.20	.84	.05		
2.48	.88	.04	.88	.02
2.68	.88		.85	.05
2.92			.84	.03
3.16			.88	.03
Relative (fl/s)				
4.6	.84	.05		
5.6	.84	.05		
6.6	.84	.05		
7.6	.84	.04		
8.6	.88	.02	.84	.04
9.6			.85	.05
10.6			.89	.05
11.6			.89	.03

Table XXXIII: Statistical summary of % $\dot{V}O_2$ max at various velocities.

SPEED	%$\dot{V}O_2$ max			
	WALK		RUN	
	MEAN	SD	MEAN	SD
Absolute (km/hr)				
4	17.95	2.32		
5	21.31	2.90		
6	26.54	3.39		
6.5	29.46	3.86		
7	33.16	3.91		
7.5	38.04	5.02	42.75	3.18
8	43.42	5.49	45.90	3.61
8.5	45.70	2.12	49.47	4.86
9			50.87	5.16
10			55.26	4.19
Relative (st/s)				
0.6	18.50	2.42		
0.7	20.34	2.88		
0.8	22.08	2.39		
0.9	26.25	3.62		
1.0	28.02	3.71		
1.1	34.50	5.18		
1.2	40.53	5.37	44.04	4.15
1.3	44.50	3.30	48.38	4.58
1.4			49.87	5.98
1.5			52.24	5.75
1.6			55.75	5.29
Relative (v/$\sqrt{gh}$)				
0.27	18.56	2.66		
0.31	20.36	1.99		
0.35	23.08	3.05		
0.39	26.35	3.17		
0.43	29.85	4.24		
0.47	34.31	5.18		
0.51	40.06	5.28	42.83	5.56
0.55	41.05	0.92	48.08	3.78
0.59			50.45	5.16
0.63			52.09	5.05
0.67			55.03	5.97

Table XXXIII continued:

SPEED	$\%\dot{V}O_2$ max			
	WALK		RUN	
	MEAN	SD	MEAN	SD
Relative (ll/s)				
1.24	18.52	2.93		
1.48	20.03	3.30		
1.72	23.69	3.79		
1.96	27.51	5.19		
2.20	32.37	5.54		
2.44	36.18	6.22	48.68	1.89
2.68	41.80	4.24	48.15	7.38
2.92			50.69	6.10
3.16			54.53	7.89
Relative (fl/s)				
4.6	18.95	2.32		
5.6	23.25	3.42		
6.6	27.74	4.12		
7.6	34.95	7.22		
8.6	43.55	6.65	48.38	5.93
9.6			50.71	5.76
10.6			54.84	5.73
11.6			59.05	7.54