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THE CONTRIBUTION OF PSYCHOGENIC FACTORS LIMITING PROLONGED WORK PERFORMED AT DIFFERENT RELATIVE INTENSITIES

BY

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ABSTRACT

This study investigated the physiological and psychological limitations to prolonged work performed at different relative intensities, through the use of an eclectic integrative methodology.

Ten young male caucasian subjects (mean VO_2 max. 60,0 $ml.kg^{-1}.min^{-1} \pm$ 7,9) were randomly exposed to treadmill runs at each of four relative intensities, namely 55%, 65%, 75% and 85% of VO_2 maximum, with the instruction to run to the point of subjective discomfort at which they were no longer willing to continue. Physiological measures of oxygen consumption (VO_2), heart rate (HR), respiratory exchange ratio (R), minute ventilation volume (Vi), breathing frequency (Vf), tidal volume (Vt) and psychological measures of Ratings of Perceived Exertion (RPE), Perceived Thermal Comfort (PTC), Perceived Pain and Perceived Fatigue were recorded throughout the protocol. The relative intensity was held constant by slight decreases in treadmill speed as subjects fatigued, and through feedback from an on-line oxygen consumption computer-aided data acquisition system.

Significant increases in both physiological and psychological measures occurred with increases in relative intensity ($p < 0,05$). HR and Vf increased over time ($p < 0,05$) whilst R and Vt decreased over time ($p < 0,05$). All psychological ratings increased in intensity over time ($p < 0,05$).

Mean endurance times to exhaustion were 243 minutes $\pm$ 70 at 55% relative intensity, 159 minutes $\pm$37 at 65%, 96 minutes $\pm$25 at 75 % and 23 minutes $\pm$ 8 at 85%, being within the range reported by earlier researchers.

A regression equation for prediction of endurance time given a known relative intensity was developed for this sample:

$$\% VO_2 \text{ max.} = 117,8 + (-10,6 \times LN (time)) \text{ (where } r = -0,91)$$

Convergence rankings indicate the greater contribution of local factors in the overall gestalt of perceived exertion, pain and fatigue, with biomechanical limitations to prolonged work (running) strongly implicated. High intercorrelations between psychological rating scales suggest the use of the scale considered most applicable to the task at hand and the psychological response measure required. A coefficient of multiple correlation of 0,94 established the close interrelationship amongst the physiological and psychological parameters measured.

Pre- and post-test Fatigue Cluster Analysis questionnaires indicated that the most important clusters contributing toward the sensation of fatigue and subsequent decision to cease activity were Task Aversion and General Fatigue (r = 0,96), followed by Leg Fatigue and Thirst.

Motivation, the task at hand and an attainable goal appear to be important considerations in prolonged work performance. Relative intensity appears a valid tool for use in prolonged work studies due to its high predictive capacity for endurance performance times (r =- 0,91). It is concluded that workloads considerably below 55% of maximal aerobic capacity are indicated as acceptable workloads for an 8 hour working day.

DEDICATION

DEDICATED TO MY WIFE, RUTH,

AND DAUGHTERS CORAL AND CLAIRE

"THE GREAT THING IN THIS WORLD IS NOT SO MUCH WHERE WE STAND AS IN WHAT DIRECTION WE ARE MOVING." (OLIVER WENDELL HOLMES).

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FINANCIAL ASSISTANCE RENDERED BY THE HUMAN SCIENCES RESEARCH COUNCIL TOWARDS THE COST OF THIS RESEARCH IS HEREBY ACKNOWLEDGED. OPINIONS EXPRESSED OR CONCLUSIONS ARRIVED AT ARE THOSE OF THE AUTHOR AND ARE NOT TO BE REGARDED AS THOSE OF THE HUMAN SCIENCES RESEARCH COUNCIL.

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CHAPTER 1

INTRODUCTION

South Africa today, despite rapid technological advancement, continues to manifest itself as a land of contrast with first and third world societies existing side-by-side. To the ergonomist the developing country presents itself as diverse job types open to study, spanning the spectrum from hard manual and blue collar activity to sedentary white collar functions. To the human movement specialist, the kaleidoscope of man-in-motion, whether in the workplace or on the sportsfield suggests an exciting and challenging research forum.

The fast moving era of technological change, mechanisation, specialistion, robotisation and computerisation so aptly referred to by Toffler (1970) as Future Shock may create the impression that physical work forms belong in the past. The cybophobics among us can take heart - physical work activity exists, and will continue to do so for some considerable time, even in fully developed countries. The following job types and their concomitant energy costs confirm this. Kukkonen-Harjula et al (1984) reported oxygen consumptions corresponding to $49 \pm 7\%$ of maximum in lumberjacks logging with power saws in Finland, a developed country. In England, Legg and Myles (1981) using a psychophysiological technique reported that soldiers engaged in a repetitive lifting task self-selected mean oxygen costs of 21% of maximum, a figure they agree, is low in comparison to other studies of its kind.

Canadian commercial diver's energy costs ranged from 30 to 70% of maximum during a variety of underwater tasks (Bell and Wright 1979). Consultation of Passmore and Durnin's (1955) work on energy expenditures for varying tasks illustrates further the great many physical occupations still in existance today. An example of physical work from the sporting world is the average 50% of maximum oxygen uptake reported in ultra-marathoners over a 24 hour period by Davies and Thompson (1979).

DEFINING THE TOPIC

Whilst the energy cost of varying activities is well researched and accounted for (Astrand and Rodahl 1977; McArdle *et al* 1981; Passmore and Durnin 1955) the optimal level of energy expenditure for prolonged work as well as the physiological and psychological limitations to prolonged work remain an enigma. The question of individual differences with regard to sustaining prolonged endurance-type work appeared to warrant further investigation.

Consider the following Aesop fable and it's implications:

> "Two frogs fell into a milk pail. One frog, thinking there was no salvation, drowned, (he gave in to the inevitable). The other frog, because of some inner quality, decided to keep swimming in the milk. He kept beating and beating his legs until eventually he found himself floating on a pad of butter". (From Forgus *et al* 1979).

Interesting questions arise when considering the prolonged physical work output capability of man. For example, for what duration can varying intensities be sustained without deleterious effects? What are the relative contributions of psychogenic effects leading to work stoppage. Is there a difference in the relative contribution of psychological factors at different intensities of physical work i.e. a differential intensity of psychological response? Is the relationship between the physiological limit and psychological limit constant for different intensities? Can a prediction equation for the intensity/duration relationship be established i.e. can the duration of activity at a particular intensity be predicted?

A number of researchers have made attempts to answer some of the above questions, each approaching the problem from a particular perspective. Investigators appear to have reached consensus in so far as "endurance in prolonged physical activites is related to the aerobic work capacity of the individual" (Deivanayagam and Ayoub 1979). As early as 1962 Wyndham et al were of the opinion that "an objective and sound physiological basis for the optimal level of work would be the level of oxygen consumption, compared with the maximal oxygen intake". Saha et al (1979) have expanded this to refer to the term - Acceptable Workload (AWL).

> "The acceptable workload (AWL) represents that level of physical activity which can be sustained by an individual in an 8 hour working day in a physiologically steady state and which will not cause fatigue or discomfort and it is generally expressed in terms of 'relative load' (RL) i.e. the percentage of maximum aerobic power (VO_2 max) spent while performing a task. Muller (1953) termed it 'endurance limit' (EL)."

Wyndham et al (1962) examined the physiological basis for the "optimum" level of energy expenditure in black mineworkers. They found that men who were highly trained could work to a level of 55% of their maximal oxygen uptakes without anaerobic metabolism occurring in the body. Saha et al (1979) reported that a 35% relative load (RL), i.e. 35% of VO_2 max., could be regarded as an acceptable workload (AWL) for sustained physical activity in Indian workers. Astrand and Rodahl (1977) suggest that 50% of VO_2 max as an intensity, may be sustained for up to eight hours but results in fatigue. Evans _et al_ (1980) have indicated that "the best predictor of speed for self-paced hard work of males and females for 1-2 hours in duration appears to be based on 45% of maximal aerobic power." Myles _et al_ (1979) has suggested that well-trained subjects exercising at self-paced intensities for prolonged periods of time (up to 8 $hours.day^{-1}$) may reduce their energy expenditure to below 40% of maximum. Bonjer (1968) suggests a ratio of 3:1 between VO_2 max. and the acceptable average oxygen uptake over 8,5 hours. Astrand (1967) observed that building industry workers left to themselves exert about 40% of max. over the working day.

In summary of the above it appears that a range of 35 to 55% of maximum VO_2 is reported as acceptable for prolonged work. The majority of these studies have been rather one-sided in their approach i.e. a purely physiological method was adopted in reaching conclusions.

CONCEPTUAL BASIS OF PRESENT STUDY

The modus operandi of the present study has it's genesis staunchly linked to the Human Kinetics Conceptual Model for Studying Human Movement, of Charteris _et al_ (1976) in which four fundamental propositions apply:

1) human movement must be comprehended in a dimension of time;
2) movement implies interaction of the moving object with the physical world through which it is moving;
3) movement, in the human context implies a psycho-social dimension without which the essential humanity of the moving

organism is incomprehensible;

4) human movement, as a focus of attention is best elucidated by an interdisciplinary holistic approach (Charteris et al 1976).

Particular attention in the present study is levelled at the above propositions 3 and 4. It is the author's contention that a Gestaltist approach is the preferred route to an adequate elucidation and understanding of man-in-motion. In this study the focus is on prolonged physical work and the physiological and psychological limitations pertaining thereto.

COMPLEXITY OF SUBJECT MATTER

It is considered appropriate at this point to illustrate further the complexity of the subject matter to be dealt with by expanding upon the holistic theme outlined above. For example, Broadbent (1979) in his paper entitled "Is a fatigue test now possible?" states that any hope of measuring the effect of prolonged work must lie in studying the organisation of the whole behaviour and not in looking at particular parts of it. With regard to fatigue he is in agreement with Grandjean (1969) who states that "at present there is no practical physiological or psychological objective test of fatigue which can be used in industry with success." However, Broadbent (1979) maintains that ergonomists have a great deal to offer to the study of the chronic effects of work. He points out the socio-technological nature of modern industry and the importance of the cognitive component in job performance, and that "a little more research effort will produce more satisfactory indicators of the chronic state of the person."

Combs et al (1976) in their humanistic approach to the study of persons state that we need to see our body structure in better perspective, as one of a number of factors, rather than the sole or principle determinant of capacity. By this is meant that behaviour and functioning are always a function of the whole perceptual field at any moment and the perceptions available to a person in his perceptual field will be a product of these factors. It appears self-evident then, that any researcher wishing to make headway in this field, must take into account the cognitive and perceptual components of man-in-motion.

The nature of fatigue is as elusive today as it was in the early 1930's when American scientists initiated some of the original research into this phenomenon (Noakes and McArthur 1985). Blum and Naylor (1968) expand on the complex nature of fatigue by stating that investigators working in this area are in general disagreement as to it's nature and "many are perplexed by the diverse character of the concept." They cite Dill (1933) as reporting "that fatigue is not an entity but merely a convenient word to describe a variety of phenomena." It appears as if further research into these phenomena is highly justified, even today. In support of this Deivanayagam and Ayoub (1979) state that knowledge about a workers "endurance" has many useful applications such as job design, scheduling, personnel selection, safety and quality control.

In considering related phenomena Blum and Naylor (1968) state that if fatigue is regarded as elusive and difficult to measure, mental fatigue must be regarded as much more so. They cite the example of college students, who after a lengthy assignment often insist they cannot read another page, are exhausted and must go to bed. If at that particular moment the telephone rings and an attractive date is in the offing, the fatigue caused by the "strenuous" mental activity becomes a thing of the past. The question is asked - "was there any mental fatigue in the first place?" Undoubtedly, the major component of fatigue here is attitudinal, and this factor may well be at play in physiological fatigue as well. The psychological component cannot be overlooked.

Another phenomenon related to fatigue is monotony or boredom. It's nature appears to be characterised by the perceptions and response of the individual rather than the nature of the job itself (Blum and Naylor 1968). This is yet another factor to be considered and may involve the effect of music and rhythm on physical performance as examined by Anshel and Marisi (1978).

A related factor not to be overlooked is personality. It has been suggested that persisting at a task is a personality characteristic to a certain extent (Heckhausen 1967). Eysenck (1973) is on record as stating that pain tolerance is positively related to extroversion, a personality trait. Ladouceur and Carrier (1983) have demonstrated the cognitive component involved in pain tolerance. Thus personality and cognitive style should not be overlooked in any examination of prolonged work limitations.

If personality is to be regarded as important then so too is the question of motivation. To illustrate, theories of work motivation should:

1) account for the phenomenon of voluntary behaviour being initiated;

2) explain how behaviour is chanelled in a particular direction; and 3) account for the maintenance of work-related behaviour (Steers and Porter 1979). Morgan's (1970) work on the influence of motivation on physical work capacity and performance illustrates another dimension. He reminds us of the unique examples of individuals placed by chance in a situation of extreme stress, and where they have performed superhuman feats.

The above examples serve to outline the complex nature of limiting variables in prolonged work. Two further subject areas reiterate this point. Shephard (1984) illustrates the functional importance, interactions with exercise and changes of physiology and performance, that sleep and biorhythms have. Secondly, from a physiological point of view it is self-evident that cardiovascular responses are of importance in this study - yet clearly the question of anaerobic threshold (Astrand and Rodahl 1977, MacDougall 1977, Withers 1977, Skinner and McClellan 1980, Graham 1978 amongst others) must form an integral part of a study related to prolonged physical work at different intensities.

If the complexity of the subject matter appears to have been belaboured at all, it is merely to give the reader a clear indication of enormity of the task ahead; which represents an attempt to elucidate the complex nature of prolonged work and the limitations applicable thereto.

PURPOSE OF THE STUDY

The purpose of the study was to investigate the physiological and psychological limitations to prolonged work performed at different relative intensities. In so doing, a number of factors limiting prolonged work, both physiological and psychological were examined in an attempt to answer the simple question - what makes man stop working? More specifically, the investigation sought to answer the question of why man elects to cease physical activity at a specific point in time.

Another aim of the study was to elucidate inter-subject differences with regard to the factors limiting prolonged work, as well as the possible intra-subject variance over time in this regard.

HYPOTHESES

The following hypotheses were adopted:

1) That there is no difference in the factors limiting prolonged work performed at the relative intensities 55%, 65%, 75% and 85% of maximal aerobic capacity.
2) That there is no difference in the physiological and psychological responses of subjects at 25%, 50%, 75% and 100% of their endurance time at each of the relative intensities.

STATISTICAL HYPOTHESES

1) HO: $u_{55} = u_{65} = u_{75} = u_{85}$

   HA: $u_{55} \neq u_{65} \neq u_{75} \neq u_{85}$

2) HO: $u_{25} = u_{50} = u_{75} = u_{100}$

   HA: $u_{25} \neq u_{50} \neq u_{75} \neq u_{100}$

where: u_{55} to u_{85} = the means of the population responses to relative intensities of 55%, 65%, 75% and 85% of VO_2 maximum.

where: u_{25} to u_{100} = The means of the population response at 25%, 50%, 75% and 100% of endurance time.

DELIMITATIONS

The study was confined to work upon the treadmill, specifically running on the level at the predetermined relative intensities. Physiological parameters measured were confined to heart rate (HR), oxygen consumption (VO_2), respiratory quotient (R), ventilation frequency (Vf), ventilation minute volume (Vi), tidal volume (Vt) blood pressure (BP), body temperature changes and sweat rate determination.

Psychological measures were confined to a baseline determination of extroversion (E) and neuroticism (N); Ratings of Perceived Exertion (RPE), ratings of Perceived Thermal Comfort (PTC), ratings of Perceived Pain (PP), and Perceptions of Fatigue (PF). Pre- and post-test treatment questionnaires aimed at elucidating possible psycho-social factors influencing behaviour patterns demonstrated during the treatment conditions.

LIMITATIONS

The number (10) of subjects may be a limitation in that the data is insufficient to generate any conclusive results with respect to trend and factor analysis. The low subject numbers may be insufficient to offset the inter- and intra-subject variance.

Subjects worked at varying times during the day and were exposed to differing environmental conditions. Diurnal variations coupled with mild environmental changes may effect performance responses and subsequent endurance times.

No physiological recovery data was collected. Measures such as recovery heart rate can be clear indicators of fatigue (Brouha 1953).

No rectal probes were used to collect core temperatures in an attempt to minimise possible negative influences whilst subjects worked. The oral temperatures measured are a limitation in that they differ from core temperatures, resulting in spurious derived Mean Body Temperatures.

Relative Intensities at the lower end of the range i.e. 35 and 45% of maximum were not examined. A clearer overall picture of endurance responses may have emerged if they had been examined.

CHAPTER 2

REVIEW OF LITERATURE

Any academic enquiry can be approached by use of the scientific and/or the philosophical method (Best 1978). Substantiation, according to Best, can be divided into the empirical and the logical. The important contribution of philosophy to human movement is in criticism and clarification, by tracing the logical consequences of what is said, and thereby uncovering disguised nonsense.

Best's (1978) assertion that philosophical examination may reveal that cherised beliefs have to be reconsidered, modified, or even abandoned - an uncomfortable and disconcerting process - is illustrated in Charteris et al (1976) Human Kinetics Conceptual Model for studying Human Movement. In terms of these authors' Centre - M focus (human movement focus) research designs need to be slanted away from the elucidation of some parent discipline and aimed toward the elucidation of the Centre - M focus. They state that:

> "the scholar addressing a human movement problem must use primarily his academic adaptability and only secondarily the tools of his respective peripheral cognate disciplinary trade to answer man-in-motion questions, not, for example, physiological or sociological man-centered questions."

Clearly, Charteris et al (1976) advocate the use of an eclectic, integrative methodology in academic enquiry related to human movement, and this is in accordance with the logico-empirical approach of Best

(1978).

In his writing on the measurement of human workload Weiner (1982) refers to the bodily response to external stress as being manifest in "linked and concurrent physiological, psychological and emotional reactions, since the body responds through an integrated functional framework." See Figure 1. Thus stressor stimuli evolve appropriate responses in the human reactive system of three domains - physiological, psychological and affective, through appropriate pathways. Affector responses are mediated not only at the autonomic but cognitive and emotional levels as well.

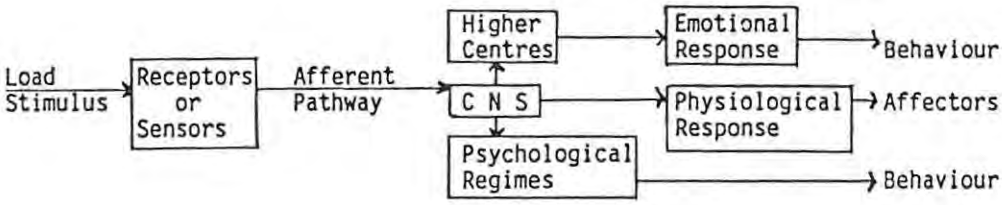

Figure 1 : General Stress Response
(From : Weiner 1982)

When an external load is imposed upon any of the human physiological regulatory systems they counteract or offer "resistance" to the load (Weiner 1982). By virtue of their response the systems are said to be "stressed", and the intensity of the response provides measures of the intensity of the external load which the body is withstanding. Stress responses can be measured in a number of ways, for example as in energy usage as rate of consumption, or electromyography recording contractile activity, or physiological stress in terms of heat loss. Physiological and psycho-physiological responses to external loadings can be regarded as "internal" stress corresponding to the "external" stress load or stressors (Weiner 1982). This concurs with earlier statements by Brouha (1953). Stress responses are active, adaptive or adjustive responses to external stress.

Weiner (1982) defines strain as constituting those changes indicative of homeostatic disturbance which appear when stress responses become insufficient to cope with the imposed load. While stress responses continue to be evoked, they are accompanied by disturbance or dislocation of steady or equilibrium state. Selye (1956) referred to a pattern of non specific responses - the General Adaptation Syndrome - which includes a sequence of alarm, resistance, and exhaustion that is characterised by certain physical events.

In his reference to the problem of fatigue Leplat (1978) poses the question as to what extent prolonged working modifies the state of the operator. Several factors need to be considered in the analysis of factors determining work-load, amongst which are those related to the requirements of the task, anatomical-physiological factors, physical surroundings, as well as psychological and social factors. Thus Leplat (1978), Charteris et al (1976) and Best (1978) all appear to be advocating one central theme, that the investigation of any phenomenon (in this instance that of prolonged work) must be approached from a holistic gestaltist methodology. These authors concur with Renshaw (1975) who declares that human movement studies as an area of academic concern, is a good example of a situation in which a number of specialists with their distinctive contributions can work together as members of a co-operative enterprise. He suggests that human movement can be described, analysed and explained adequately only through philosophy, the physical sciences and social sciences. He warns that to engage in empirical enquiry without conscious awareness of philosophical issues, would be to pursue a path which might be considered unexamined and misguided.

Muscular work in industry may be classified into three general types. The first is heavy muscular work too strenuous for a steady, continuous rate to be maintained. The second is that of moderately heavy work that is continuous and in which the rate of expenditure of effort is much lower than the first type and is balanced by rate of recovery. The third is light work involving small amounts of energy expenditure but which may induce postural strain causing fatigue (Crowden 1932). These three classifications appear to be convenient for discussion of the implications for man-in-motion as they are dealt with similarly by the work physiologists Astrand and Rodahl (1977) and McArdle et al (1981).

What then are the movement responses at low, medium and high intensity work?

High intensity work rates result in considerable insult to the cardio-vascular system. After short initial response lags the heart rate reaches near maximum and is perceived as a pounding sensation. Highly accelerated breathing rates cause burning sensations in the chest. Lightheadedness and dizziness are experienced along with muscle fatigue, muscle cramping, twitching, spasms and/or pain. This leads to faulty neuromuscular patterns of ataxic gait, unco-ordinated movement, unsteadiness, inability to keep in rhthym, with finally exhaustion leading to collapse. Autokinesis has been reported to occur (Jain 1983) as well as performance and learning impairment (Carron 1972).

At moderately high intensities of longer duration objective and subjective responses involve the perception of increased body temperatures, redness of the skin, thirst, dry mouth and discomfort (Weiser et al 1973), leading to irritating aches and pains as well as the occurrence of gradually increasing breathing rates and elevated heart rate (Astrand and Rodahl 1977). The end result is as described with high intensity activity. Subjects become weak, muscles stiffen leading to poor co-ordination, apparent mental confusion and final cessation of activity.

With prolonged lower intensities marked sensations of weariness, general bodily fatigue, visual, mental, nervous and chronic fatigue arise. Monotony may lead to general inattention, lethargy, stupor and visual disturbances (Grandjean 1980). Again, disturbances of regulation and co-ordination become apparent (Simonson 1971, Bates et al 1977).

FACTORS INFLUENCING WORK OUTPUT AND DURATION

There appears to be agreement amongst researchers with regard to the difficulty in determining the "optimal" work-load for prolonged durations of physical work. It has not been possible to find a physiological parameter which would be valid as a criterion for the definition of the highest tolerable load in prolonged exercise (Saltin and Stenberg 1964). Early attempts to formulate cycles of work were based on the absolute metabolic cost in order to avoid undue fatigue during physically demanding tasks (Krajewski et al 1979). More recently the approach to the design of work and rest periods has been to use the relative intensity of the metabolic cost, i.e. the oxygen

(O_2) uptake (VO_2) as a fraction of the maximal oxygen capacity (VO_2 max.) (Wyndham et al 1962, Astrand 1967, Astrand and Rodahl 1970, Bonjer 1971, Saha et al 1979, Krajewski et al 1979). Krajewski et al (1979) refer to the relative O_2 cost as the fraction of VO_2 max or $_fVO_2$ max.

There are limitations to looking at VO_2 max. in isolation. The burden on the circulatory and respiratory systems cannot be properly deduced from O_2 consumption studies alone, and the relevance of VO_2 as a measure of functional load is rather restricted, as is the relevance of a HR measure when seen in isolation (Burger 1969). For example, according to Costill et al (1973) VO_2 max. alone does not adequately predict a winning performance among runners with similar aerobic capacities. Studies that have suggested success is dependant to a smaller degree on running economy and $_fVO_2$ failed to relate laboratory data to comparable running performances. When considered as a percentage of maximal aerobic power oxygen consumption was found to be highly related to distance running performance with a correlation of 0.94 (Costill et al 1973). At running speeds above 70% of max. VO_2, faster runners were found to accumulate less blood lactate than slower runners at similar speeds and relative percentages of their aerobic capacities. These findings suggest that success in distance running is dependent on the economical utilization of a highly developed aerobic capacity and the ability to employ a large fraction of that capacity with a minimal accumulation of lactic acid.

These findings and the effects of training are confirmed by Bransford and Howley (1977) who state that trained runners are more economical in running than untrained. They cite training, natural selection, efficient mechanical movement and a more efficient oxidative energy supply as possible explanations for the higher economy. There appears to be a linear relationship between VO_2 and the speed of treadmill running for a specific range of speeds, the relationship holding regardless of sex or whether trained or untrained. However, differences in O_2 cost of running at any measured speed were demonstrated between trained and untrained individuals.

The steady-state running velocity at which lactate begins to accumulate in the blood (the blood lactate threshold or LT) has been observed to correlate highly with distance running performance, r = 0,92 to 0,99 for 8 to 42 km (Hagberg and Coyle 1983). Physiologically, the velocity at lactate threshold is a function of the O_2 consumption at lactate threshold (VO_2 at LT) and the velocity achieved at that VO_2 (submaximal economy). It is suggested that performance is related more to the ability to expend higher levels of energy without accumulating lactate in the blood than it is to the economic conversion of that energy into running velocity.

The dynamic evaluation of O_2 consumption in exercise tests serves two purposes: 1) evaluation of exercise carried out in steady-state conditions; and 2) oxygen intake assessment for rating of performance efficiency. In an exercise test the O_2 consumption curve may show one of three patterns: 1) real steady-state; 2) apparent steady-state; 3) non-steady-state (ascending pattern) (Balanescu 1979). Steady-state is defined by McArdle et al (1981) as being the flat portion or plateau of the oxygen consumption curve (submaximal exercise). It appears more precise to talk of a steady-rate, as reflecting a balance between the energy required by the working muscles and the rate of adenosine triphosphate (ATP) production via aerobic metabolism; where O_2 consuming reactions supply the energy for exercise, and lactic acid accumulation is minimal.

Linear relationships between increased work rate and physiological parameters of metabolism such as heart rate, VO_2 and blood pressure exist up to a point (Astrand and Rodahl 1977, McArdle et al 1981). Monod and Scherrer (1965) found a linear relation between the total work done at each rate and its duration. The slope of this relation was termed the critical power and was found to represent the power output that a muscle group can maintain without exhaustion occurring. They expressed this linear relation in the equation: $W_{lim} = a + b T_{lim}$; where maximal work (w_{lim}) was thought to result from an energy reserve (a) and an energy reconstitution whose maximal rate was (b). Moritani et al (1981) extended this concept of critical power to whole-body exercise and their experimental results indicated that the maximal energy reconstituion rate (b) was correlated with the onset of anaerobic threshold (AT) as determined by the gas exchange method ($r = 0{,}92$ $p < 0{,}01$). In addition, the sum of a + b (energy reserve and maximum rate of energy reconstitution) was found to be highly correlated to VO_2 max. ($r = 0{,}95$ $p < 0{,}01$).

The concept of anaerobic threshold rests on the notion that during sufficiently heavy exercise the ability of the circulation to supply O_2 is inadequate to meet the metabolic requirements of the muscles. Therefore, the aerobic energy supply is supplemented from energy reserves available via anaerobic glycolysis with an obligatory lactate accumulation. It is argued that the physiological significance of anaerobic threshold and critical power are similar in that critical power appears to represent the maximal rate of work beyond which energy reserves will ultimately be depleted (Moritani et al 1981).

There appear to be three phases during the progressive transition from exercise of low intensity to maximal intensity exercise (Skinner and McClellan 1980). Figure 2 is a schematic representation of typical changes in blood lactate, heart rate and selected gas exchange parameters during progressive exercise from rest to maximum O_2 consumption. These authors propose a hypothetical model to explain what is occurring during the various phases, and in addition suggest a new terminology. (See Table I). Of significance for prolonged endurance-type work is the fact that individuals who are endurance trained have higher percentages of type I fibres (slow-twitch) and higher relative "aerobic threshold" (AER T) values. This, together with elevated free fatty acid (FFA) levels which inhibit glycolysis, raise relative AER T and reduce AER T blood lactate, appears to be an important factor in the individuals ability to sustain prolonged work (Skinner and McClellan 1980).

The specificity of training suggested by Skinner and McClellan (1980) supports the writing of Holloszy et al (1978) who state that all fibre types undergo adaptive increases in mitochondrial enzymes with specific training. However, the increase in mitochondrial enzymes in white muscle (type II fast twitch) is small in absolute terms when compared to the responses of red fibre types (type I slow twitch) when the training programme consists of prolonged continuous running at moderate speeds. For adaptive changes to occur in white muscle interval training with short bouts of work of sufficient intensity to recruit these white units is suggested.

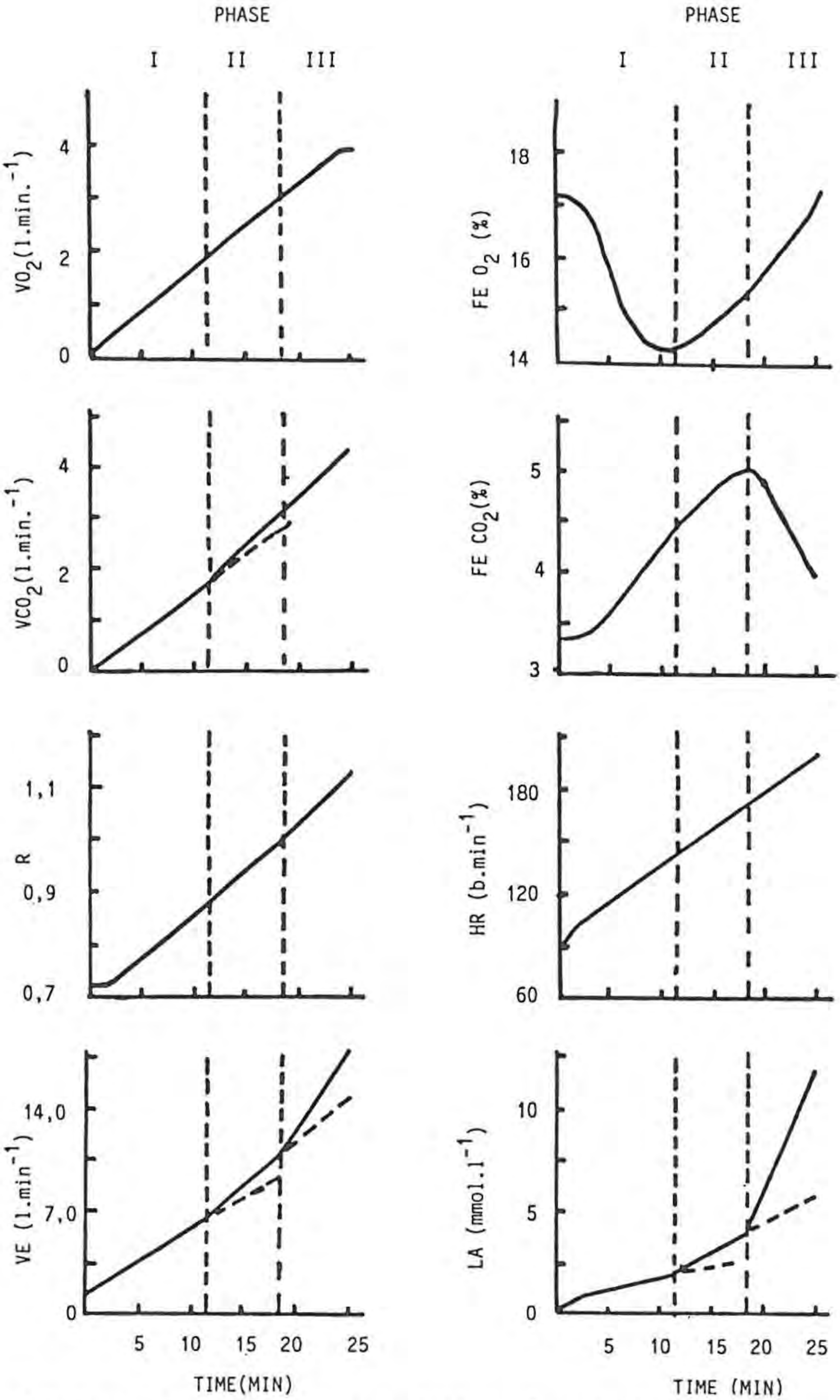

Figure 2 : Schematic representation of typical changes in blood lactate, heart rate and selected gas exchange parameters during progressive exercise from rest to maximal oxygen consumption. (From Skinner and McClellan 1980).

Table 1 : Hypothetical Model of Selected Characteristics of the Various Thresholds and Phases During Progressive Exercise from Rest to Maximal Oxygen Consumption (From Skinner and McClellan 1980)

	Rest	Phase I	Aerobic Threshold	Phase II	Anaerobic Threshold	Phase III	$\dot{V}O_2$ max
Predominant Type of Metabolism		Aerobic		→		Anaerobic	
Predominant Substrate		Fat>Carbohydrate		→		Carbohydrate>Fat	
Predominant Muscle Fiber Type		I		I, IIa		I, IIa, IIb	
Relative Intensity (% $\dot{V}O_2$max)			40–60		65–90		
Heart Rate ($b \cdot min^{-1}$)			130–150		160–180		
Blood Lactate ($mmol \cdot l^{-1}$)			~2		~4		

A number of authors have addressed the question of hormonal, enzyme and other metabolic responses which occur as a result of exercise of varying duration and intensity. In subjects exercising at 95% VO_2 max for 6 minutes each hour over 24 hours, resting plasma free fatty acid increased approximately threefold while blood glucose decreased from the fourth to sixteenth hour. Blood lactate and pyruvate levels were elevated after each exercise bout. Respiratory exchange ratios (R) declined steadily suggesting that over extended periods of time progressive carbohydrate (CHO) depletion occurs, with free fatty acid elevated indicating fat oxidation can play a significant role in energy liberation during near maximal work (Houston et al 1978). These authors report a significant decrease in body mass of the subjects, with the greatest decrement occurring over the first 12 hours.

Greater free fatty acid release occurs in fit subjects than in the unfit and serum insulin is depressed irrespective of fitness, after exercise for 20 minutes at 750 $kpm.min^{-1}$ on a cycle ergometer representing 35% and 55% $_fVO_2$ max. for the fit and unfit subjects respectively. When working at the same relative intensity blood glucose and glycerol were higher, plasma free fatty acid, blood ketones, plasma insulin and plasma growth hormone were lower in trained subjects. Blood lactate was little changed in the fit subjects but increased in the unfit (Sutton 1978).

Serum free fatty acids concentrations rise to a peak during exercise and then fall to a plateau 1-2 hours after exercise (Koeslag, et al 1980). Immunoreactive insulin concentrations in serum decline during exercise and remain low for some hours after. Marathon runners demonstrate marked increases in blood glucose during exercise but this falls before the end of a race once glycogen depletion occurs. Human growth hormone rises significantly to peak after glycogen depletion. Referring to blood ketone body concentrations these authors found that although untrained subjects demonstrate higher heart rate and blood lactate concentrations at the same workload as trained athletes, neither trained or untrained individuals demonstrated ketonaemia during intense or prolonged exercise. However, older subjects develop post-exercise ketonaemia reaching maximum about 3 hours after exercise. Ketone bodies are important regulators of fuel-homeostasis having anti-lipolytic, antiproteolytic and antiglycolytic actions during fuel crises involving carbohydrate metabolism. A high carbohydrate diet is indicated in the prevention of post-exercise ketonaemia (Koeslag et al 1980).

Referring to type I red skeletal muscle fibre Holloszy et al (1978) maintain that generally 65% or more of the O_2 consumption during heavy aerobic exercise is accounted for by carbohydrate as evidenced by respiratory quotients of 0,9 and above. During heavy aerobic exercise generally only about 10 or 20% of the oxidised carbohydate is derived from blood glucose i.e. liver glycogen. The point of exhaustion, when predetermined workloads can no longer be maintained, coincides with depletion of muscle glycogen stores. Further, the duration for which heavy aerobic work at a given work rate can be maintained appears to be determined by the concentration of glycogen in the muscles at the beginning of exercise. Very high carbohydrate diets as opposed to normal diets can result in an increase in muscle glycogen concentrations substantially above normal levels, with duration of exercise at a standard workload greatly enhanced. The reverse is also true, low carbohydrate diets result in submaximal muscle glycogen levels and impaired performance. In all cases at the point of exhaustion muscle glycogen stores are depleted. Thus it appears that muscle glycogen is indispensible for performance of heavy aerobic exercise (Holloszy et al 1978).

Heavy aerobic exercise cannot be continued after muscle glycogen stores are exhausted. However, at moderate aerobic levels i.e. 60% $_fVO_2$ max. or less, an individual can continue to exercise for a long time through oxidation of fat; which can provide essentially all the energy required by the working muscles during light to moderate aerobic activity. This illustrates the relative importance of free fatty acid and carbohydrate as substrates for energy production in skeletal muscle during prolonged aerobic exercise (Holloszy et al 1978). Of significance is the fact that trained individuals have a greater capacity for fat oxidation, and derive more energy therefrom than from carbohydrate at the same submaximal level of work and VO_2 in comparison to the untrained. Consequently, men deplete their muscle glycogen stores less rapidly when trained than when untrained. Of note is that from 10 to 45% of total energy can be derived from free fatty acid oxidation. Further, free fatty acid oxidation has an inhibitory effect on carbohydrate utilization (Holloszy et al 1978).

In support of the above Thomson et al (1978) refer to the selective glycogen depletion patterns in human skeletal muscle which occur in response to exercise of different kinds and intensities. At submaximal workloads the slow twitch (ST) type I fibres which are highly oxidative with low glycolytic capacity, are preferentially depleted; whereas at supramaximal loads the fast twitch (FT) fibres which have high glycolytic capacities (type IIB being the highest) and have oxidative capacities below type I, are preferentially depleted. To illustrate, at 85% VO_2 max. the recruitment of fibre types is in the order type I, IIA and then IIB. As the intensity increases above maximal load the order of depletion changes to type IIB first, then IIA followed by type I. They summarise by stating that in man three principle fibre types occur of varying oxidative capacity - type I > IIA > IIB; and that glycogen depletion in order of oxidative capacity in man is similar to that in animals such as the horse and rat.

Anticipation of a potentially stressful situation can alter the activity of the central nervous system (CNS). Plasma catecholamines increase over time during prolonged exercise at a constant workrate (Powers et al 1982), whilst the rate of norepinephrine (NE) excretion increases with increasing work loads (Howley 1976), and is related to the relative intensity of the work, the length of the exercise period and the state of training of the subject. The stimuli that could contribute to both increases in plasma epinephrine (E) and NE concentrations during exercise include hypoglycemia, dehydration, increased perceived exertion and rising core temperature (Powers et al 1982).

Laboratory and field studies have demonstrated that prolonged strenuous physical exertion induces a decline in serum magnesium levels (Cohen and Zimmerman 1978). The ominous portent of hypomagnesemia is that it is associated with neuromuscular dysfunction, post-exertional cramps and, on the basis of electrocardiographic (EKG) findings, disturbances in cardiac conductivity. The decline in serum magnesium levels is attributed to sweating, a net movement to the red cell interior and skeletal muscle uptake (Cohen and Zimmerman 1978). In addition to the above, these authors report an increase in potassium and serum sodium, and a decrease in chloride in runners during a standard marathon run. Hyperkalemia may be associated with abnormal EKG tracings at levels above 5,5 $mMol.l^{-1}$ and when coupled to hypoglycemia and/or heat injury can be fatal. A close correlation between changes in plasma volume and in total plasma sodium and chloride, provides evidence of good control of plasma levels of these electrolytes, their change being in proportion to the changes in plasma volume.

In subjects exercising at 5 submaximal treadmill intensities (30, 45, 60, 75 and 90% of VO_2 max.) red cell volume (RCV) remained constant being accounted for by decreases in plasma volume (PV) at all work levels. Plasma volume was a linear function of work intensity from rest through 60% max. VO_2 where a "break" point occurred, with the abrupt changes in PV occurring at about 65% to 70% of VO_2 max. - this point being coincident with significant lactate accumulation. This suggests an overlap of "critical points" such as the occurrence of anaerobic threshold simultaneous with the "break" point in plasma volume though this was not verified (Wilkerson _et al_ 1977).

Moore (1982) refers to the abnormally high amounts of endogenous morphine- like substances (endorphins) which have consistently been measured in the blood plasma of exercising subjects. Beta-endorphin has an opiate effect on the central nervous system, and acute and chronic positive mood changes have been said to occur with running and jogging (Markoff _et al_ 1982, Moore 1982). A consistent finding is the reduction in state anxiety (as opposed to trait anxiety) and a frequently stated idea, for which supporting evidence exists is that endorphins may serve as modulators of pain (Markhoff _et al_ 1982). Endorphins have been linked to such factors as appetite control, thermoregulation, antidiuresis, depression of ventilatory response to CO_2 and response to pain. Stimulation of beta-endorphins appears to be related to intensity of effort (Moore 1982). Beta-endorphin/beta-lipopropin values increased two to five times after running but the increase was statistically significant only after a 60% VO_2 max.run, and not after an 80% VO_2 max. run or after a self-paced run. Endorphin levels were related to perceived exertion ratings (Farrell _et al_ 1981). Endorphin-produced pain desensitization has been offered as a possible explanation for athletes' ability to ignore pain and injuries - causing themselves increased disability (Moore 1982).

The caloric expenditure averaged for the whole of the working time is limited by the physical working capacity which is dependent upon two things: 1) the capacity for O_2 uptake and 2) the capacity for food intake (Bink 1962). Clearly, muscle glycogen depletion occurs with prolonged exercise (Taylor _et al_ 1971, Green _et al_ 1978, Green 1978), and it has been demonstrated that muscle glycogen concentration is a major determinant of endurance-exercise capacity (Bergstrom _et al_ 1967, Holloszy _et al_ 1978). The effect of feeding on endurance performance is important. Foster _et al_ (1979) examined the effects of pre-exercise feedings and found that the ingestion of 75g of glucose 30 minutes prior to cycle rides at 80% VO_2 max. had the effect of depressing serum free fatty acid and reducing performance time by 19%. A liquid meal (10g protein, 12,5g fat and 15g carbohydrate) had no effect on exercise time to exhaustion at 80% VO_2 max. Neither treatment had an effect on performance at 100% VO_2 max. They conclude that glucose feedings before endurance exercise increase the rate of carbohydrate oxidation and impede the mobilization of free fatty acid, thereby reducing exercise time to exhaustion. They point out the contrast in their findings to other reports which indicate a beneficial effect of glucose ingestion either prior to or during prolonged exercise, but maintain that these benefits are to be seen only with prolonged mild (30-67% VO_2 max.) exercise as opposed to more severe exercise conditions. Low values for blood lactate at the end of 80% VO_2 max. endurance ride (≈4,3 mMol) suggest that muscle glycogen depletion was the major cause of fatigue. The finding of no effect by dietary variables on performance at 100% VO_2 max. was not surprising in that high intensity exercise is thought to be limited by disturbance of acid-base homeostasis attributable to the rapid production of hydrogen ions (H^+) from glycogenolysis (Foster _et al_ 1979).

During exercise carbohydrate and free fatty acid are generally regarded as the major energy sources. Protein has seldom been considered as an important energy source, based largely on 24 hour urinary nitrogen values. Recent determination of nitrogen sweat suggests that total nitrogen in sweat is, in fact, increased with exercise. Prolonged exercise substrate shifts and hormonal changes are in many ways analogous to a situation which occurs during starvation. Protein is thus considered to be utilised during exercise to a greater extent than is generally assumed (Lemon and Mullin 1980, Lemon and Nagle 1981). It is suggested by these authors that the practice of carbohydrate loading employed by endurance athletes may have a significant "protein sparing effect" during prolonged exercise.

During prolonged exercise, blood borne glucose and intra-muscular glycogen are the two major sources of carbohydate used by the active muscles. It has been demonstrated that muscle glycogen concentration is a major determinant of endurance-exercise capacity (Hargreaves et al 1984). Many investigators have therefore looked at increasing the availability of carbohydrate by ingestion during prolonged exercise in order to delay fatigue and improve endurance performance. Benade et al (1971) established that a mid-shift feed of sucrose in black mine workers caused an immediate rise in R values which persisted for the rest of the work period. Further, performance was improved as a result of the shift toward carbohydrate metabolism. Ivy et al (1983) determined that the ingestion of a glucose polymer supplement during walking at 45% VO_2 max. significantly increased the time to exhausation by 11,5% when compared to the control. The treatment is considered to offset hypoglycaemia, a primary limiting factor for low-intensity long duration exercise.

Hypoglycaemia occurs during exercise when the rate of glucose uptake from the blood exceeds the rate of glucose release from the liver. This is likely to occur when there is near total liver glycogen depletion. Evidence suggests that in activities lasting less than 3 to 4 hours at intensities of 85% VO_2 max. an individual will be limited by muscle glycogen depletion rather than by hypoglycemia - provided adequate prior carbohydrate loading is done. However, in contrast hypoglycemia is likely to be an important cause of exhaustion during exercise at 70 - 75% VO_2 max. lasting longer than four hours. The important implication here is that adequate carbohydrate replenishment must occur during such activities (Noakes and McArthur 1985). See Figure 3. Based in their experimental finding these

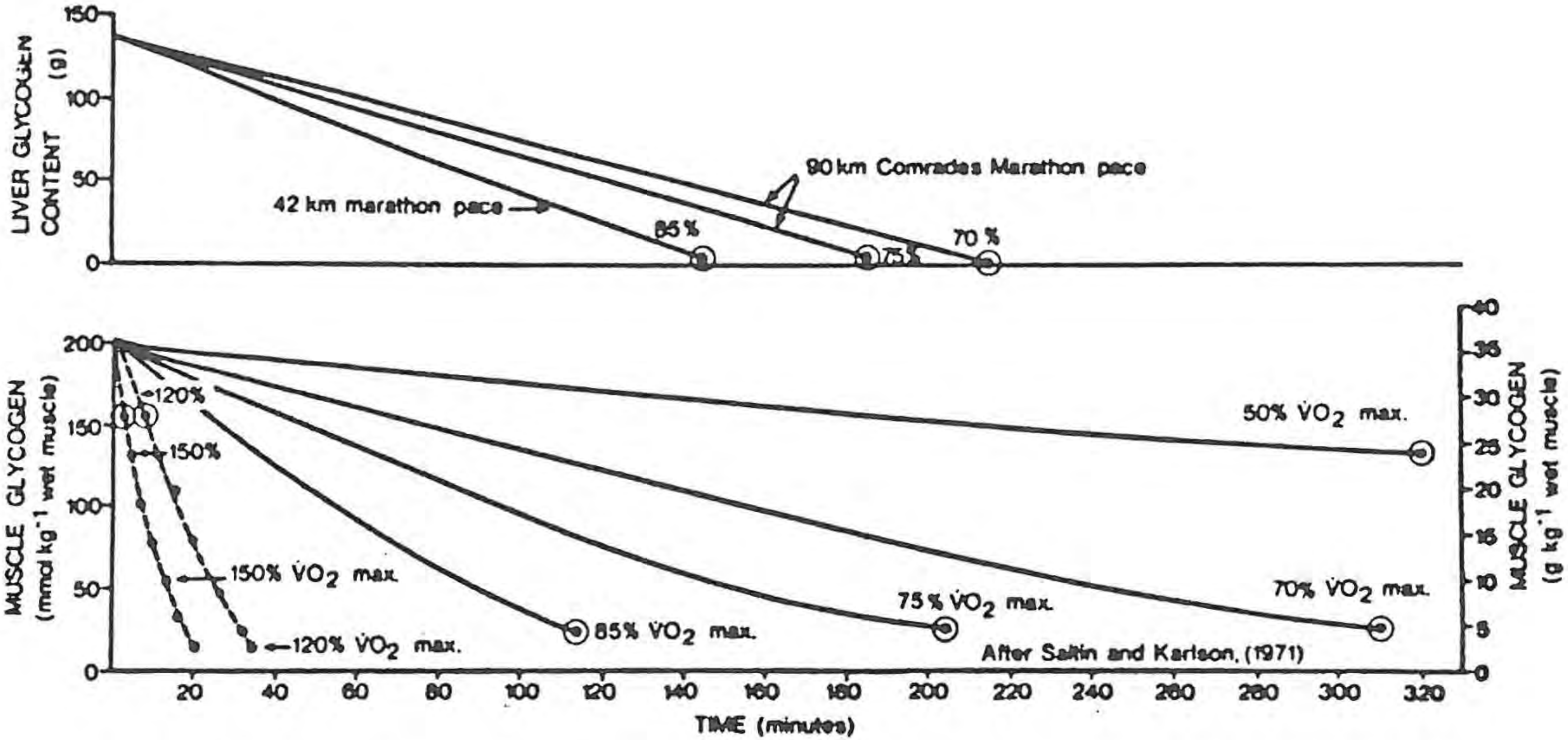

Figure 3: Calculated rates of liver (upper panel) and muscle glycogen (lower panel) utilisation during prolonged exercise at various exercise intensities suggest that at an exercise intensity of 70-75% VO_2 max. liver glycogen depletion leading to hypoglycaemia precedes muscle glycogen depletion. (From Noakes and McArthur 1985).

authors suggest that a 10% carbohydrate solution (either glucose lactate, sucrose, fructose or glucose polymer) drunk at the rate of 500 $ml.hr^{-1}$, is optimum for most endurance activities that last more than 4 hours.

Hargreaves _et al_ (1984) conclude that repeated solid feedings of carbohydrate maintain blood glucose levels and reduce muscle glycogen depletion during prolonged work. In addition, lowered RPE values were found during such treatment when compared with the central condition. Findings on glycerol ingestion prior to exercise are that the rate of gluconeogenesis from glycerol in man is too low to make a major contribution to energy metabolism during exercise. Such pre-exercise feedings of glycerol delayed the development of hypoglycemia slightly, but could not prevent its development, spare muscle glycogen or improve endurance performance (Miller _et al_ 1983).

Other researchers have examined ways to ellicit a glycogen-sparing effect. Following the ingestion of caffeine, endurance performance on a cycle ergometer at 80% VO_2 max. was enhanced due to the likely combined effects of caffeine on lipolysis and it's positive effects on nerve impulse transmission (Costill _et al_ 1978). The ingestion of caffeine results in an elevation of free fatty acid and enhances the rate of lipid catabolism, which is associated with the sparing of muscle glycogen and enhanced capacity for endurance work (Ivy _et al_ 1978).

Shephard (1984) emphasizes the importance of sleep and bio-rhythms on human performance. Biological functions show characteristic circadian ($\approx$ 24 hr.), circaseptan ($\approx$ 7 day), circalunar ($\approx$ 28 day) and circa annual rhythms. Various physiological and psychological factors affecting performance influence the 4 classes of rhythm. Normally, synchronisation with external signals occurs, but this can be upset by rapid time shifts (international travel), sleep deprivation, unusual work schedules and total environmental control. Arousal appears to be maximal in the afternoon, with associated improvements in pattern recognition, reaction speed and muscle force; perceived effort falls, fatigue is lessened and all-out effort is better tolerated. Body temperature peaks in late afternoon and heart rate follows arousal and core temperature (Reilly et al 1984). Respiratory responses to effort are less in the afternoon. Disturbances of biorhythm such as sleep deprivation, physical fatigue and emotional stress result in poor arousal until adjustment occurs. Further, psychomotor performance shows occasional lapses and psychophysiological tests may reveal greater expenditure of effort. In addition it may be difficult to distinguish the effects of sleep deprivation and fatigue (Shephard 1984). Rossi et al (1983) suggest a relation between diurnal type, performance level in the individual and the time of day when a sporting match should be played.

During exercise internal body core temperature (Tc) rises to new plateau levels with increasing intensities of steady-state exercise independent of ambient temperature over a wide range. The rise in Tc is found to be proportional to relative rather than absolute work (Gisolfi 1983). Changes in sweating and skin blood flow (SBF) are largely explained by changes in Tc and skin temperature (Ts), though SBF is influenced by cardiovascular as well as temperature regulations. State of hydration can markedly alter these effectors indicating that fluid volume and/or composition also contributes to these control mechanisms. Tc rises to higher values in a dehydrated state and with loss of body mass (Gisolfi 1983, Sawka _et al_ 1980). Increases in rectal temperature (Tr) and heart rate HR, with decreases in stroke volume (SV) and cardiac output ($\dot{Q}$) occur during the time course of prolonged treadmill running. This appears characteristic of a cardiovascular "drift", which is believed to result from thermoregulatory shunting of blood to the cutaneous vessels. As Tc increases cutaneous vasodilation occurs decreasing venous resistance and pressure. During strenuous exercise, these adjustments occur gradually over time and may result in competition for circulation between cutaneous vessels and the metabolically active skeletal muscles. At high body temperatures cutaneous blood flow for heat dissipation may decrease central blood flow causing the cardiovascular "drift" with its attendant decreased $\dot{Q}$ - resulting in a physiological mechanism potentially limiting prolonged work (Sawka _et al_ 1979).

In relation to the above, Sengupta _et al_ (1979) found that the direct linear HR - VO_2 relationship with increased steady-state submaximal work is true for "comfortable" temperatures but not so for hot and humid conditions where vasodilation for heat loss purposes enhances heart rate response and not the work intensity. Consuming a litre of water on the run is more effective in preventing marked increases in rectal temperature than drinking an equal amount of water 30 minutes prior to exercise. Similarly, drinking on the run is more effective than sponging down the upper body with cool water in preventing marked rectal temperature increases (Gisolfi and Copping 1974).

The complex nature of fatigue as introduced earlier (Chapter I) warrants further review. According to Dill (1933):

"We can say that fatigue is not an entity but merely a convenient word to describe a variety of phenomena. The common fallacy of supposing that the word fatigue corresponds to a definite thing has been a source of much confusion. Fatigue from short bursts of activity, whether by the whole body or by isolated muscular groups, is characterized by increase in lactic acid and temporary inability to continue. Fatigue from depletion of fuel reserves does not occur commonly in man but, when it does, chemical analysis of the blood reveals a low level of blood sugar. Fatigue from working in a hot environment has several manifestations, the most simple to measure being the increase in heart rate. Finally in the instance of two individuals doing the same task, one may become more fatigued than the other because the poor nervous coordination of the unskilled man makes it necessary for him to expend more energy than the other. In general, fatigue from any of these causes is greater the more nearly the individual approaches his capacity for work".

Brouha (1953) agrees that fatigue is a vague and general term applicable to many situations, produced by many factors and characterised by many symptoms. It is known physiological and sociological influences are involved in it's production but no single precise definition of fatigue exists. Physical, mental and nervous fatigue are terms used by physicians, physiologists and psychologists, and the common factor which characterises these states is a tendency toward inactivity. It has been described a "negative appetite for activity", this negative appetite being usually more pronounced for the specific activity which produced the fatigue and may not exist for other activities (Brouha 1953).

Blum and Naylor (1968) confirm that fatigue has been defined as an altered psychological or physiological state in relation to the status of recovery or normal capacity. Whatever fatigue may be, it appears safe to say that any muscular work, even sitting in a chair, will result in fatigue provided the work of the muscles and the resulting expenditure of energy are at a faster rate than is recovery. Many factors contribute to fatigue onset such as the duration of the work period, the intensity of work and the musculature involved. "Fatigue rarely concerns a single muscle but rather the individual as a whole" (Blum and Naylor 1968).

By measuring one or more physiological function such as heart rate, blood pressure, cardiac output, pulmonary ventilation, VO_2, chemical composition of blood or urine, body temperature and sweat rate it is possible to measure how much the "working level" varies from the "resting level." This will give an estimate of the degree of physiological stress experienced in performing a given task and can lead to an estimate of the degree of fatigue to be expected from the task (Brouha 1953). Changes in the above factors are proportional to the degree of stress (Brouha 1953, Astrand and Rodahl 1977). However, not all factors can be successfully used to evaluate fatigue. For example, in industry little or no increase of lactic acid is found in the blood of workers who experience fatigue (Brouha 1953). In support thereof, Saltin and Stenberg (1964) report lactic acid concentrations declining throughout a work period at 75% VO_2 max. Therefore it would seem unrealistic to link increasing fatigue only with the concentration of blood lactates. Fatigue during hard work of long duration is different from that encountered in maximal exercise for 5 to 15 minutes (Astrand et al 1963). The above statements suggest that in evaluating fatigue states composite measures of a variety of parameters are necessary.

Characteristic patterns of subjective fatigue symptoms appear to occur during work shifts. Yoshitake (1978) found a pattern in which "drowsiness and dullness" predominated to be frequent both among those who repeat many symptoms and those workers reporting few symptoms. This pattern was not characteristic of any particular type of work. An "inability to concentrate" pattern was a prominent characteristic of mental workers who reported many symptoms, especially after night work. "Physical discomfort" was found mainly among those who reported few symptoms and who were engaged in physical work.

Conspicuous changes in both tiredness and readiness for work are reported by both older and younger workers in successive hours of work. This suggests that workers possess definite attitudes as to when during the work shift they are most ready to work and when they are most tired. Older workers appear to be more introspectively conscious of feelings of tiredness and readiness for work than younger workers. The curves for tiredness and restfulness feelings throughout the workshift are remarkably similar for manual, office and supervisory employees. Maximal subjective fatigue is reported in the fourth and eighth hours of an 8 hour shift. Maximal restfulness is reported in the second and sixth hours of shift, i.e. the second hour of each four-hour work period (Griffith et al 1950).

Wojtczak-Jaroszowa et al (1978) examined psychomotor and mental performance at different times during prolonged sessions of physical work. They indicate that performance levels were determined by three factors: circadian fluctuations, elapsed time from the beginning of a session, and physical work done prior to testing.

In his "Introduction to Personality" Mischel (1971) maintains that to study the "total individual" or the "whole person" may be a worthy goal but it is practically impossible. To progress beyond recognising and admiring the complexity of man, the researcher must select things about people that he can study. According to Eysenck (1964) classification is an absolutely fundamental part of the scientific study of human personality and he argues that a satisfactory typology is as necessary in psychology as was Mendeleev's table of the elements in physics. Eysenck refers to the Greek Hippocrates (400 B.C.) and Galean typologies of choleric (irritable), melancholic (depressed), sanguine (optimistic), and phlegmatic (calm, listless). Mischel (1971) recalls other classifications such as Sheldon's (1942) somatotyping of endo-, meso- and ectomorphs; a method he states, that is stereotypical and disproven with regard to personality. Mischel regards typologies as limited in their SIMPLICITY because human behaviour is COMPLEX.

Whereas typologies assume discrete, discontinuous categories, traits however, are continuous dimensions on which individual differences may be arranged quantitatively in terms of the amount of the characteristic an individual has. This standpoint begins with the common sense approach that individuals often differ greatly and CONSISTENTLY in repsonse to the same psychological situation or stimulus (Mischel 1971). A trait is defined by Guildford (1959) as "any distinguishable, relatively enduring way in which one individual varies from another."

Forgus and Shulman (1979) have the following postulates for a theory of personality (regarded as pertinent to human movement): 1) all behaviour is adaptive; 2) personality is a learned pattern of behaviour; 3) culture influences the patterning of a person; 4) each personality has it's own intrinsic and unique organisation; 5) personality determines the selection of response; 6) understanding the pattern permits the prediction of behaviour.

A number of researchers have looked at personality traits in relation to human movement response styles. A great amount of evidence has shown that two relatively independent superfactors identified by Eysenck (1960) as neuroticism and extroversion - introversion, represent most of the variance in the personality domain (Jensen 1970). This variance may be divided into many factors but extroversion (E) and neuroticism (N) are two of the most comprehensive. N refers to the general emotional lability, emotional over-responsiveness and predisposition to neurotic breakdown under stress; whereas E refers to the outgoing, uninhibited, impulsive and sociable proclivities of a person (Eysenck 1958). A means to measure E and N is the Maudsley Personality Inventory (M.P.I.) developed by Eysenck. Jensen (1970) states that persistence in menial and monotonous tasks is related to the M.P.I. dimensions. For example, subjects with high N scores are less apt to stand up well throughout an arduous laboratory experiment. Hendry (1975), in a university study on personality and movement found that active students were on average, stable and extroverted. Morgan and Costill (1972) in a study of marathon runners concluded that the runners in their study scored within normal limits on extroversion - introversion but appreciably lower for anxiety. Morgan (1974) established that athletes from various subgroups differed on a variety of psychological states and traits. For example, he maintains wrestlers are extroverted and marathon runners introverted, but he cautions that highly successful athletes may not fit the group stereotype and one must not lose sight of the importance of individuality. High level performers appear to be characterised by psychological profiles which generally distinguish them from lower level performers. Investigations yield results supporting the view that high-level performers are more extroverted and stable. Morgan (1974) notes that Olympians scored lower on tension, depression, fatigue and confusion, and higher on psychic vigour. Mikel (1983) found runners to be more introverted than a college norm group, but similar on extroversion to an adult industrial workers norm group. He points out that there are conflicting reports with regard to the running and extroversion relationship.

Challenge and Type A behaviour patterns have been studied by Carver et al (1976). Type A's display exaggerated achievement strivings, aggressiveness when frustrated and have a marked sense of time urgency, and are commonly associated with higher risk of coronary heart disease. The above authors have however, demonstrated some positive specific elements in the pattern of type A behaviour. For example, type A's tend to suppress or deny subjective states that threaten to disrupt their achievement. An example of such a potentially disruptive state is fatigue, which hampers effective performance thereby threatening mastery. Type A college students who were experiencing veridical physical fatigue suppressed that experience to a greater deal than did type B's in order to persist at a challenging treadmill-walking task. Despite pushing themselves closer to their own physical limits by the end of their exertions on the treadmill, type A's were simultaneously reporting less fatigue than were type B's (Carver _et al_ 1981). Taken as a whole, pattern A may be characterised as a behavioural style aimed at maintaining environmental control, which emerges when the individual confronts suitably challenging circumstances. Type A characteristics appear quite adaptive in that when type A's were challenged by injury (football) they appeared to push themselves even harder to do their best. "The potential short-term adaptiveness of A - type characteristics in attempts to achieve difficult objectives is an aspect of the behavioural style that is often overlooked amidst the widespread concern over the relationship between this style and the cardiovascular pathology with which it has been associated." (Carver _et al_ 1981).

Campbell and Pritchard (1976) ask the question: "What is motivation?" In attempting an answer they argue that "motivation" has meaning if we take it merely as a summary label that identifies a class of independent variable/dependent variable relationships. It is necessary to try to characterise its parameters. They propose that the common expression in psychology - performance = f (ability x motivation) should be rewritten as follows:

> "Performance = f (aptitude level x skill level x understanding of the task x choice to expend effort x choice of degree of effort to expend x choice to persist x facilitation and inhibiting conditions not under control of the individual)"

This is intended to illustrate some obvious points. Performance is not synonymous with effort, ability or a combination of the two. The choice to work on a task, the understanding of what is to be done, the choice to persist and environmental constraints all play an important role. It is most meaningful to view motivation as a label for the determinants of a) the choice to initiate effort on a certain task, b) the choice to expend a certain amount of effort and c) the choice to persist in expending effort over time. Motivation has to do with a set of independent/dependent variable relationships that explain the direction, amplitude and persistance of an individuals behaviour, when holding constant the effects of aptitude, skill, understanding of the task and the constraints operating in the environment (Campbell and Pritchard 1976).

In considering the organisation of motivated behaviour, goals are the end point of behavioural movement and are selected by a unique motive hierarchy in interaction with environmental incentives. Further, motives interact and affect each other for example pursuit of competence may be inhibited by simultaneous arousal of insecurity. Satisfaction of motives in goal directed behaviour is always directed by the perceptual system with dominant goals taking precedence over others. A goal may permit a variety of situational fluctuations. Some people respond to environmental stimulation in highly consistent ways, others reveal great specificity, with varying responses. To illustrate, despite the consideration that personality is consistent does not mean that people do not discriminate from one situation to another. It is necessary to consider consistency of cognitive style (Forgus and Shulman 1979).

Many theories of motivation have been propounded, and a cross section warrants review. To illustrate, the person high in achievement motivation has an expectancy of success whereas the low achievement person has a fear of failure. These achievement dynamics were expressed by Atkinson (1957) in the equation:

$$TA = (M_s \times P_s \times I_s) - (M_{af} \times P_f \times I_f)$$

where: TA = the tendency to approach the achievement task

M_s = motivation to achieve success

M_{af} = motivation to avoid failure

P_s = probability of success

P_f = probability of failure

I_s = incentive value of succeeding at task

I_f = incentive value of failing at task

According to Forgus and Shulman (1979) the basic paradigm of achievement motivation theory is that the individual's hope of success is stronger than his fear of failure.

Drive theory proceeds from a basic assumption that the excitatory potential (E), which determines the strength of a given response (R), is a multiplicative function of the total effective drive state (D) and habit strength (H). Thus, R = f (E = f (D x H)). The theory has considerable support when a task is simple, such as a 1-response learning situation, but occurs rarely in motor behaviour (Martens 1971). Drive theory predicts a linear relationship between drive level and performance. Experimental evidence suggests that the relationship is monmonotic rather than linear and this relationship has been discussed in terms of arousal or activation theory (Martens 1971). This relationship between performance and arousal (or anxiety) has been termed the "inverted-U-hypothesis" or the "Yerkes-Dodson (1908) law." In general the greater the stress the greater the anxiety, which is a subjective experience related directly to the severity and duration of the external stressor. Anxiety has been found to motivate behaviour in several ways, often interfering with performance and leading to avoidance behaviour (Calder and Stow 1975).

Calder and Stow (1975) demonstrated that there is interaction between intrinsic and extrinsic motivation. Subjects stated that enjoyment was higher without reward in a challenging interesting task - demonstrating intrinsic motivation. Similarly if the task is perceived as not challenging, outside incentives are required. Intrinsic motivation decreases when extrinsic rewards such as money are offered. The expectancies and perceptual style of the individual are important (Calder and Stow 1975) as is the interaction between the person and the situation. (See Figure 4).

Conventionally work motivation theories have been classified into two types - content and process theories. Historically content theories emerged first and attempt to specify the correlates of motivated behaviour i.e. what states, feelings or attitudes are associated with motivated behaviour. Typical of this approach is Maslow's need hierarchy ranging through physiological, safety and security, love and belongingness, self-esteem and self-actualisation needs; and Herzberg's two-factor theory of work motivation i.e. Motivation-hygiene; content-context, or intrinsic-extrinsic theory (Barling 1983).

However, central to current industrial psychology is the Valence-Expectancy theory of work motivation (VIE), also known as Valence Theory, Expectancy Theory, Instrumentality Theory or even Path-Goal Theory (Barling 1983). VIE has two major foundations, cognitive and drive theory, and the general aim of VIE is to predict effort-to-perform.

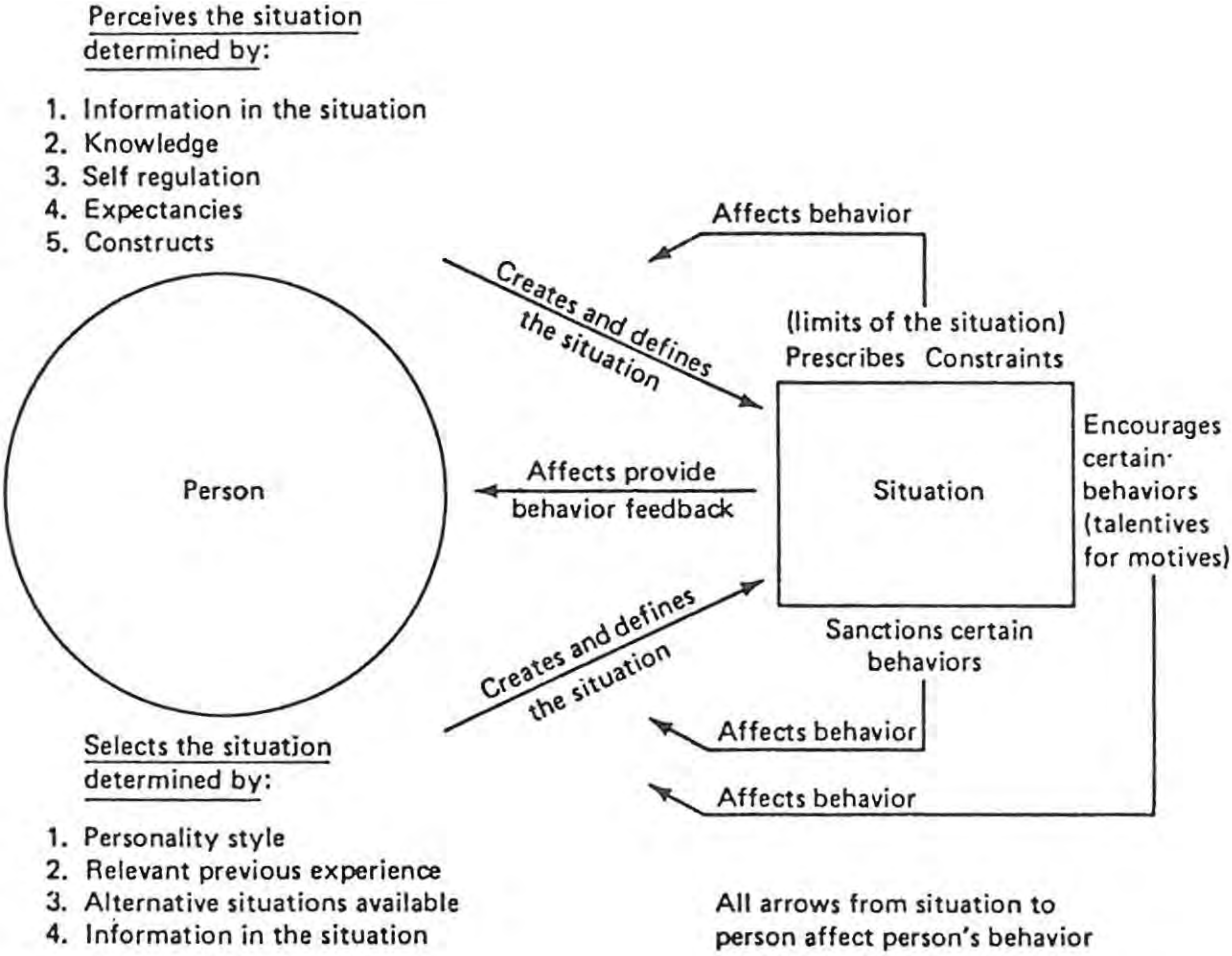

Figure 4: The complex interaction between person and environment. The situation provides incentives to behaviour or inhibits behaviour. Thus the situation is perceived as having positive and/or negative press. The person, in turn, creates and defines the situation through selective perception and attention. The interaction is bi-interactional with constant feedback. (From Calder and Stow 1975).

VIE theory may be schematically presented as follows:

Cognitive/Belief Components: skill/ability

$$\begin{bmatrix} \text{Expectancy} & \times & \text{instrumentality} & \times & \text{valence} \\ [E \rightarrow P] & & [P \rightarrow O] & & \end{bmatrix} \rightarrow \text{Effort} \xrightarrow{\text{skill/ability}} \text{Performance} \rightarrow \text{Rewards} \rightarrow \text{Satisfaction}$$

Figure 5: Schematic Presentation of VIE Theory

The focus is on three cognitive beliefs that together predict effort, expectancy, instrumentability and valence. The interrelationship is multiplicative, therefore if any of the beliefs is low, final effort to perform is low. The expectancy belief is frequently denoted as E → P, reflecting the belief that given sufficient effort successful performance will ensue. Successful past experience, self-esteem and self-concept will influence this belief. The instrumentability component reflects the belief that successful performance would result in a particular outcome, and is often denoted P→O. Valence reflects the value any individual places on the outcomes available and can range from highly negative (aversive) to more positive (highly desired) outcomes. Note that if the E → P belief is low, individuals would believe that no matter how hard they tried, successful performance cannot be accomplished. In this situation it is doubtful whether any effort would actually be expended. It must be remembered that effort is not synonomous with performance. It is possible to have high effort with minimal performance. This is because effort interacts with skill/ability in predicting actual performance (Barling 1983). There is overlap between VIE theory and the performance equation proposed by Campbell and Pritchard (1976).

Rejeski and Lowe (1980) investigated the effects of ability (high versus low), effort (high versus low), and outcome (success versus failure) on causal attributions. After riding a bicycle ergometer, subjects were asked to attribute the cause of their increased or decreased performance to ability, effort, task difficulty and/or luck. Successful outcomes were attributed both to ability and effort and unsuccessful outcomes were attributed to lack of ability but not lack of effort. Their results were interpreted to support a situationally specific conceptuatisation of sport achievement. McCaughan (1983), in support of the above, studied individuals classified as high or low need achievers. It was found that high need achievers ascribe failure to lack of effort, whereas low need achievers believe failure reflects lack of ability. High need achievers alter allocation of effort to induce a successful outcome and have been shown to persist longer after failure than low need achievers. Psychological barriers which normally establish limits to one's ultimate capacity can be broken down allowing an individual to surpass the level previously designated as his physical capacity (Wilmore 1970). A statistically significant increase in endurance capacity (work output and riding time) above two control conditions where subjects were motivated by a competitive situation occurred. The maximal physiological responses to the work capacity tests were essentially the same under all three conditions indicating that the increased performance (work output and riding time) brought about by motivation did not occur as a result of alterations in the maximal levels of the measured variables. It appears that the reserve in work output above predetermined capacity is made possible through an increased anaerobic metabolism coupled with an increased tolerance to pain. Wilmore concludes that supramaximal performances result from the breakdown of psychological inhibitions or barriers.

The review of motivational theory indicates the importance of perception and this topic warrants further review. Ryan (1976) examined the perceptual characteristics of vigorous people. Perception is involved in practically everything we do and it is difficult to think of any act that does not involve perception of some kind. Of note is that though individuals may all receive the same objective stimulus they do not necessarily perceive it the same way. Ryan has found that the ability to tolerate pain for example, may be related to the type of activity (of lack of it) that a person is engaged in. Comparing contact athletes, non-contact athletes and non-athletes it was established that no differences occurred in pain threshold i.e. they all perceived the pain sensation at the same point. However, there were significant differences in how much pain the three groups were willing to tolerate. The contact athletes tolerated the most, the non-athletes the least and the non-contact athletes fell in between. Morgan (1974) reports higher pain tolerance in the extrovert than in the introvert.

Pain expectancy is the anticipation that pain is unavoidable in a given situation. Pain acceptance is characterised by a willingness to experience pain. Various reasons are given for the willingness to tolerate pain e.g. sociological reasons such as peer pressure to be "manly", and also because of repeated experiences of pain e.g. contact sport (Ryan 1976). However, a most plausible explanation appears to be the one propounded by Petrie (1960) as cited by Ryan (1976). Petrie refers to the general perceptual characteristic of "augmenting" or "reducing" sensory inputs. The characteristics of the reducer include tolerance of pain, intolerance of sensory deprivation, mesomorphy and extroversion. Augmenters tolerate pain poorly. This has been shown to be true of the experimental pain of heat, muscle ischemia and pressure, as well as pain of surgery and childbirth. Further, reducers judge time as passing more slowly than augmenters. It appears then that individuals either increase or decrease the intensity of stimulation according to their perceptual style (Ryan 1976).

Lynn and Eysenck (1961) support the above. They report pain tolerance as positively related to extroversion and negatively to neuroticism. Extroverted subjects are postulated to develop inhibition/satiation more quickly, and dissipate it more slowly; prolonged pain sensations should thus be inhibited more quickly and strongly in extroverts, leading to diminished pain sensations. Morgan and Horstman (1978) state that psychological traits such as extroversion, field dependence, anxiety and neuroticism, as well as psychological states such as depression and vigor are correlated with the perception of pain. Smith (1968) in his report on the relationship between muscular fatigue, pain tolerance, anxiety, extroversion-introversion and neuroticism traits of college men - found no difference between extroverts and introverts regarding their persistence in tolerating an isotonic and isometric endurance task. Further, the more neurotic subjects did not differ from the more stable in threshold and tolerance fatigue levels, and the least anxious subjects were no different than the high anxious subjects relative to their performance on the isotonic and isometric tasks. Reports in the literature appear equivocal in the study of personality traits and states related to fatigue and pain thresholds. With regard to awareness and control of pain, cognitively based strategies appear to be the most effective. Awareness and immediate feedback e.g. watching a stopwatch during a pain endurance task appears to yield better performance results than other techniques such as positive and pleasant imagery (Ladouceur and Carrier 1983).

Gondola and Tuckman (1983) tested college students to determine the effects of exercise and diet on self-reported discomfort. High exercisers reported significantly less physical discomfort than moderate or low exercisers. Greater consumption of sweets and fast food were signficantly related to reported physical discomfort regardless of levels of exercise. High levels of fruit and vegetable consumption were associated with less discomfort in high exercisers, as was high dairy consumption. Men ingesting high caffeine levels reported significantly more discomfort than those ingesting moderate to lower levels of caffeine.

In a semi-paced laboratory assembly task the time course of subjective general discomfort showed an ascending trend (Kuorinka 1983). However, general ratings appear to be easily biased and local discomfort ratings seem to be more reliable for ergonomic purposes. Pain is one of the ways discomfort is expressed. Neurobiological and psychological mechanisms which play a role in the sensation of pain may also govern the sensation of discomfort. The Concise Oxford Dictionary (1976) definition of discomfort is: "uneasiness of body or mind; lack of comfort". It is difficult to define discomfort which is a phenomenon of perception. It's related phenomena are fatigue and perceived exertion (Kuorinka 1983).

The word fatigue is commonly used to label different events occurring at diverse levels of biological organisation. Fatigue often implies changes in function, from the failure of muscles to maintain contraction to decrements in the work performance of the whole organism. It also sometimes refers to subjective responses to prolonged mental or physical work. The measurement of subjective events is necessarily indirect, depending on self-report techniques. Self-report methods of measuring subjective responses to physical work have generally used one dimensional scalings of tiredness. While useful, such unidimensional scalings ignore the complexity of subjective responses to strenuous exercise (Weiser et al 1973). These authors advocate the use of a self-report physical activity questionnaire (P.A.Q.) which consists of three independent sets of scaled adjective items labelled fatigue, task aversion and motivation. The fatigue set appears best to describe physical fatigue. Subsequent work by these authors divided the fatigue set into two namely, leg fatigue and general fatigue. Another cluster, thirst is also advocated. These fatigue clusters are suggested as symptomatology reports of adequate reliability to study subjective responses to physical work (Weiser et al 1973).

Currently, one of the most widely used subjective response scales is the Rating of Perceived Exertion (RPE) as developed by Borg (1962). Regardless of whether one is concerned with muscular peformance of man in athletics, industry, in the military or under everyday circumstances, the concept of perceived exertion offers a unique approach to the study of behaviour. Perceived exertion can be defined as one's subjective rating of the intensity of work being performed. When responding to R P E the task of the exercising subject is to assign a numeral to represent the subjective sensation of the amount of work being performed. This is a valuable tool in the human performance setting, since the important consideration is frequently not "what the individual is doing" but rather, "what he thinks he is doing". In other words the continuation of work, as well as the intensity at which one elects to work, is dependent in part upon the processing of perceptual information, for example pain. It is difficult to explain the exact nature of perceived exertion. As a construct, one might intuitively argue that it is analogous to pain - a review of the literature on the topic of RPE reveals that, like pain, it is a subjective, quite personal, and extremely complex sensation (Morgan 1973).

Perceived exertion is a psychobiological process (Morgan 1973). Borg (1982) argues that in his opinion perceived exertion is the single best indicator of physical strain. An overall RPE integrates various information, including the many signals elicited from the peripheral working muscles and joints, from the central cardiovascular and respiratory functions and from the central nervous system. All these signals, perceptions and experiences are integrated into a configuration or Gestalt of perceived exertion.

According to Borg (1978) three parallel continua of effort occur, the perceptual, the performance, and physiological continuum, all of which complement each other. To achieve full understanding of man at work the subjectively perceived differences over a full range of work should be studied in relation to preferred intensities of effort, adaptation levels and stress conditions. Subjective changes should be related to performance, physiological indicators and measures of working capacity. The Borg RPE scale varies from 6 to 20 to approximate one tenth of HR (from 60 to 200). In many studies (Borg 1973, Mihevic 1981) correlations of RPE and HR ranging from 0,80 to 0,90 have been found, as well as correlations with other physiological variables. Borg (1982) stresses that the close relationship of RPE/HR is not to be taken too literally because of heart rate variations due to age, type of exercise, environment, anxiety, and other factors which would alter the meaning of the HR obtained. Thus, no causal relationship between heart rate and RPE is suggested.

Due to the known linear relationship of heart rate and VO_2 (Astrand and Rodahl 1977, McArdle et al 1981) RPE is also linearly related to VO_2. Thus as far as heart rate and VO_2 reflect physiological strain RPE can be used as a strain indicator. Ekblom and Goldbarg (1971) proposed a two-factor model for explaining the perceptions which mediate RPE. Thus a local factor representative of sensations or feelings of strain in the working muscles and/or joints; and a central factor representative of sensations or feelings primarily associated with the cardiorespiratory system - is advocated. In relation to RPE as a strain indicator these authors suggest that with work loads involving the use of small muscle groups local factors seem to predominate. By local factors is meant the feeling of strain in the working muscles due to muscle lactate, muscle temperature, electromyography (E.M.G.), and general muscle sensations as a result of mechanoreceptors and proprioceptors such as Golgi tendon activity. In contrast, with large muscle groups heart rate, pulmonary ventilation (minute volume and respiration rate), circulation and rate of O_2 consumption are added to the strain factor. According to Mihevic (1981) individuals readily perceive sensations of volume, pressure and ventilation during breathing, it being unlikely that heart rate and O_2 consumption are directly sensed. Further, the perception of peak exercise intensity has been demonstrated to be coincident with peak ventilation. Taken collectively ventilation and respiration rate are readily monitored during exercise and provide a source of sensory information for the perception of effort during exercise (Mihevic 1981).

The mechanisms for monitoring perceptual signals involve a multi-factor response (Robertson 1982). The Gestalt nature of perceived exertion originally advanced by Borg (1962, 1982) suggests that multiple physiological responses which influence perception of effort are integrated by the individual and differentially weighted according to their importance during various types of exercise (Mihevic 1981). When a particular physiological cue is markedly altered over others during exercise, it appears that the resultant sensation can easily dominate the overall RPE (Pandolf 1982). He proposes an experimental model of RPE (Figure 6) as a basis for differentiated ratings of perceived exertion which demonstrate the inter-relationships between perceptual ratings and particular physiological responses during physical exercise. Levels of subjective reporting i.e. superordinate, ordinate, subordinate and discrete symptoms are suggested. With regard to duration of exercise RPE during short term exercise may be dependent on neurologically mediated perception cues, whereas RPE for longer duration may be mediated by less rapidly responding biochemical processes (Mihevic 1981).

Young men and women perceive an exercise intensity equal to the anaerobic threshold as "somewhat hard". Further, the similar

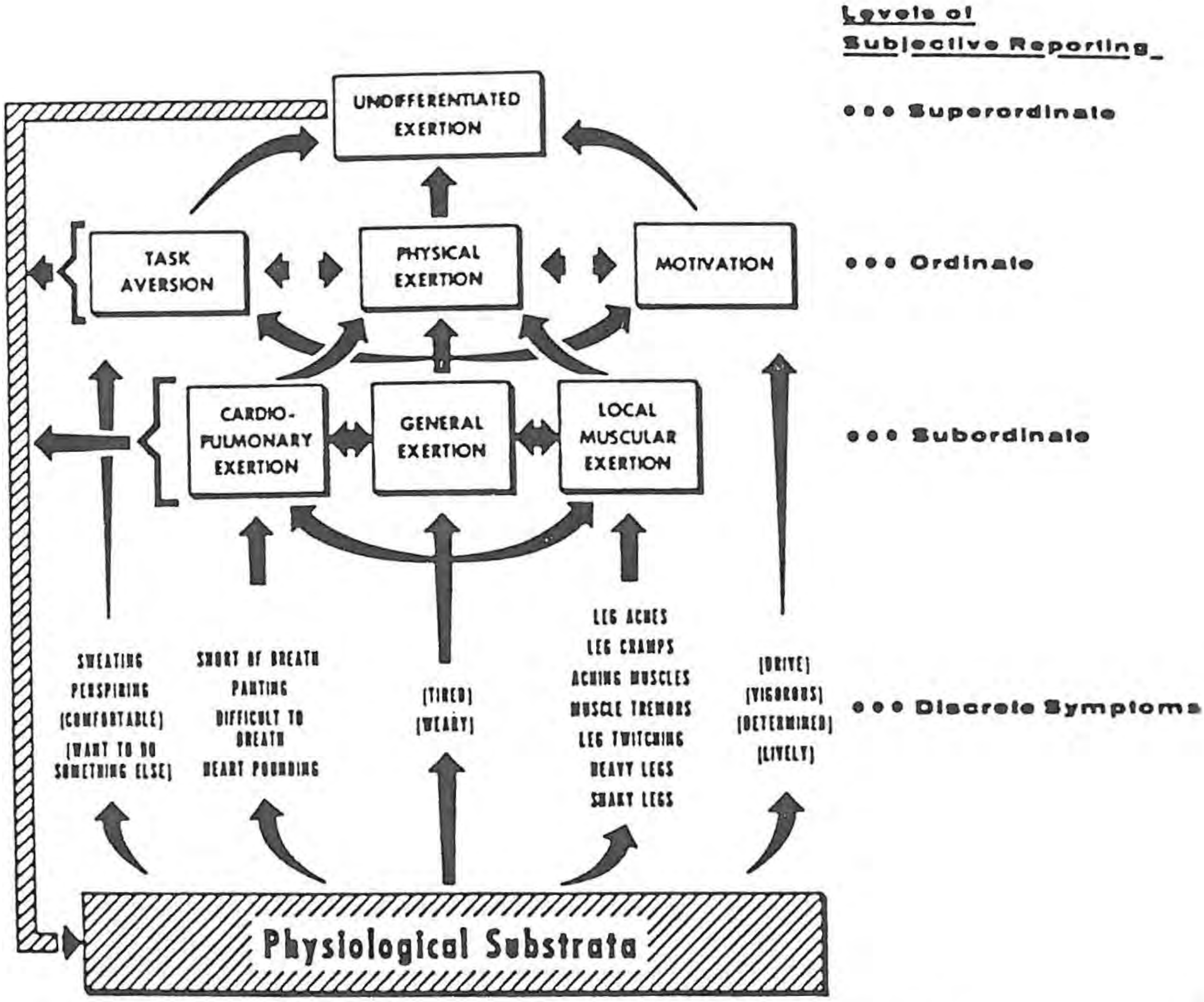

Figure 6: An experimental model that describes the levels of subjective reporting applicable to different types of physical exercise and presents a basis for differentiated ratings of perceived exertion (From Pandolf 1982).

perception of the exercise intensity corresponding to anaerobic threshold by different individuals makes it possible to prescribe an exercise intensity equivalent to the anaerobic threshold using RPE (Purvis and Cureton 1981). Skinner et al (1973) report that although they found differences between lean and obese subjects when RPE was related to absolute values of VE and VO_2, relative to maximal values there was no difference. RPE appears to be most closely related to the proportion of maximal capacity required for a given workload. Rejeski and Ribisl (1980) examined expected task duration and perceived effort. RPE's in moderately fit males are controlled, in part, by external cues, i.e. the goal that is presented them. Individuals delay the unpleasant consequences of fatigue by suppressing subjective estimates of tiredness until their task is virtually complete. Such "cognitive pacing" occurs usually at moderate intensities and it should be noted that cognitive mediation cannot compete with strong internal cues at higher intensities.

Noble (1982) cites a number of clinical applications of RPE for example, stress test applications, prescription of training intensity, occupational and sport applications. Borg et al (1980) have adapted the scale for use as an angina scale, illustrating intensities from 1 to 9 and Borg (1980) has further developed a Category - Ratio scale for use in evaluating curvilinear physiological responses, such as that of lactic acid production. However, Borg (1982) concludes that:

> "At present I think however that the old RPE scale is the best one for most simple applied studies of perceived exertion, for exercise testing, for predictions and prescriptions of exercise intensities in sports and medical

rehabilitation."

A final perceptual characteristic warrants mention. This is the perception of thermal comfort (PTC). Comfort is a recognisable state of feeling, but possesses no identifiable sense organ like the basic five senses. It is usually associated with conditions that are pleasant and compatible with health and happiness; and discomfort, with pain which is unpleasant. Thermal comfort as a sensation, though difficult to define, has been designated as that state of mind that expresses satisfaction with the thermal environment (Gagge et al (1967). For steady exposure to cold and warm environments thermal comfort and neutral temperature sensations lie in the range for physiological neutrality ($28^{O}C$ - $30^{O}C$), in which there is no physiological temperature regulatory effect. Discomfort increases more rapidly below $28^{O}C$ than above $30^{O}C$. In general, discomfort is associated with a change in average body temperature from $36{,}5^{O}C$. Thermal discomfort is an excellent stimulus for behavioural activity by man (Gagge et al 1967). The condition for thermal comfort is heat balance, which Olesen (1982) expressed in the equation:

$$S = M \pm W \pm R \pm C \pm K - E - RES$$

Where S = heat storage; M = metabolism, W = external work; R = heat exchange by radiation; C = heat exchange by convection; K = heat exchange by conduction; E = heat loss by evaporation; and RES = heat exchange by respiration. Gagge et al (1967) advocate the use of a rating scale of thermal sensation. The numbers (1 to 7) on a scale from cold to hot, indicate numerical progression which is useful for analytical purposes as a nominal scale.

SUMMARY

Use of both the scientific and philosophical method is advocated in addressing human-movement centred problems. Adequate academic enquiry related to human movement presupposes an eclectic integrative methodology. Fragmentation occurs in the literature survey reflecting the complexity and diversity of factors influencing work output and duration. The human organism responds to stress and strain through an integrated functional framework of linked and concurrent physiological, psychological and emotional reactions.

CHAPTER 3

EXPERIMENTAL METHODS AND PROCEDURES

CHOICE OF SUBJECTS AND PERSONAL DATA RECORDED

Ten healthy male caucasian subjects volunteered to take part in the study and provided written informed consent. The age of the subjects was recorded in years. The nude body mass was measured on a Seca beam balance scale and recorded. A Harpenden skinfold caliper was used to measure skinfolds at the mid-arm (triceps and biceps), the subscapular (below the inferior angle of the scapular), and the supra-iliac site (5 cm above the anterior superior iliac spine). The percentage body fat was calculated using the method of Durnin and Womersley (1974) and recorded. Stature of subjects was measured using a Holtain stadiometer. The Du Bois-Meeh (1916) regression formula was used to predict nude body surface area (B.S.A.).

DESIGN OF THE STUDY

A repeated measures design was adopted. Subjects reported individually to the laboratory on five separate occasions and undertook the following:

1) A VO_2 max. test and baseline personality measure;
2) A run to a point of subjective discomfort at which they were no longer willing to continue, at one of four different relative intensities ($_{f}VO_2$ max.) administered in a random fashion i.e.

55%	65%	75%	85 % VO_2 max.

During each run various physiological and psychological parameters were measured as described hereunder. A five minute rest period every hour, on the hour, was allowed, during which some of the physiological measures were obtained.

Blind Technique and Randomisation

A single blind technique was adopted in that subjects were unaware of the $_fVO_2$ max.at which they were working. Subjects were requested to be available for a maximum period of seven hours for each of the four treatments as the exercise duration was unknown and a maximum work time of seven hours was applied.

PILOT TESTING

In order to test the reliability and of data collected and to eliminate procedural problems a test-retest procedure was conducted. Three volunteer subjects undertook two VO_2 max. tests and two full data collection runs at $_fVO_2$ max. of 85% each. Particular attention was given to the time taken to reach the desired $_fVO_2$ max. and the consistency of the control of $_fVO_2$ max. A students related T-test (Ferguson 1981) was performed on the data obtained to establish whether there were significant differences between tests 1 and 2.

ENVIRONMENTAL INFLUENCES AND SAFETY

The time of day during which testing was applied was standardised as much as possible. All testing was done at the Rhodes University Work Physiology laboratory where conditions remain fairly stable over time. The variability in environmental conditions is reported in Chapter 4.

Subjects dressed comfortably in running shoes, shorts and T-shirts (if desired). A fan was provided to circulate ambient air. At all times an experimenter was present. In addition an assistant was always on hand whenever subjects undertook their VO_2 max. test in order to assist if subjects tripped or fell.

VO_2 MAXIMUM TEST

A direct, continuous VO_2 max.test was applied to all subjects prior to the main experimental protocol.

A continuous automated on-line computer-based method for gas analysis, Vt and HR as developed and validated by Goslin et al (1984) was used. An explanation of this method is included later in this chapter under the heading "Gas analysis, on-line system".

Subjects commenced their VO_2 max. test by running at 8 $km.hr^{-1}$ on a Quinton treadmill (model 643). Every minute the speed was increased by 1 $km.hr^{-1}$. until a a speed of 17 $km.hr^{-1}$ was reached, whereupon further increments in VO_2 were achieved by 1% increases in grade every minute where necessary, until VO_2 max. was reached. Gas sample and analysis was achieved by the automated system sampling for 25S every half minute. VO_2 max. was seen to have been achieved if any three of the following criteria were met simultaneously.

a) $VO_2 < 2$ $ml.kg^{-1}$ for Δ increase in speed and/or grade

b) $R > 1$

c) $RPE > 17$

d) HR approximately age predicted maximum

e) Subjective exhaustion

DETERMINING AND SETTING OF THE RELATIVE INTENSITY OF METABOLIC COST

Once the VO_2 max. for each subject had been determined, the metabolic demand as a fraction of VO_2 max. i.e. $_fVO_2$ (Krajewski <u>et al</u> 1979), or the relative intensity of metabolic cost expressed as percentages; were duly calculated for each individual and expressed in $ml.kg^{-1}.min^{-1}$ of oxygen consumed. The percentages were arbitrarily predetermined at 55%, 65%, 75% and 85% of max. VO_2.

A review of the literature on prediction of oxygen cost (Shephard 1969, Mayhew 1977, Leger and Mercier 1984) revealed considerable variance in predicted values obtained. For the purposes of this study the accurate and timeous setting of the $_fVO_2$ was critical and was achieved by reference to the known VO_2 values recorded by each individual at a given running speed, as determined during the VO_2 max. test. The continuous sampling of the on-line computer-aided data acquisition system provided ongoing feedback as to the $_fVO_2$ at which the subject was working. For all treatments it was possible to stabilize the subjects at the required $_fVO_2$ within 3 to 5 minutes. Thereafter, in order to maintain work outputs at the $_fVO_2$ desired, small adjustments were made by changing the speed as the subject tired.

BASELINE PERSONALITY MEASURE

The short form of the Maudsley Personality Inventory (MPI) (Eysenck 1958) was administered once to all subjects prior to the commencement of any physical data collection. This inventory elicits measures of two important personality dimensions, namely neuroticism (N) or emotionality and extroversion (E) (Eysenck 1958, 1973); and is to be regarded primarily as a research instrument as opposed to a clinical tool (Eysenck 1956).

Reliability

The split-half reliabilities for the short form MPI (corrected) are 0,79 for N and 0,71 for E, these values being acceptable for group comparisons. The correlation between extroversion and neuroticism is - 0,05 (Eysenck 1958).

The correlation between the long and short form MPI's are 0,86 and 0,87 respectively for N and E (Eysenck 1956). According to Jenson (1958) "the short form has satisfactory reliability and high correlations with the total scales and can be useful when time is limited."

Jenson (1958) further states that "probably no other psychological test - certainly no personality inventory - rivals it in psychological rationale." He reports split-half Kuder- Richardson estimates of item inter-correlation for each scale between 0,75 and 0,9 and test retest reliability 0,7 to 0,9 which Jenson states is "amongst the highest to be found in personality inventories".

PHYSIOLOGICAL RESPONSE PARAMETERS MEASURED

VO_2, HR and Vf were measured by the on-line system throughout the treatment (Tr) periods at the undermentioned frequencies:

Tr 55% - every 15 minutes	Tr 65% - every 10 minutes
Tr 75% - every 5 minutes	Tr 85% - every 5 minutes

Sweat rate was determined by the change in body mass method (Astrand and Rodahl 1977). Subjects removed clothing, dried themselves with a towel and nude body mass values were recorded every hour during the five minute break, and again at cessation of activity.

Oral temperature and four skin temperatures (pectoralis major, biceps, quadriceps and gastrocnemius) were also recorded during the rest period using a banjo temperature probe (Yellow Springs Co.Inc. Model 408). Blood pressure was recorded once at the cessation of exercise, immediately the subject stepped off the treadmill and always within 1 minute of stopping.

PSYCHOLOGICAL RESPONSE MEASURES

Five subjective response parameters were measured throughout each treatment application. These were Ratings of Perceived Exertion (RPE) general; RPE local (i.e. legs); Perceived Thermal Comfort (PTC); Perceived Pain; and Perceived Fatigue (appendices D, F to H). The subjective ratings were obtained in a continuously changing randomised order with the same sampling frequencies as for the physiological parameters.

Ratings of Perceived Exertion (RPE)

All subjects were given a standardised instruction (appendix E) on how to respond to the RPE chart which was shown at the appropriate moment. Subjects responded by pointing (touching) the rating of their choice. This was then verbally verified by the researcher and recorded.

An attempt was made to differentiate between local and central factors as outlined by Mihevic (1981), Rejeski (1981), Borg (1982), Cafarelli (1982), Pandolf (1982) and Robertson (1982); by obtaining an RPE general and RPE local (specific) rating. The specific rating in this instance was with reference to the legs only. Subjects were required to report on the perceived sensations of effort in the legs only, as distinct from the body as a whole.

Statistical Significance of RPE

Correlation coefficients of 0,87 to 0,9, have been reported between HR and RPE, and RPE versus other physiological parameters (Borg 1962, 1974, 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 determined whether subjects could perceive small differences in varying work intensities presented in random order.

Ratings of Perceived Thermal Comfort

Gagge et al (1967) scale of thermal sensation was used to measure ratings of PTC (see Appendix F). The numbers indicate numerical progression which is useful for analytical purposes as a nominal scale (Gagge et al 1967). A standard instruction was given all subjects on how to respond.

Ratings of Perceived Discomfort and Pain

A 10 point category scale (Appendix G) as advocated by Morgan and Horstman (1978) was used to rate the perception of discomfort and pain. The above authors found test-retest reliabilities to range from 0,64 to 0,84 across trials separated by a three week period.

Ratings of Perception of Fatigue

The five point category scale of Smith (1968) (Appendix H) was slightly modified by the addition of a zero point and used to rate perceptions of fatigue. Smith found test - retest reliabilities of 0.77 and 0.93 for fatigue threshold and tolerance levels respectively.

STANDARDISATION AND CONTROL OF VARIANCE

Subjects were requested not to alter normal eating patterns throughout the study. They were requested to refrain from undertaking exhaustive exercise on the day prior to, and during the time immediately prior to testing. Further, subjects were instructed not to eat any heavy meals or drink any fluid with caffeine content, within a two hour period before testing. A final requirement was that the subjects wore the same pair of running shoes during each test.

Pre-and Post-Test Questionnaire

A pre-test questionnaire (Appendix I) was administered in order to establish rest/sleep, eating, social and behaviour patterns prior to the test period. The questionnaire further examined subject's moods and motivational state, based on purely subjective responses to questions asked.

A post-test questionnaire (Appendix J) was administered to obtain subject's reasons for stopping. Further assessment of mood and subjective ratings of performance in terms of personal expectations was obtained.

Both the pre- and post-test questionnaires incorporated an adjective list taken from the fatigue Key Cluster Analysis list of Weiser et al (1973). Each adjective was placed along a dimension of severity by using a 5 point Likert-type scale where 1 = absent and 5 = severe. The clusters were labelled 1) Task Aversion, 2) Leg Fatigue and 3) General Fatigue. The test-retest reliabilities for 1 to 3 are 0,75; 0,84 and 0,74 respectively (Weiser et al 1973).

Motivational Tool and Prevention of Boredom

A phenomenon related to fatigue is monotony or boredom. At the lower $_{f}VO_2$ levels, specifically 55%, boredom in carrying out the endurance task was considered to be an important factor.

Following upon the statement of Blum and Naylor (1968) that the characteristic of monotony is that it is dependent upon the individual's perception of the task at hand it was decided that music and the use of videotaped film would help offset the effects of boredom. Consequently, in accordance with the findings of Bushey (1966) and Anshel and Marisi (1978), music as an aid to performance on the physical endurance task was introduced. Further, subjects were free to choose their own music and view videotapes of their choice during any of the applied treatments as they desired.

Feeding

Subjects were allowed to drink water and cola as they desired, and to eat a reasonable range of foods of their own choice. The quantities consumed were determined and recorded.

Privacy

Due regard was given all subjects with respect to privacy. A screened area was provided for weighing of subjects and when obtaining urine samples. Access to the laboratory to observe subjects exercising was limited to the researcher, supervisor and assistants.

GAS ANALYSIS - ON LINE SYSTEM

The measurement of VO_2 levels worked at was done using a system developed and validated by Goslin et al 1984. The following is an extract (with modifications where applicable) taken from the paper validating the system.

The hardware configuration (see Figure 7) enabled the subject to inhale ambient air through the inlet port of the Mijnhardt dry gasmeter where inspired volume was measured. The air proceeded from the outlet of the gasmeter through Collins ridged tubing (3 cm diameter) to a Hans Rudolph 2700 pulmonary valve. Total inspiratory resistance in this system was quite low at 0,3 to 0,5 cm w.p. depending upon the air flow. Expired air was directed, though similar ridged tubing, to a 4 litre Perspex mixing chamber. Within the chamber, a small circulating fan ensured the smooth mixing of the air which was sampled from the chamber at the rate of 750 $ml.min^{-1}$ for analysis. Upon exit from the flow-through mixing chamber, the air passed through a 1 metre section of ridged tubing before venting to the room. This prevented the contamination of the contents of the mixing chamber with room air. The 4 litre volume of the chamber was chosen as being slightly greater than the maximum tidal volume expected during exercise. In this fashion wide fluctuations in the gas fractions were avoided while ensuring a reasonably sensitive response to real changes in air composition. Inspired air temperature was measured by a solid state thermister located inside the gasmeter.

Expired air analysis was performed by a previously calibrated PCI medical Ametek Applied Electrochemistry N-22 oxygen sensor and S-3AI oxygen analyser, and a Gould Godart Capnograph Mark III carbon-dioxide analyser. Heart rate was monitored continuously by a Respironics Exersentry and locally manufactured opto-isolator, the signal then being fed into a Quinton Cardiotachometer (Model 611). Analogue signals from the temperature sensor, the Cardiotachometer and two gas analysers were fed into a multiplexor and then into a 12 bit, 8 port analogue-to-digital converter. The subsequent digital signals were sequentially sampled, at a rate of approximately 220 times per minute, by a South West Texas 6800 microcomputer (32 K core memory). On-going visual feedback of oxygen consumption, ${}_{f}VO_2$ max. rate of change of oxygen consumption, respiratory exhange ratio, treadmill speed and elapsed time were provided on the computer's video display terminal. A permanent record of all measured and computed parameters was output to the C-Itoh dot matrix printer at each specified time interval.

The following data are printed after every sample: experiment elapsed time, sample duration, VO_2 (ml.$^{-1}$.kg^{-1}.min), VO_2 (1.min^{-1}), ${}_{f}VO_2$ max. (%), VCO_2 (1.min^{-1}), respiratory exchange ratio, minute volume inspired, heart rate, ventilatory equivalent for O_2 and CO_2, oxygen pulse, ventilatory frequency, tidal volume and estimates of cardiac output and stroke volume (Consolazio _et al_ 1963, Faulkner _et al_ 1977). In addition, the gas fractions of O_2 and appropriate STPD factor are recorded for each sample, as well as the treadmill speed.

During the developmental phase, all aspects of the hardware were calibrated against known standards. Volume calibration was performed, in a pulsatile manner, against a Singer gasmeter previously calibrated by the negative pressure water removal method. The mixing box fractions were compared to bags of expired air collected simultaneously. The computer sample timer was compared to several digital clocks. The gas temperature probe was immersed in a water bath and found to be linear from 0 to 38 degrees. Heart rate and ventilation rate were compared with those obtained by conventional palpation techniques.

STATISTICAL ANALYSES

Related Students T-tests (Ferguson 1981) were done to determine whether significant differences occurred between test-retest measured parameters recorded during pilot testing. This was necessary to determine whether the test procedures adopted were reliable.

A two factor analysis of Variance (Ferguson 1981) was done in order to examine the relationship between duration of activity as percent of time (factor one) and relative intensity (percent VO_2 max.), being factor two. Factor one (percent time) had four levels namely 25%, 50%, 75% and 100% of duration of activity. Factor two (percent VO_2 max.) had four levels namely 55%, 65%, 75% and 85% of max. VO_2. A post hoc analysis in the form of a Sheffe test (Ferguson 1981) was done in order to establish where the significant differences between levels occurred, if any.

A One Independent Variable Linear Regression (Ferguson 1981) was done in order to extrapolate the relationship between work intensity (percent VO_2 max.) and duration of activity (absolute time to exhaustion).

Pearson Product Moment Correlation Coefficients (Ferguson 1981) were calculated to examine the relationships between heart rate, RPE,mean body temperature, perceived thermal comfort, pain perception, fatigue perception, extroversion and endurance time.

A multiple Regression Analysis (Ferguson 1981) was performed on all physiological and psychological data obtained, yielding a coefficient of multiple correlation which assisted to elucidate the interrelationship of the variables measured. The relative contribution of each variable to the cessation of exercise was accessed by calculating ratios of convergence using the coefficients of variation (Ferguson 1981).

In order to reduce the probability of committing a type I error without increasing the probability of committing a type II error, a 0,05 level of significance was chosen for all of the above statistics.

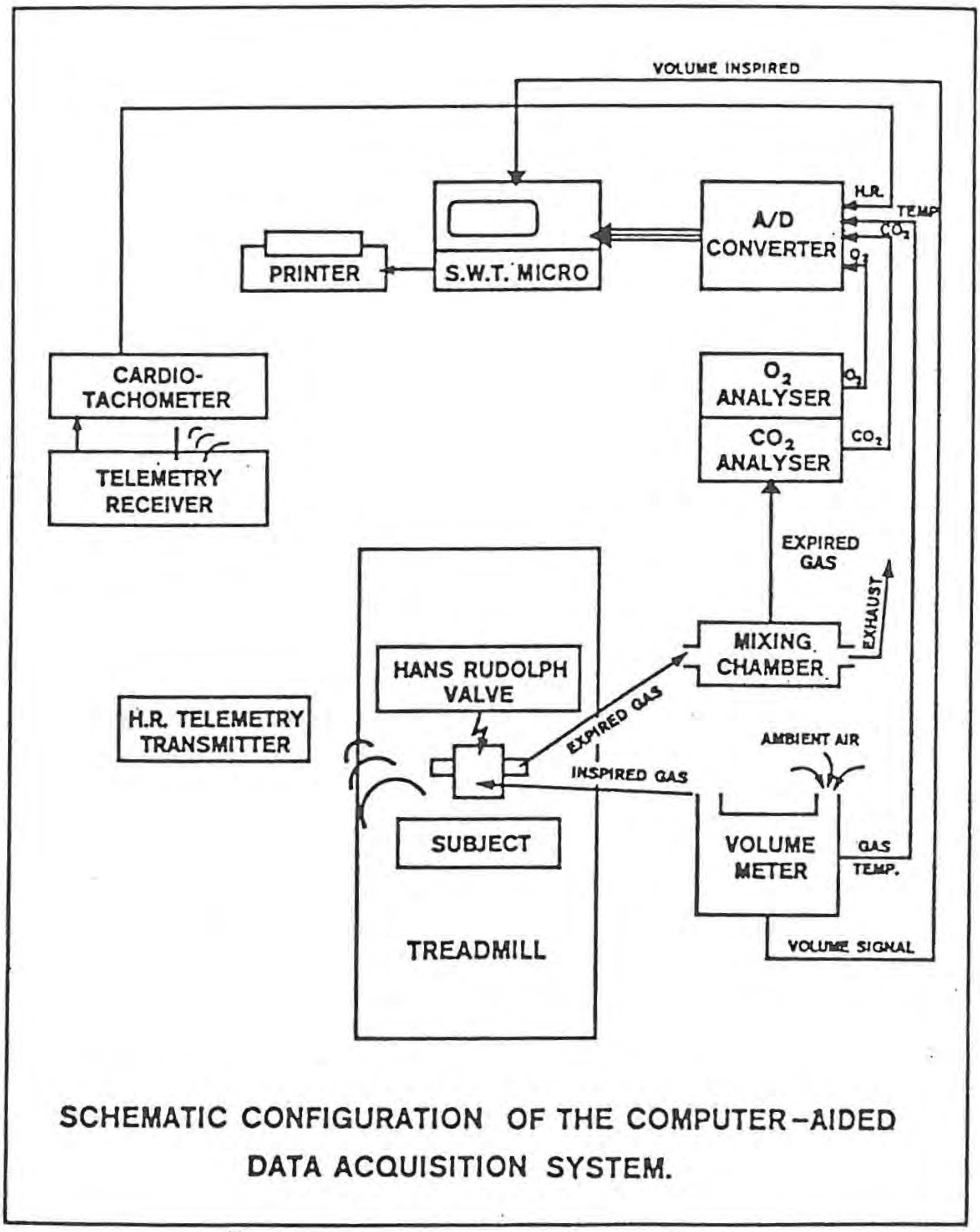

Figure 7 : A schematic illustration of the hardware configuration of the on-line computer-aided data acquisition system used in this study.

CHAPTER 4

RESULTS AND DISCUSSION

PILOT TESTING RESULTS

The prime aim of the pilot testing was to examine the reliability of the test protocol which was employed, i.e. the calibration of gas analysis equipment and the consistency of the control of the fraction of VO_2 max. at which the subject was working.

Table II: VO_2 max. ($ml.kg^{-1}.min^{-1}$) recorded for three subjects on two different occasions.

Subject	VO_2 Max.Test 1	VO_2 Max.Test 2	P<0,05
PC	57	57,7	
SR	56,2	52,7	
MW	67,3	66,0	
$\bar{X}$	60,2	58,8	1 = 2
σ	6,2	6,7	

The mean intra-subject coefficient of variation for the above testing was 2,26%. A related students T-test demonstrated no significant differences between the test results obtained ($p < 0,05$). On the strength of these results the VO_2 max. test protocol used was seen to be reliable.

Further related students T-tests demonstrated no significant differences between test-retest values at 85% of VO_2 max ($p < 0,05$) for the following measured parameters: absolute time to exhaustion, heart rate, RPE general, RPE legs, blood pressure, and oral temperature at cessation of exercise, as well as change in body mass after each test. On the basis of these results the test protocol employed was determined to be reliable. (See Appendix K).

PHYSICAL CHARACTERISTICS OF THE SUBJECTS

Table III : Summary of physiological data recorded on 10 subjects

Subject	Age (years)	Stature (cm)	Mass (kg)	Body Fat %	B.S.A. (m^2)	VO_2 Max ($ml.kg^{-1}.min^{-1}$)	Max. Mets
PC	24	183,4	68,2	8,4	1,89	57.7	16,5
GD	26	179,2	73,4	11,4	1,92	69,3	19,8
AH	27	173,5	67;3	9,1	1,81	61,4	17,5
AJ	34	182,0	88,0	17,1	2,10	48,7	13,9
AL	23	183,0	77,2	10,5	1,99	59,6	17,0
DM	25	174,4	68,8	9,1	1,83	64,7	18,5
LR	25	173,0	76,0	17,7	1,90	46,7	13,3
SR	31	162,3	62,0	18,2	1,66	56,0	16,0
AS	26	182,6	78,0	7,5	1,99	68,7	19,6
MW	22	174,2	63,3	10,1	1,77	67,3	19,2
$\bar{X}$	26,3	176,8	72,2	11,9	1,89	60,0	17,1
σ	3,65	6,64	7,88	4,1	0,13	7,9	2,3
CV (%)	13,9	3,8	10,9	34,5	6,9	13,2	13,5

It is clear that the subjects on the whole are well conditioned individuals (Table III) with high physical working capacities. This is evident from the mean VO_2 max. recorded (60 $ml.kg^{-1}.min^{-1}$) which is considerably above the level of 43,0 $ml.kg^{-1}.min^{-1}$ of oxygen recorded by Astrand and Rodahl (1977) for untrained subjects. The range of VO_2 max. levels recorded in this study was from 46,7 to 69,3 $ml.kg^{-1}.min^{-1}$. Thus, even the lowest value recorded comes from an individual who may be regarded as reasonably well conditioned.

ENVIRONMENTAL CONDITIONS

The average environmental conditions that the subjects were exposed to during the four treatment conditions were as follows:

Barometric Pressure	719,1 mm Hg	(± 3,37)
Temperature (dry)	18,7^{o}C	(± 2,4)
Temperature (wet)	15,0^{o}C	(± 1,4)
Relative Humidity	63,8%	(± 7,2)

RESULTS OF THE FOUR TREATMENT CONDITIONS

Nine subjects completed the required four treatment conditions at 55%, 65%, 75% and 85% of VO_2 max. The tenth subject (AS) completed three of the required treatments, being unable to undertake the condition at 85% of max. VO_2 due to injury. Thus 39 of the 40 data points were obtained. The missing data point for AS was established by use of the mean of the remaining nine subjects, and applied to all of the measured and derived data at 85% of VO_2 max. The rationale for this step was as follows: The means and standard deviations recorded for absolute time to exhaustion at each treatment level (i.e. 55%, 65% and 75%) were checked against the value obtained by AS. AS was always within one standard deviation of the mean. It was further observed that subjects low on exercise duration time at 85% appeared high at 55%, and vice versa. A students T-test between those over the mean at 55% and those below the mean at 55% was done for A) the duration of activity at 55% and B) the duration at 55%. A significant difference ($p < 0,05$) was found at 55% but not at 85%. Those subjects above the mean at 55% recorded an 18,25 minute $\pm$6,5 minute duration at 85% and those below the mean at 55% a 24,2 minute $\pm$9,3 minutes duration at 85%. There being no significant difference here it was decided to apply the mean value of the nine subjects for AS's missing data measures at 85% $_{f}VO_2$ max.

Table IV : Recorded mean, standard deviation and coefficient of variation values for $_{f}VO_2$ max. at which the subjects actually worked.

Relative intensity % VO_2 Max.	Relative intensity (% Max) Actually worked at	$\bar{X}$	CV %
55	55,6	1,17	2,3
65	64,3	3,13	4,9
75	75,2	1,62	2,2
85	84,9	1,91	2,3
	$\bar{X}$	1,96	2,9

In view of the above results the original pre-requisite working levels of 55%, 65%, 75% and 85% of $_{f}VO_2$ max. may be said to have been achieved.

The endurance times to exhaustion which were recorded are reported in Table V and graphically represented in Figures 8 and 9. As expected the greater the intensity of exercise the shorter the work duration. Further, the higher the work intensity the lower the standard deviation in recorded times to exhaustion. This is not surprising given the known physiological limits to endurance performance as clearly the closer an individual approaches maximum capacity the less able he is of sustaining work output.

Table V : Mean endurance times (min.) to exhaustion of ten subjects showing standard deviation and coefficient of variation (%).

	Intensity (% of VO_2 max.)			
Subject	55	65	75	85
PC	202	143	94	29
GD	193	148	58	28
AH	358	218	95	15
AJ	202	160	155	35
AL	166	116	83	14
DM	321	229	96	28
LR	200	138	102	15
SR	335	150	80	15
AS	196	158	100	22
MW	255	126	95	15
$\bar{X}$	243	159	96	23
σ	70	37	25	8
CV	288	23,3	26,0	34,5

55% ≠ 65% ≠ 75% ≠ 85%
($p < 0,05$)

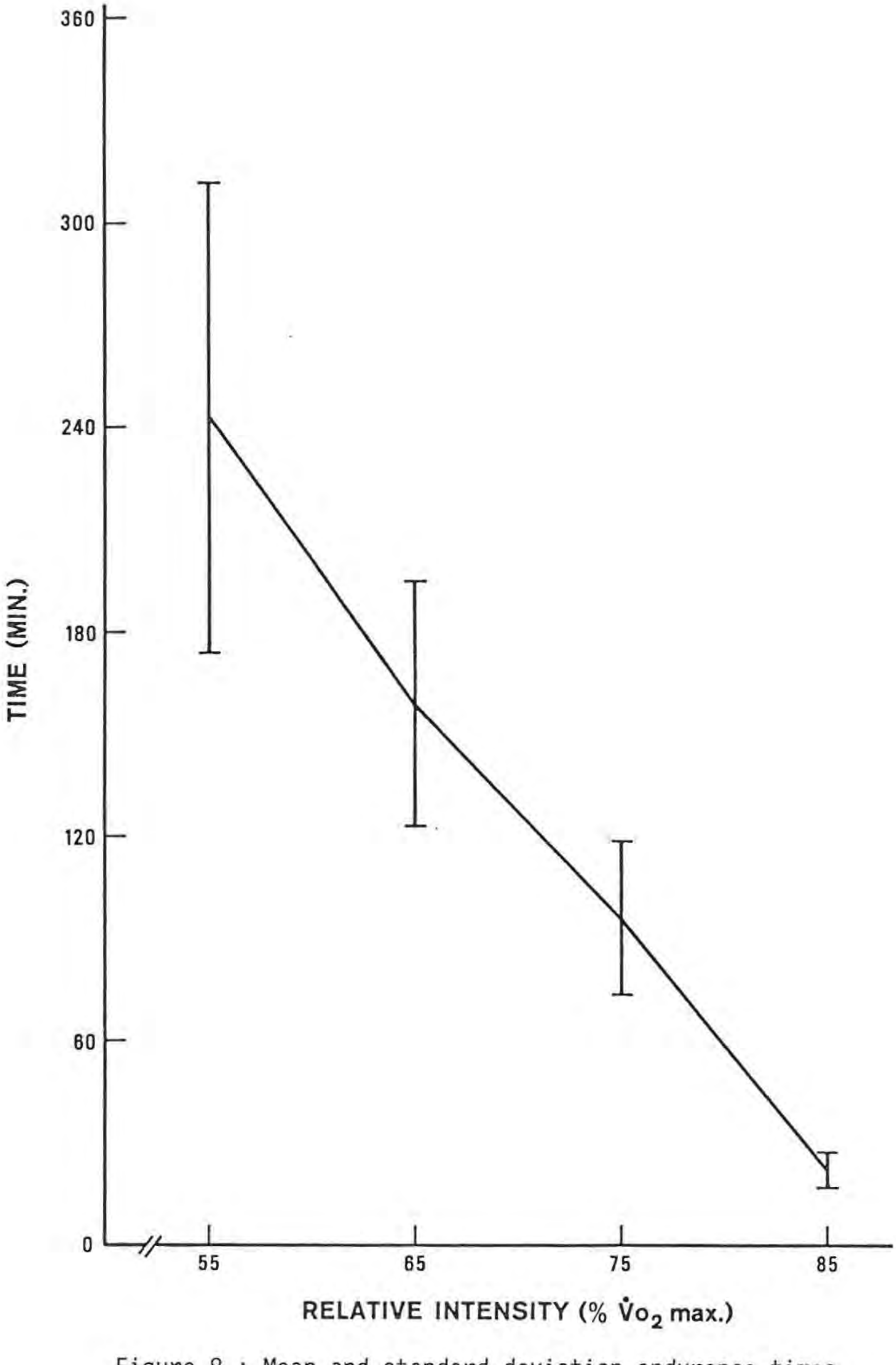

Figure 8 : Mean and standard deviation endurance times (min) of 10 subjects working at four different relative intensities (% VO_2 max).

(55% ≠ 65% ≠ 75% ≠ 85% p<,05)

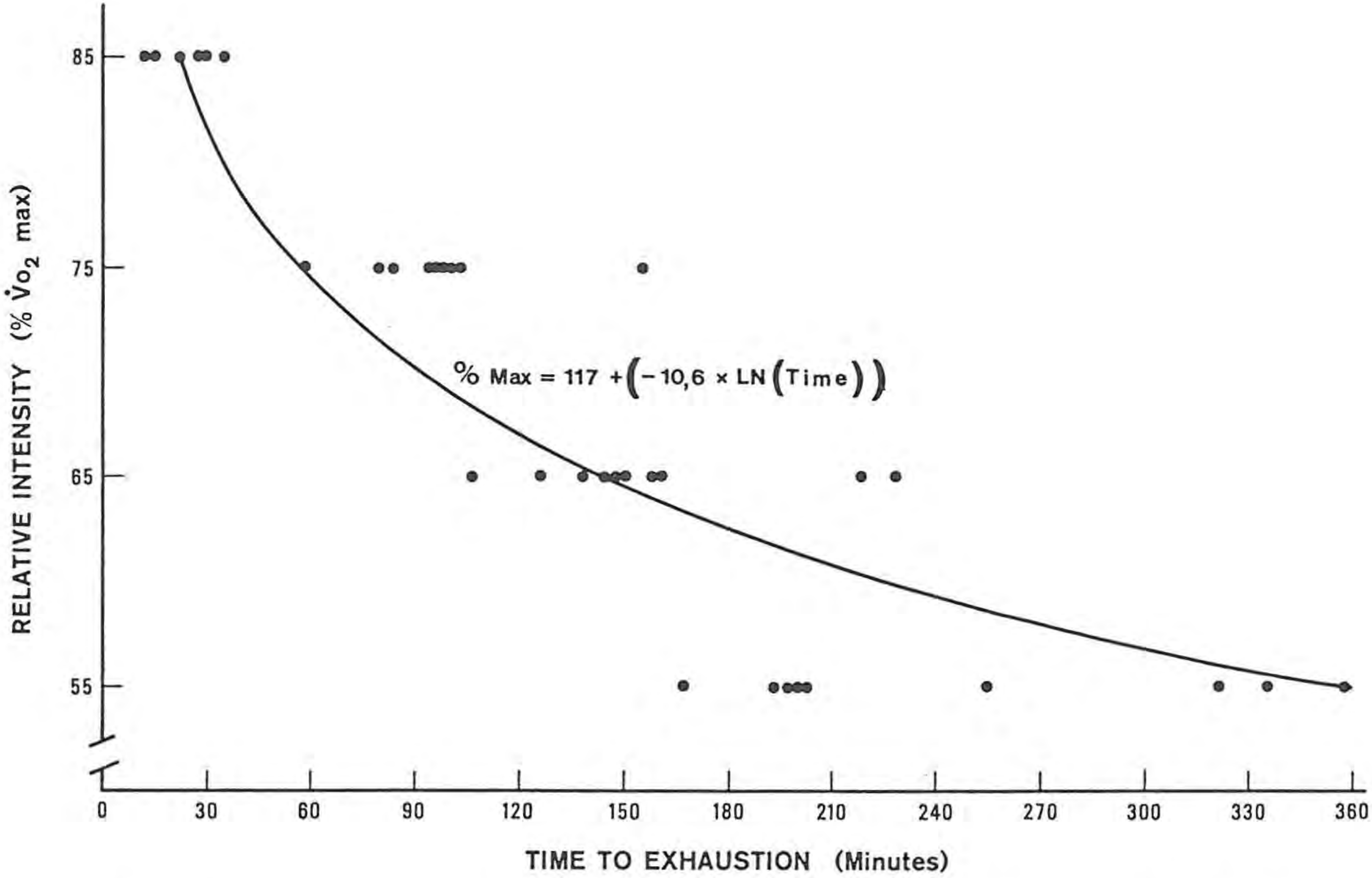

Figure 9 : Scattergram and Regression Line (Y = A + B X LN(X)) of Endurance Time (Min.) at Various Relative Intensities (% VO_2 max.)
(55% ≠ 65% ≠ 75% ≠ 85% p<0,5)

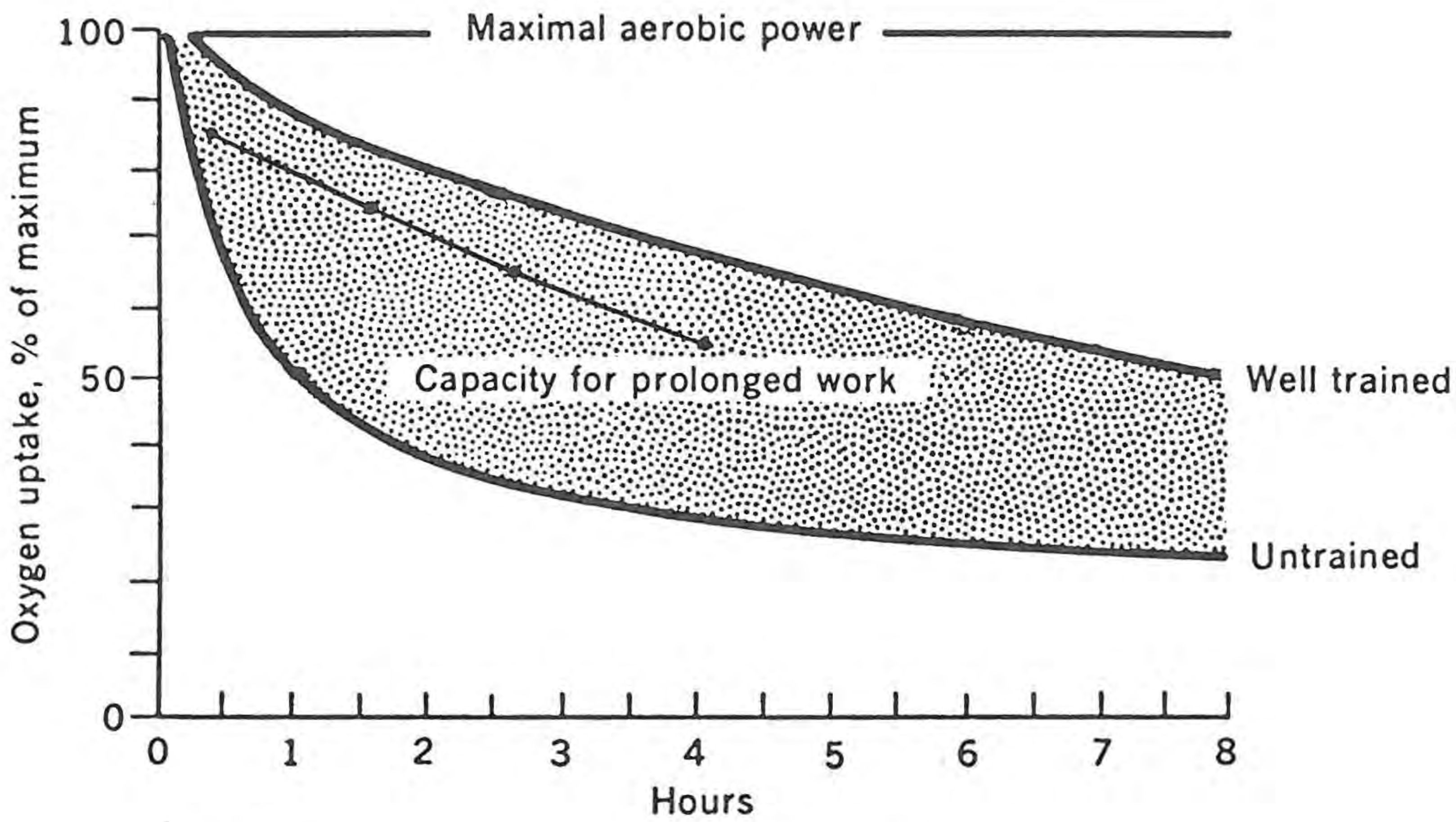

Figure 10 : A graphic illustration showing approximately the percentage of a subject's maximal aerobic power he can tax during work of different duration, and how this is affected by his state of training. (From Astrand & Rodahl 1970). The centre line represents data recorded in the present study.

The endurance times recorded in this study fall well within the range for trained and untrained subjects as reported by Astrand and Rodahl (1970). (See Figure 10). The subjects in this study appear to be poorly trained for work at high intensities as the endurance times recorded for the 85% relative intensity condition tend to be on the untrained continium (Figure 10). The highest intersubject variance (34,5%) occurred with this treatment condition. The subjects appear to be better able to tolerate work at the 55%, 65% and 75% $_fVO_2$ max. treatment levels as the endurance times for these treatments tended to be on the trained continuum. The intersubject variance was 28,8%, 23% and 26% respectively. The times to exhaustion at 55% relative intensity were much higher than those found by Weiser _et al_ (1973) whose subjects cycled at 56% of max. VO_2 for 34 minutes $\pm$ 23; but compare very favourably with endurance times of 268 min $\pm$12 which were established in a control group of 10 subjects walking at 45% of VO_2 max. by Ivy _et al_ (1983).

Based upon the recorded endurance times to exhaustion a prediction equation was developed for endurance times when working at a known percentage of VO_2 max. ranging between 55% and 85% of maximum:

$$\% \text{ MAX } VO_2 = 117{,}8 + (- 10{,}6 \text{ X } \ln (\text{time}))$$

In correlation coefficient (r) established was - 0,91 with a resultant coefficient of determination (r^2) of 0,83. Thus 83% of the variance in endurance time an individual achieved could be accounted for by the fraction of his maximal VO_2 at which he worked. The predictive index is 0,59 i.e. there is a 59% better than chance alone of obtaining the correct endurance time, given a known $_fVO_2$ max. worked at.

In accessing limits to prolonged work the necessity for explaining the variance in endurance times appears self evident. A factor contributing to this variance is inherent individual biological variability in energy expenditure, this being a consequence of tremendously complex response patterns of the human organism to any one stimulus (Katch et al 1982). At least some of the variance in endurance times established in this study can be accounted for by the fact that VO_2 max. can be expected to vary within a range of $\pm$ 5,6%, 68% of the time and for 98% of the time it can be expected to vary within a range of $\pm$11,2%. Technological error accounts for only 10% of this variability (Katch et al 1982). In addition to the variance in VO_2 maximum upon which the predetermined $_fVO_2$ max. treatments were based, it is necessary to consider the variance in the energy expenditure response of the individual upon exposure to the varying treatments as well as during the treatments. In men a coefficient of variation of up to 10% can be expected when actively engaged in different activities (Durnin and Namyslowski 1958). Differences in response may be due to an extrinsic factor such as the specific dynamic action of a meal, previous exercise, psychological variables, or merely circadian fluctuations as argued by Shephard (1984).

In view of the intra-subject variance which may occur in both VO_2 max. values measured and the intra-subject fluctuations in energy expenditure responses from test to test and during testing, the intersubject variation in endurance times recorded in this study (Mean CV = 28,15%; range 23,3% to 34,5% may be regarded as reasonably low. This is especially so in view of the dynamic nature of these endurance treatments and when compared with static submaximal endurance repeatability tests cited by Simonson (1971) where intra-subject coefficients of variation of 20% were found. The task remaining is to elucidate those additional factors which contribute to the total variance, leading ultimately to the exposition of the gestalt limiting prolonged physical work.

The graphical illustrations produced as part of the results of this study have been divided into two clear sections in order to simplify the discussion. Thus the physiological and psychological differences between intensities (Figures 11 to 18) are reported separately from the physiological and psychological changes over time (Figures 19 to 32). This is done not to detract from the aim of examining the interactive limits to prolonged work both across intensities and over time, but merely to simplify the process.

Examination of Figures 11 to 17 clearly demonstrates the increasing intensity of stress responses as a function of added external work load (Weiner 1982). The linear relationship between increases in work rate and the physiological parameters of metabolism (Astrand and Rodahl 1977, McArdle et al 1981) is obviously apparent. Heart rate, respiratory exchange ratio, ventilation frequency, tidal volume, blood pressure, mean body temperature and sweat rates increase as a function of working at a higher relative intensity. It is beyond the scope of this study to explain at the micro-level the existence of these defined relationships. To any reasonably well informed reader the relationships are self-evident and are adequately interpreted by a host of individuals as cited throughout this study such as Astrand and Rodahl (1977).

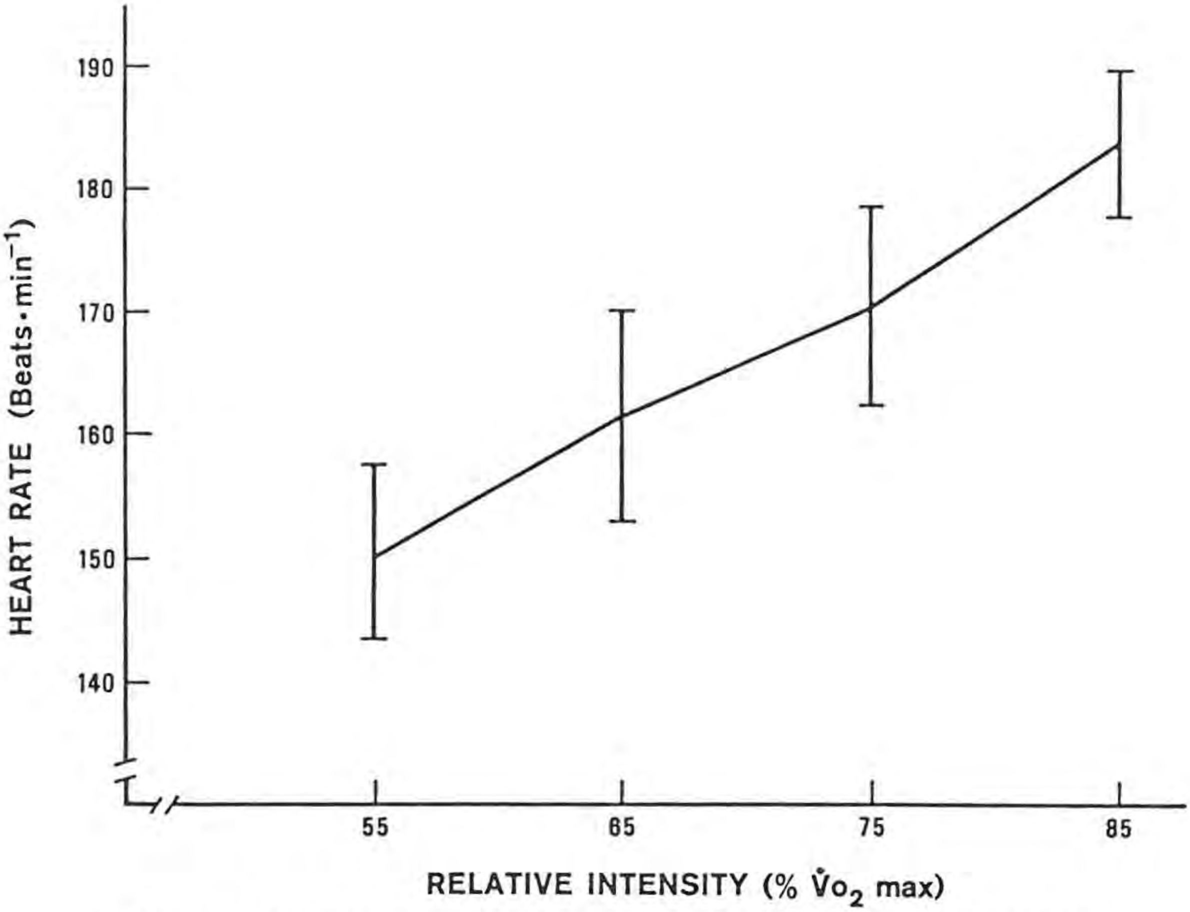

Figure 11 : Mean and standard deviation heart rate response (beats·min^{-1}) of 10 subjects at different relative intensities (% VO_2 max.)
(55% ≠ 65% ≠ 75% = 85% $p<0,05$)

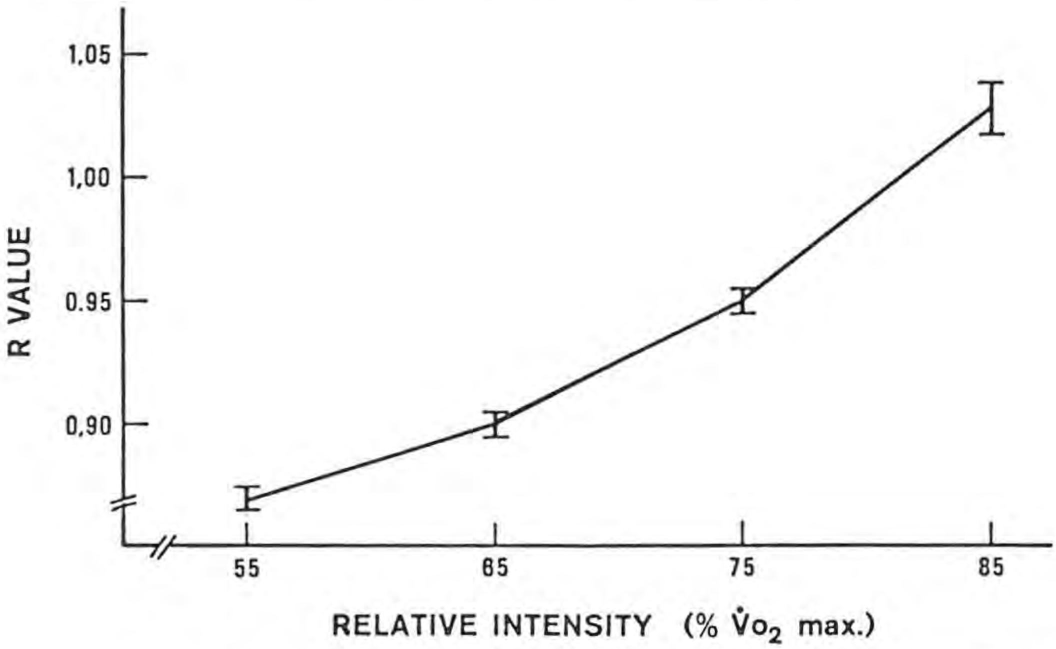

Figure 12 : Mean and standard deviation ventilatory exchange ratio (R) responses of 10 subjects at different relative intensities (% VO_2 max.)
(55% ≠ 65% ≠ 75% ≠ 85% $p<0,05$).

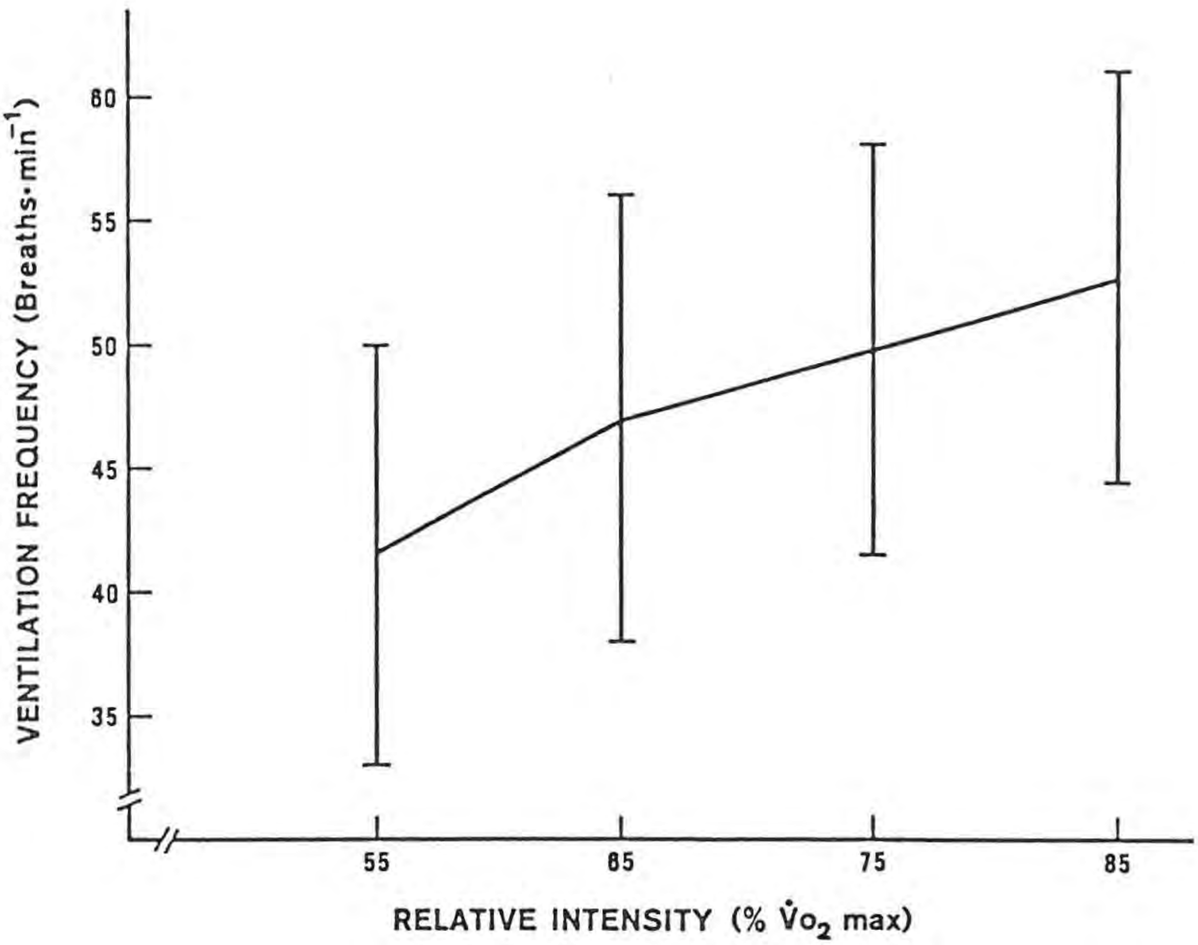

Figure 13 : Mean and standard deviation ventilation frequency (breaths.min^{-1}) response of 10 subjects at different relative intensities (% VO_2 max.) (55% = 65% ≠ 75% = 85% $p<0,05$)

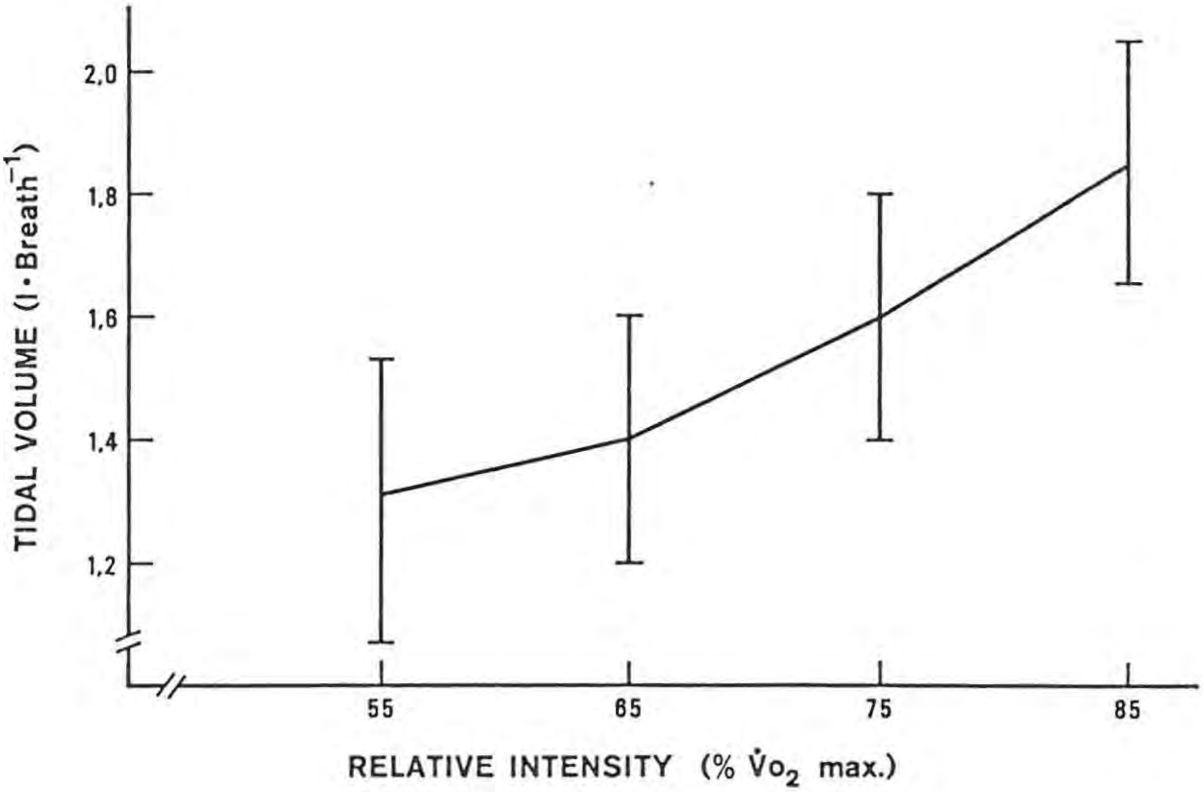

Figure 14 : Mean and standard deviation tidal volume ($l.breath^{-1}$) response of 10 subjects at different intensities (% VO_2 max.) (55% = 65% ≠ 75% ≠ 85% $p<0,05$).

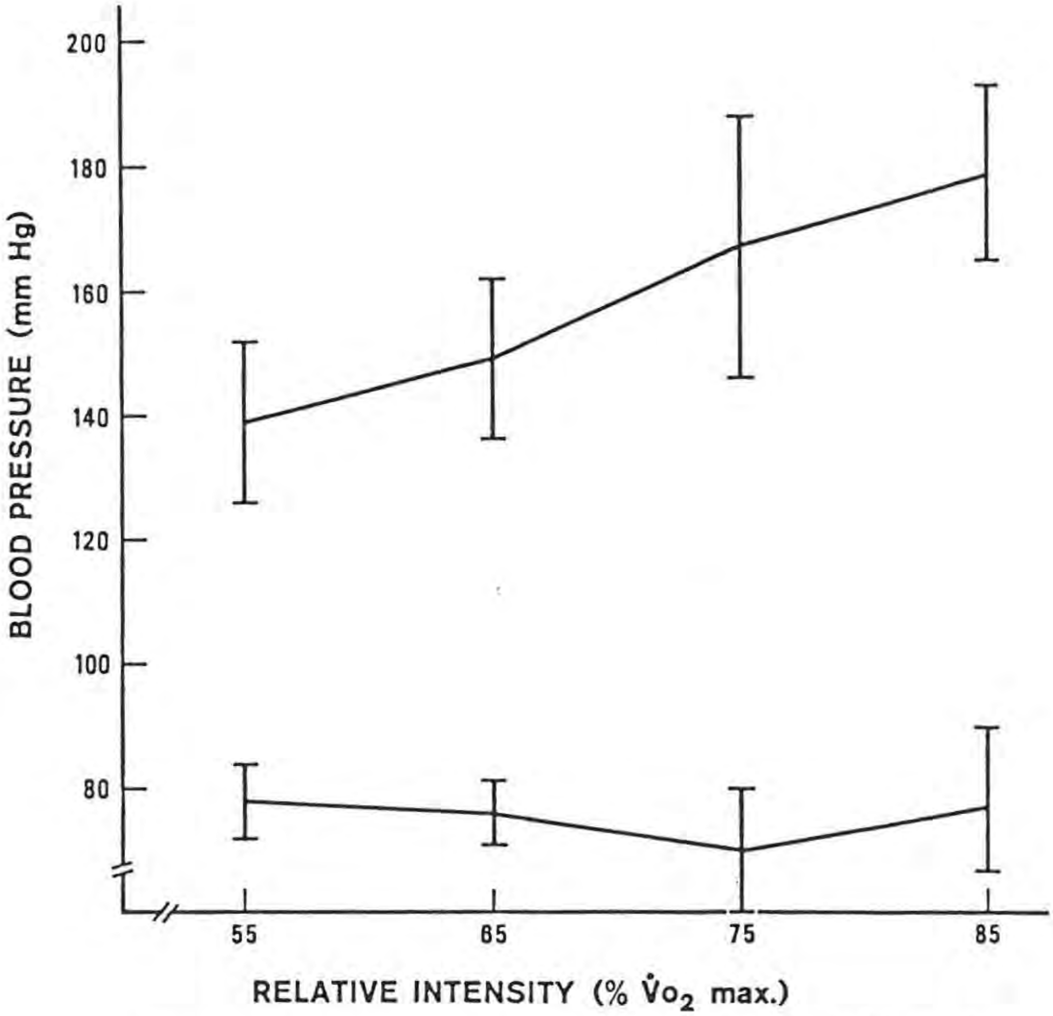

Figure 15 : Mean and standard deviation systolic and diastolic blood pressure (mmHg) response of 10 subjects at different relative intensities (% VO_2 max.).

(Systolic B.P.: 55% = 65%; 55% ≠ 75%; 65% = 75% ≠ 85% $p<0{,}05$)

(Diastolic B.P. : 55%= 65% = 75% = 85% $p<0{,}05$)

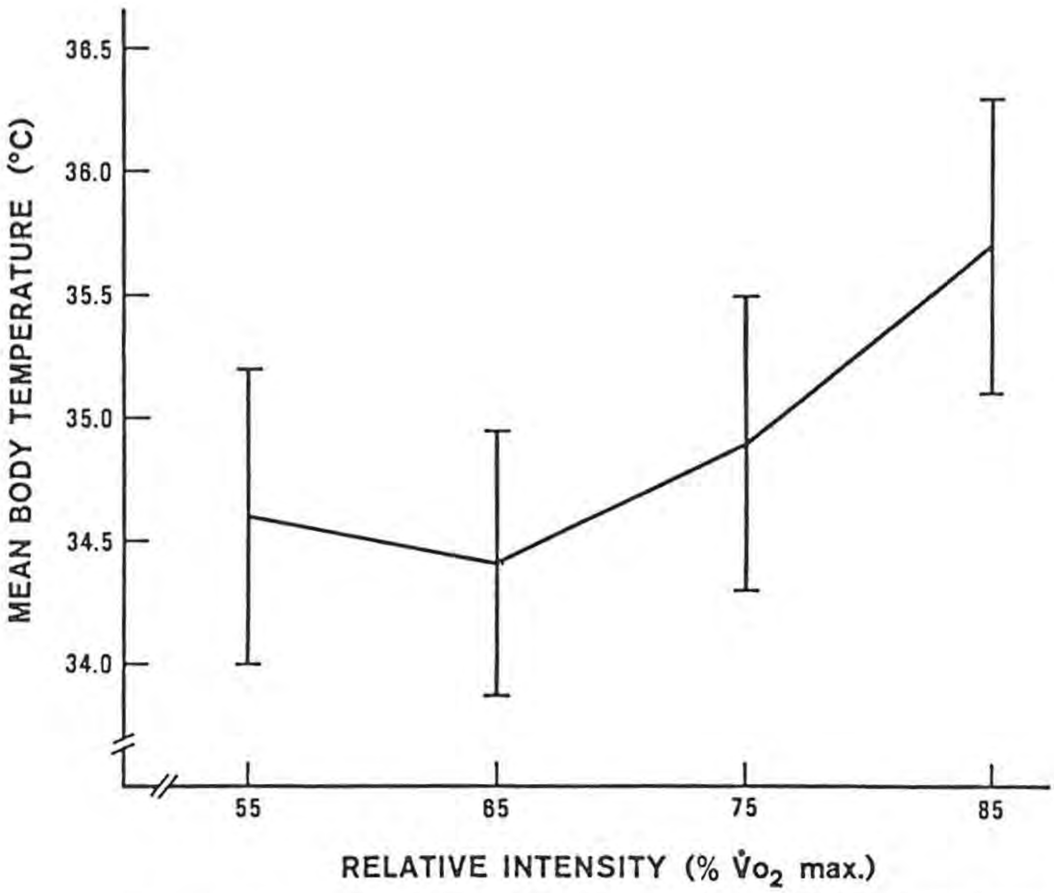

Figure 16 : Mean and standard deviation mean body temperatures (^{o}C) at cessation of exercise of 10 subjects at different relative intensities (% VO_2 max.) (55% = 65%; 55% ≠ 75%; 65% = 75% ≠ 85% $p<0,05$)

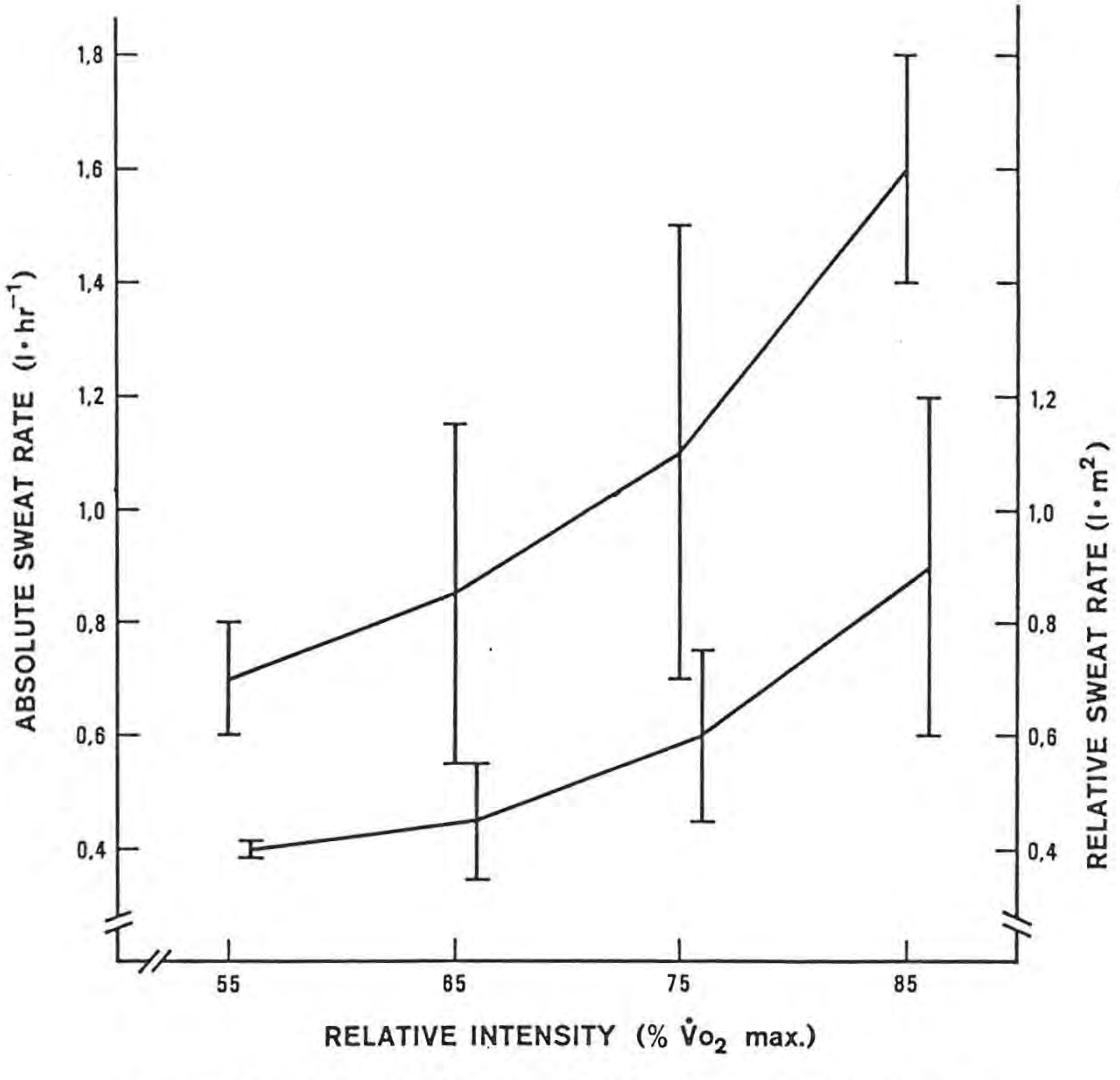

Figure 17 : Mean and standard deviation absolute sweat rates ($l.hr^{-1}$) and relative sweat rates ($l.m^2$) of 10 subjects at different relative intensities (% $VO_2max.$).
(Absolute sweat rate: 55% = 65%; 55% ≠ 75%, 65% = 75% ≠ 85% $p<0,05$)
(Relative sweat rate : 55% = 65%; 55% ≠ 75%; 65% = 75% ≠ 85% $p<0,05$)

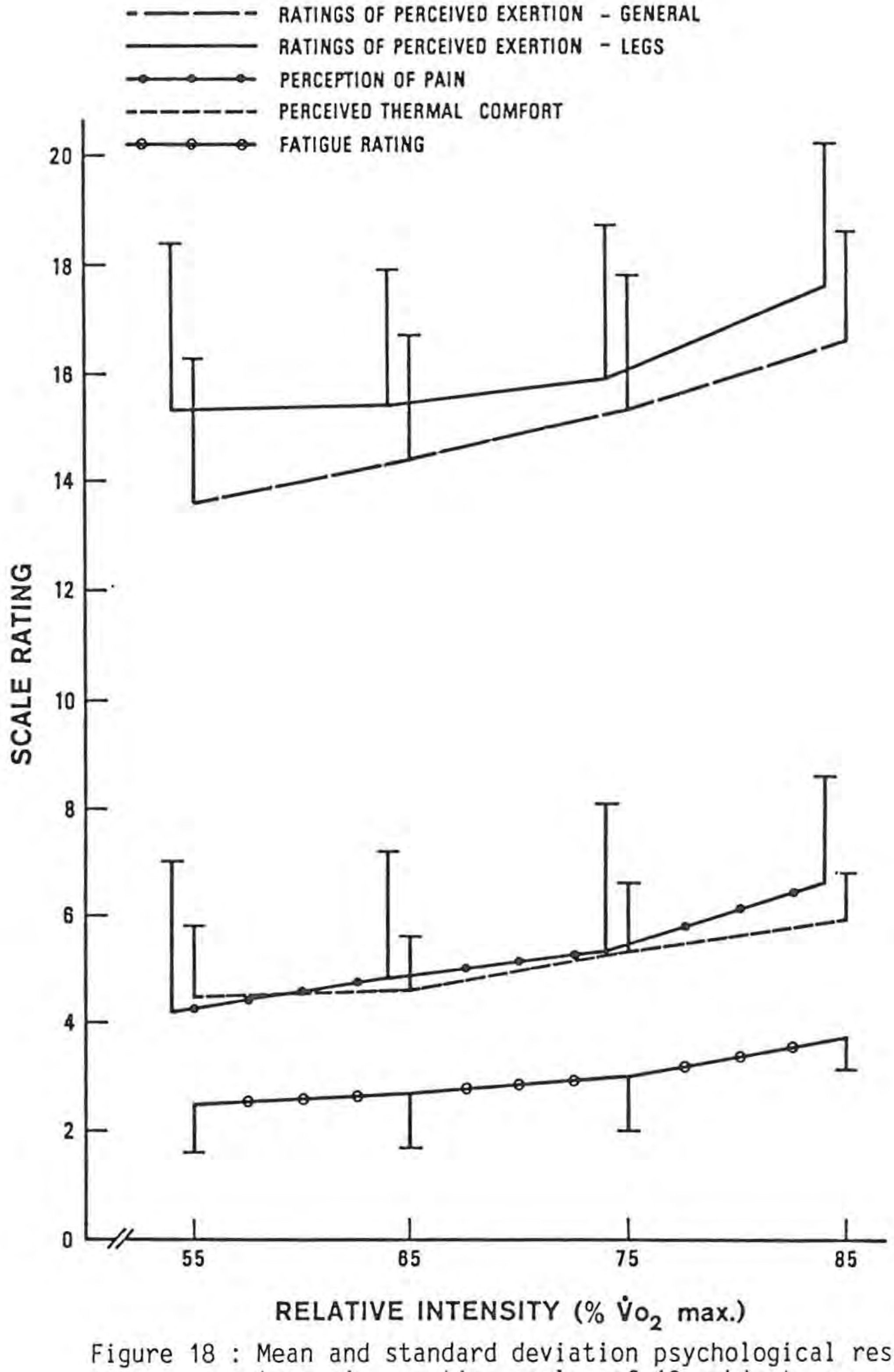

Figure 18 : Mean and standard deviation psychological responses to various rating scales of 10 subjects exposed to different relative intensities (% VO_2 max).

(RPE Legs : 55% = 65% = 75%; 55% = 65% ≠ 85%; 75% = 85% $p<0,05$)
(RPE General : 55% = 65%; 55% ≠ 75%; 65% = 75% ≠ 85% $p<0, 05$)
(Thermal Comfort : 55% = 65%; 55% ≠ 75%; 65% = 75%; 65% ≠ 85%; 75% = 85% $p<0,05$)
(Pain : 55% = 65%; 55% ≠ 75%; 65% = 75% ≠ 85% $p<0,05$)
(Fatigue : 55% = 65%; 55% ≠ 75%; 65% = 75% ≠ 85% $p<0,05$)

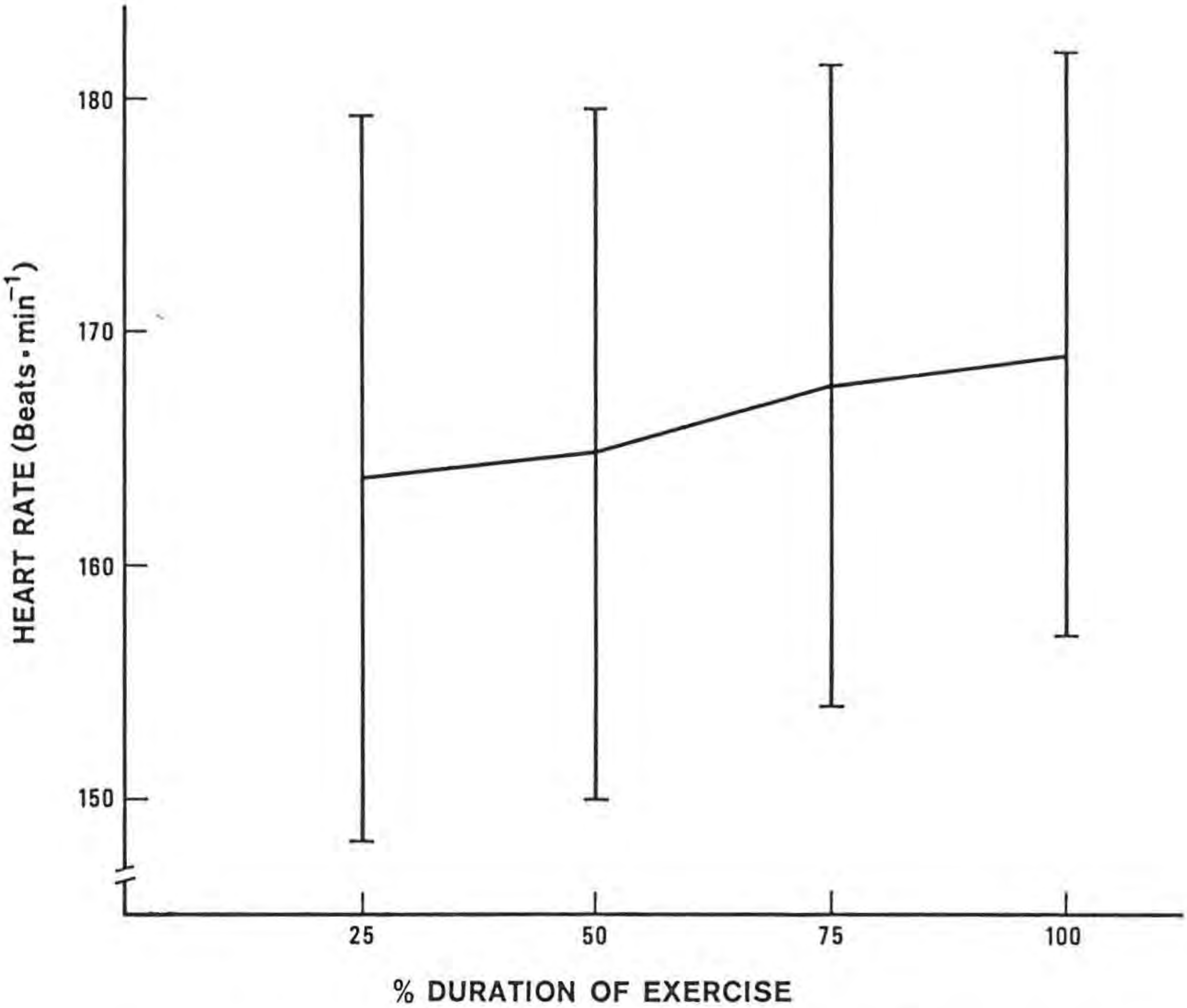

Figure 19 : Mean and standard deviation heart rate (beats.min^{-1}) change over time (% duration of exercise) for 10 subjects; mean of all relative intensities combined. (25% = 50% = 75%; 25% ≠ 100%; 50% = 75% = 100% $p<0,05$)

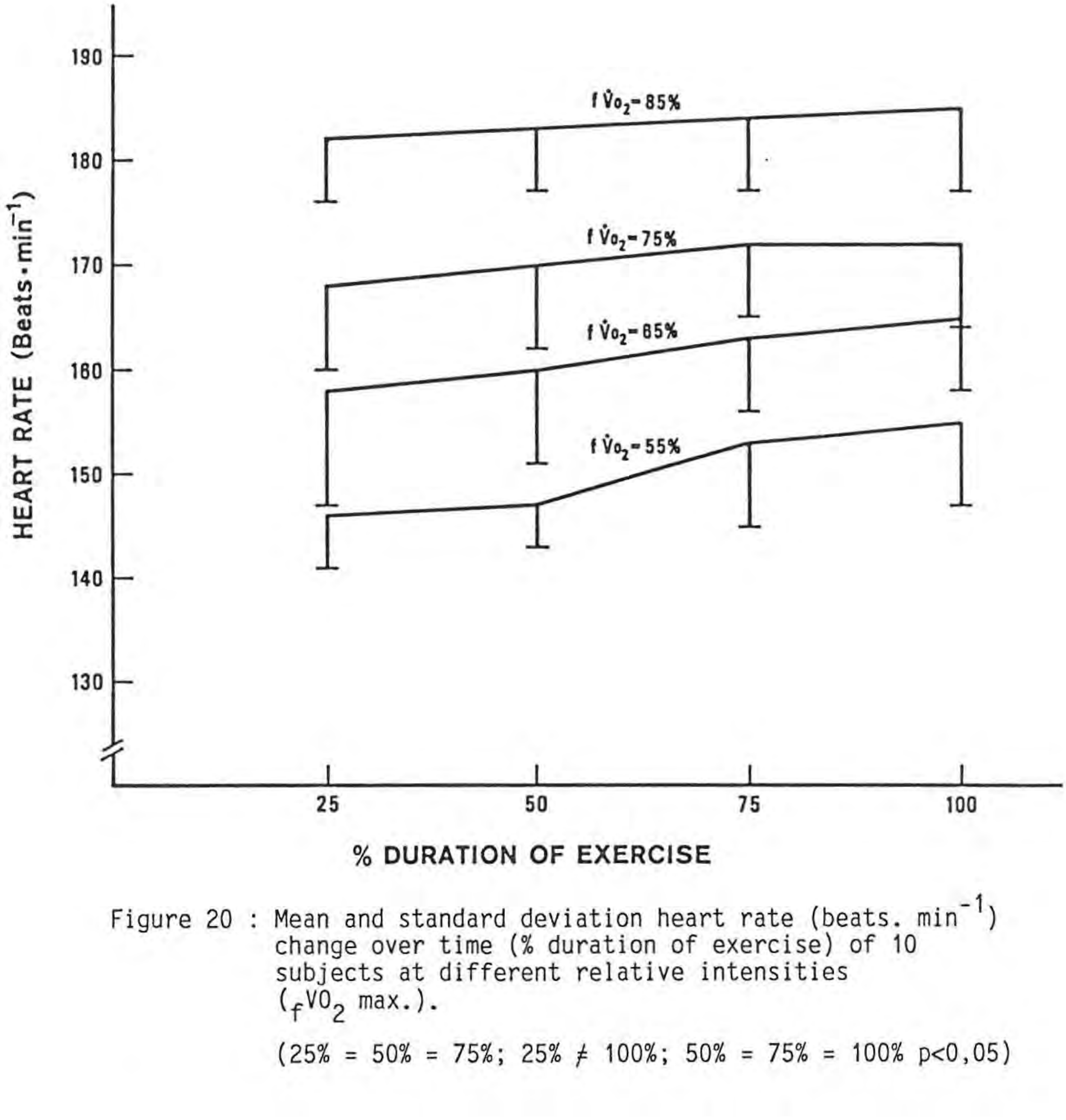

Figure 20 : Mean and standard deviation heart rate (beats. min^{-1}) change over time (% duration of exercise) of 10 subjects at different relative intensities ($_f VO_2$ max.).

(25% = 50% = 75%; 25% ≠ 100%; 50% = 75% = 100% $p<0,05$)

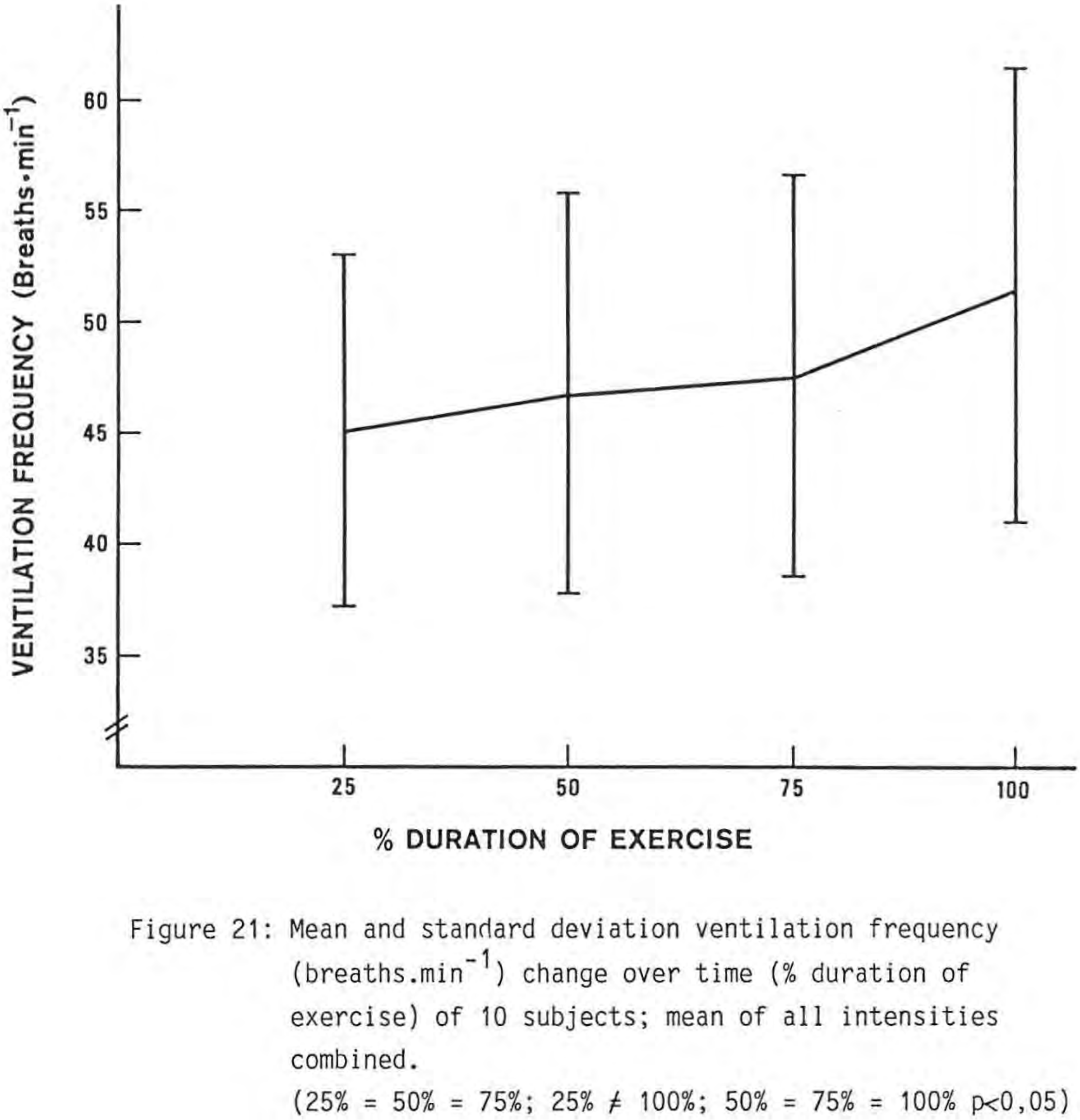

Figure 21: Mean and standard deviation ventilation frequency (breaths.min^{-1}) change over time (% duration of exercise) of 10 subjects; mean of all intensities combined.
(25% = 50% = 75%; 25% ≠ 100%; 50% = 75% = 100% $p<0{,}05$)

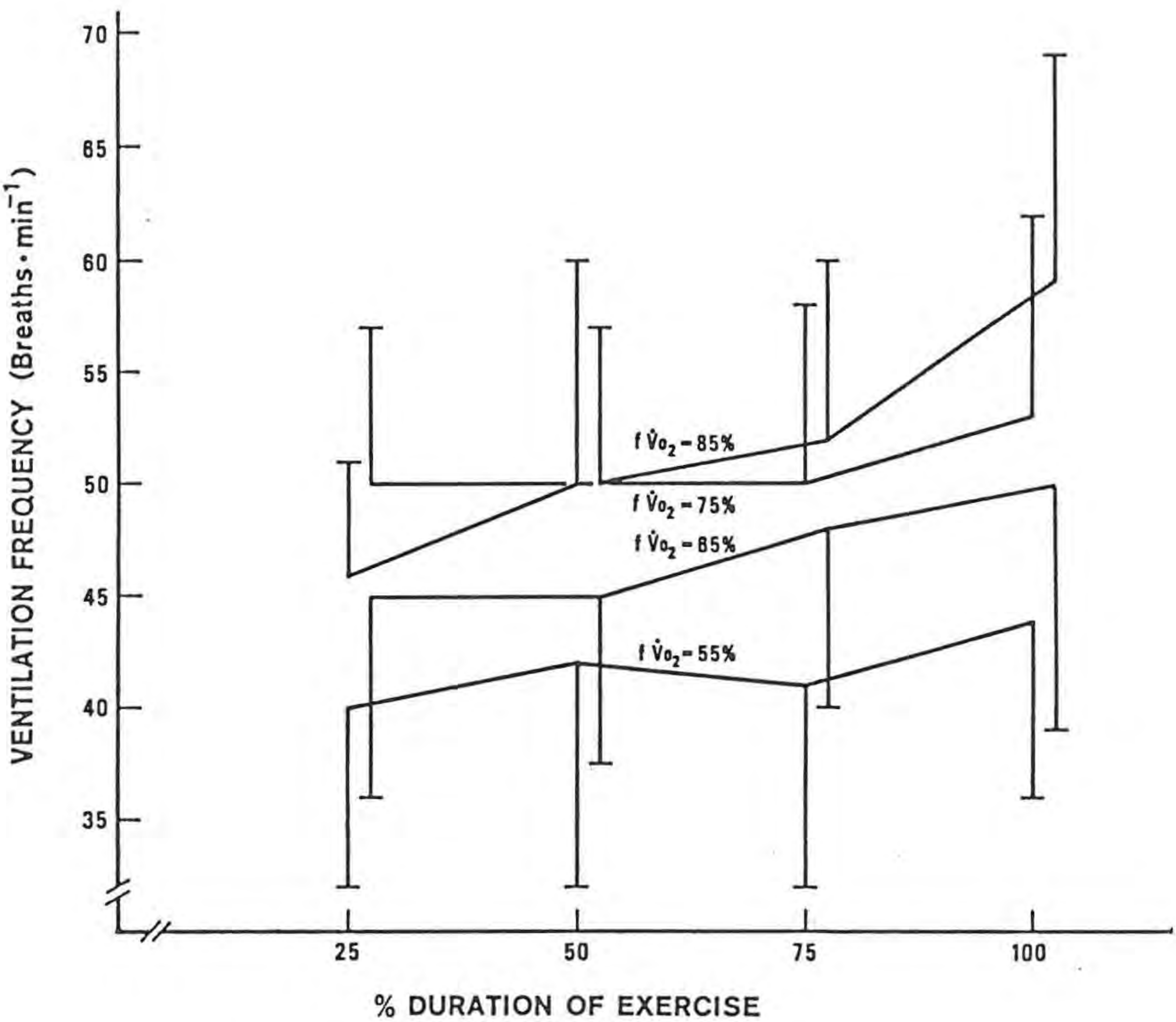

Figure 22 : Mean and standard deviation ventilation frequency ($breaths.min^{-1}$) change over time (% duration of exercise) of subjects exposed to different relative intensities ($_fVO_2$ max.).
(25% = 50% = 75%; 25% ≠ 100%; 50% = 75% = 100% $p<0,05$)

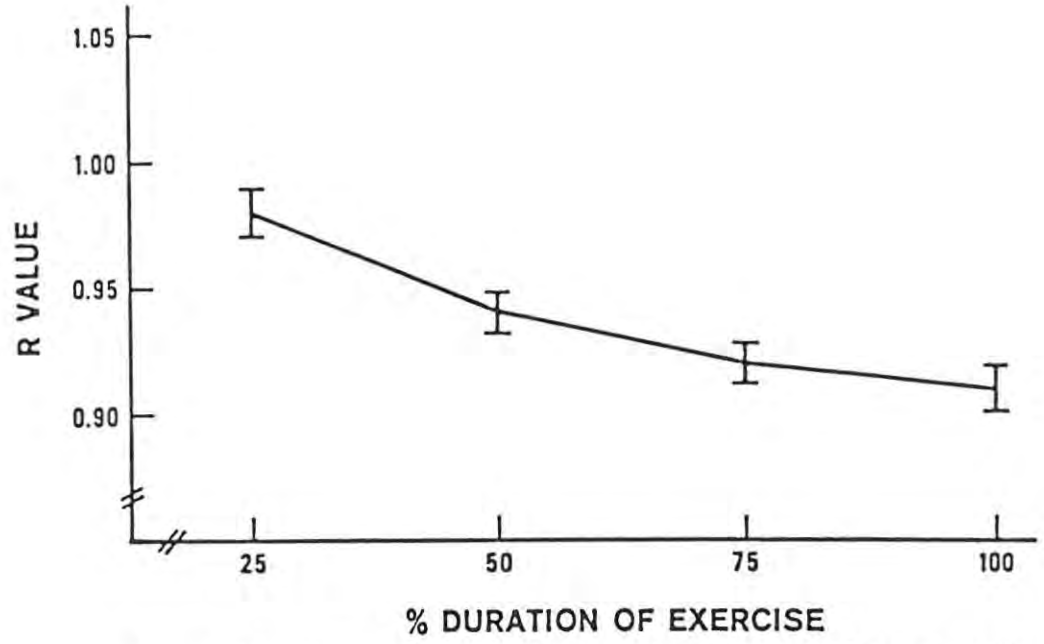

Figure 23 : Mean and standard deviation ventilatory exchange ratio (R) change over time (% duration of exercise) of 10 subjects, mean of all intensities combined. (25% ≠ 50%; 50% = 75%; 50% ≠ 100%; 75% = 100% $p < 0,05$)

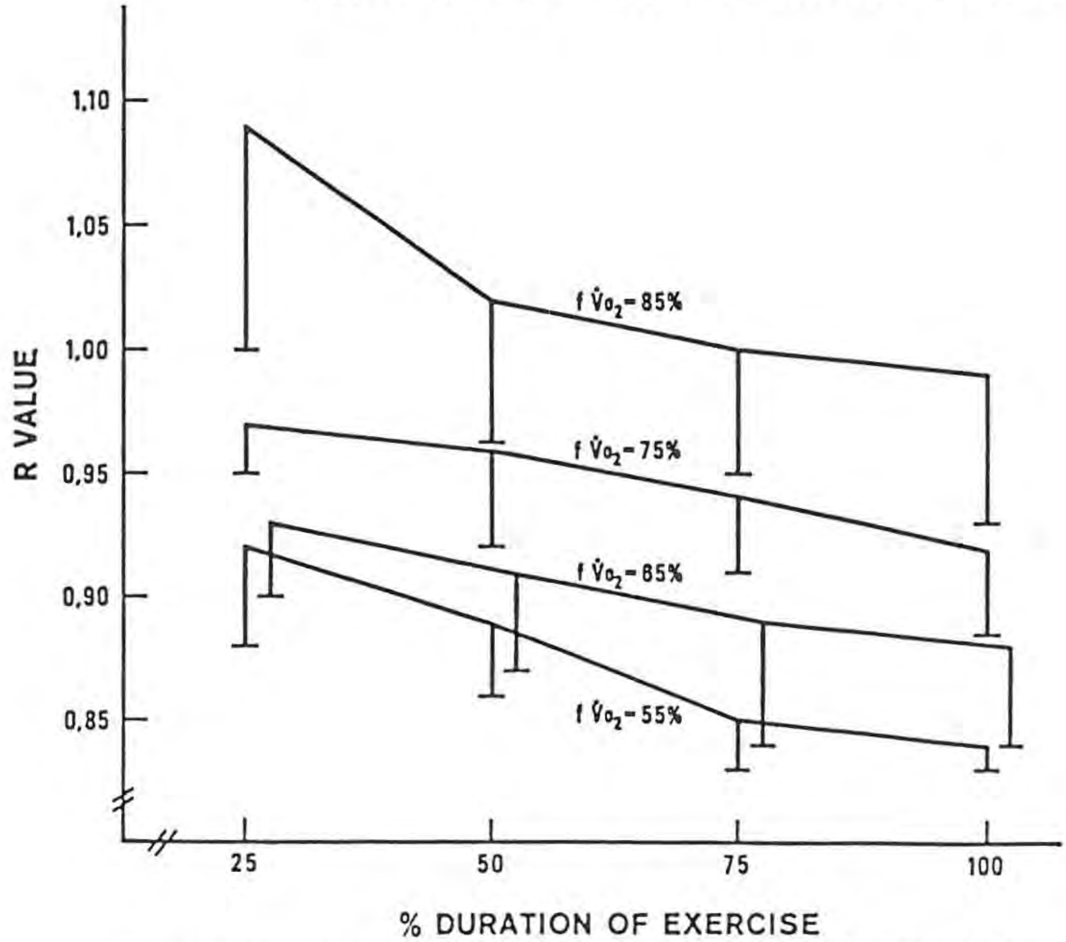

Figure 24 : Mean and standard deviation ventilatory exchange ratio (R) change over time (% duration of exercise) of 10 subjects at different relative intensities ($_fVO_2$ max.).
(25% ≠ 50%; 50% = 75%; 50% ≠ 100%; 75% = 100% $p<0,05$)

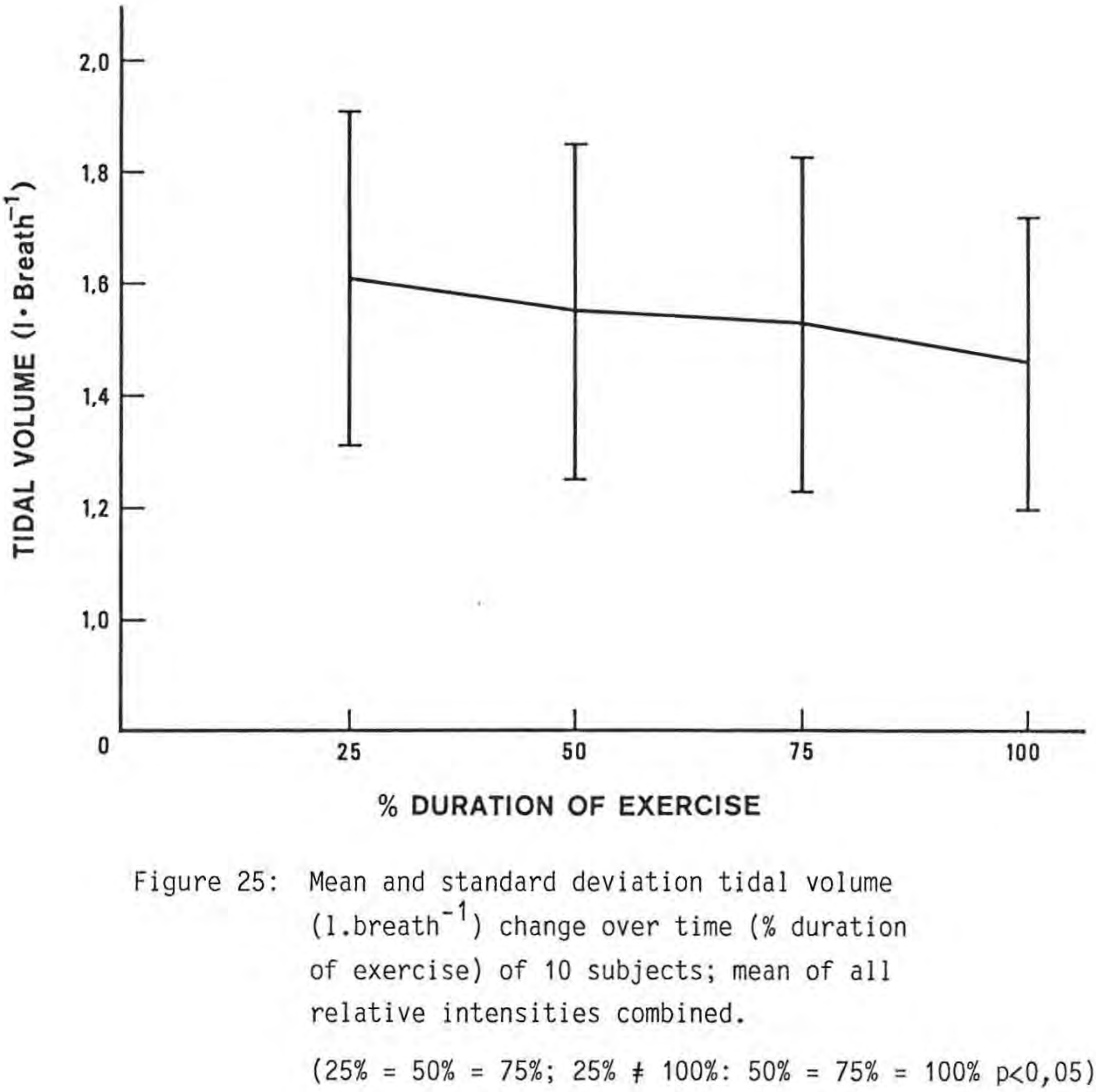

Figure 25: Mean and standard deviation tidal volume ($l.breath^{-1}$) change over time (% duration of exercise) of 10 subjects; mean of all relative intensities combined.

(25% = 50% = 75%; 25% ≠ 100%: 50% = 75% = 100% $p<0,05$)

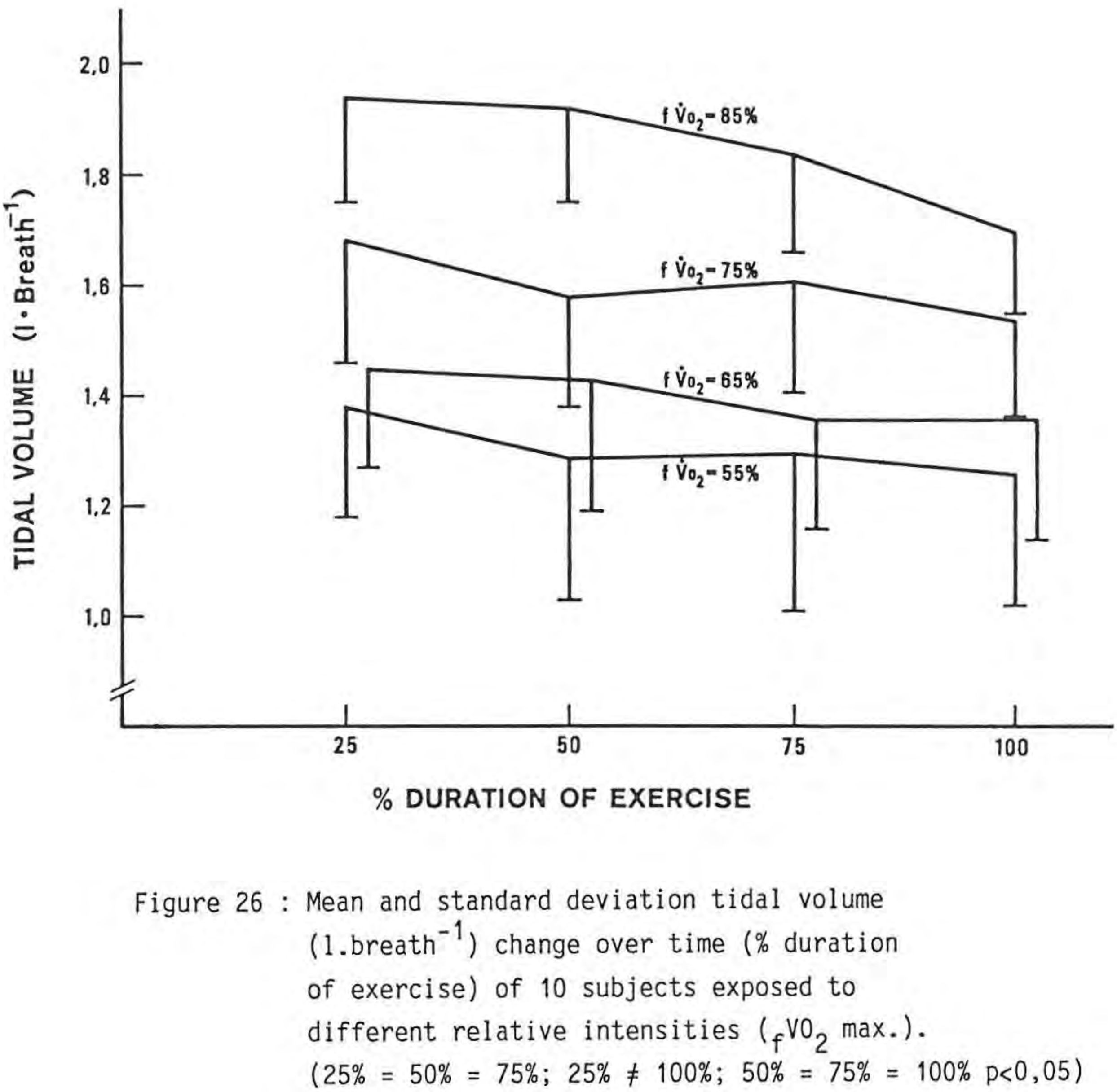

Figure 26 : Mean and standard deviation tidal volume ($l.breath^{-1}$) change over time (% duration of exercise) of 10 subjects exposed to different relative intensities ($_{f}VO_2$ max.). (25% = 50% = 75%; 25% ≠ 100%; 50% = 75% = 100% $p<0,05$)

Perhaps not as clear is the relationship between the psychological parameters measured and the relative intensity worked at. Figure 18 records the psychological responses to added workloads of the 10 subjects in this study. The responses are not as clearly defined or as linear as the physiological responses but still demonstrate an increase in intensity of response with increases in work intensity. Thus, RPE (general), RPE (legs), perception of pain, perceived thermal comfort and the fatigue ratings do appear to mirror the physiological responses recorded. Any lack of clarity of defined linearity in the relationships, could argueably be said to be a function of the inherent inadequency of the psychological tools used,which cannot hope to measure as accurately the diversity of perceptual responses characteristic of the human condition, as the precise measures of physiological response. Logically this would appear to be true, as the most clearly defined linear relationship occurs with RPE (general), the rating scale which appears to have been afforded the most time and effort in planned research into it's efficacy as a psychological tool measuring changes in veridical exertional levels.

Figures 19 to 26 illustrate four physiological changes which occurred over the duration of each treatment condition. Summarized, heart rate and breathing frequency increased over time whilst respiratory exchange ratio and tidal volume decreased over time. These changes are linked and concurrent and cannot be looked at in isolation when seeking explanations.

Sixty Five percent or more of the oxygen consumption during heavy aerobic exercise can be accounted for by carbohydrate metabolism as evidenced by respiratory quotients of 0,9 and above (Holloszy <u>et al</u>

1978). The gradual decrease in respiratory quotient values over time is indicative of progressive carbohydrate depletion coupled with increased free fatty acid levels demonstrating a greater fat oxidation role in energy liberation. Progressive recruitment of muscle fibres as a result of fatigue coupled with the greater fat metabolism requires a greater oxygen supply to the working musculature. This becomes apparent in the increasing heart rates recorded over time and is in agreement with the findings of Benade et al (1971), Thomas and Reilly (1975), Houston et al (1978), McArthur et al (1983), and Ivy et al (1983). In addition, increases in body temperature contribute to increases in heart rate over time. When body cooling mechanisms are progressively brought into operation the heart rate becomes progressively higher for the same amount of work. This results in a heavier load on the cardiovascular system, with progressive fatigue and subsequent exhaustion (Brouha 1953). In support of the above Hagberg et al (1978) established that rises in body temperature accounted for 30% of the rise in oxygen consumption during constant load bicycle ergometer work; with an increase in ventilation (primarily an increase in ventilation frequency) accounting for another 30% of the rise in oxygen consumption. This is in agreement with the "cardiovascular drift" reported by Sawka et al (1979) where increases in body temperature cause subsequent rises in heart rate.

Though not measured in this study - lactate accumulation and the concommitant pH changes which may decrease the speed of biochemical reactions in the muscle cell, thereby limiting the availability of energy (ATP) (Saltin 1973); and muscle glycogen depletion (Holloszy et al 1978) - appear to coincide with the point of exhaustion. Selective patterns of glycogen depletion occur in skeletal muscle in response to exercise of different intensities (Saltin 1973, Thomson et al 1978). These changes which occur are influenced by, amongst other factors, the genetic endowment of the individual and the training status (Bransford & Howley 1977). In addition, it is worth noting the recent report of Noakes and McArthur (1985) that at intensities of 85% VO_2 max. (work time less than 4 hours) an individual is limted by muscle glycogen depletion; but when working at 70-75% VO_2 max. for periods longer than 4 hours exhaustion appears to be caused by hypoglycemia. The high mean VO_2 max. of the subjects in this study has been referred to. Of added importance is the finding of a high ventilatory threshold (V.T.).

Figure VI : Ventilatory thresholds (% of VO_2 max.) of subjects in this study.

Subject	PC	GD	AH	AJ	AL	DM	CR	SR	AS	MW	$\bar{X}$	σ	CV %
V.T.	72	72	78	83	83	76	69	73	84	80	77	5,4	7,0

McArdle et al (1981) report that in the healthy untrained subject the anaerobic threshold lies between 55 and 65% of VO_2 max. The anaerobic threshold for endurance trained athletes occurs at a mean value of 85% VO_2 max. and for non-endurance trained athletes at 70% VO_2 max. (MacDougall 1977). Subjects in this study thus lie somewhat in-between these two levels. Success at events requiring circulo-respiratory endurance is related both to the VO_2 max. and the percentage of VO_2 max. at which an individual can work. More highly trained individuals with high anaerobic thresholds exhibit lower post-exercise blood lactate than lesser trained individuals (Withers 1977).

Well trained individuals have an enhanced ability to oxidize fat, without which an individual would be unable to utilize a large aerobic power over an extended period of time (Saltin 1973). The decreasing respiratory exchange ratios over time tend to support this argument. The importance of specific training to enhance the capability of the aerobic and/or anaerobic systems respectively (Saltin 1973, Skinner and McClellan 1980) should not be overlooked, as well as the individual differences apparent in this regard. On average the subjects in this study would have been working above anaerobic threshold only at the 85% $_fVO_2$ max. condition. However, four individuals would have been working above their thresholds at 75% of maximum. It is quite clear that in subjects exercising at the same relative intensity the greatest endurance times to exhaustion are exhibited by those individuals more highly trained and with higher anaerobic thresholds (Saltin and Rowell 1980), all other factors being equal. In support of this the correlation (r) between ventilatory threshold and endurance time at 85% VO_2 max. was found to be 0,16 whilst at 75% max. it increased to 0,43.

In high intensity exercise above anaerobic threshold involving the recruitment of fast-twitch muscle fibres the production of ammonia as a result of the deamination of adenosine monophosphate plays an important role in the fatigue process. Elevated blood ammonia concentrations act as an added respiratory stimulus contributing toward increased ventilation. The presence of blood ammonia is strongly correlated with VO_2 during exercise, and it's contribution to hyperpnea (a discomforting condition) may play an important role in central perceptions of fatigue. Different states of motor dysfunction occur with ammonia build-up, for example ataxic gait.

The integrity of cell action is compromised leading to dysfunction. Thus, ammonia may have as important a role to play in fatigue as lactic acid is classically supposed to have (Mutch and Bannister 1983). In any event, the negative effects of ammonia only serve to compound the effects of lactate and the associated pH changes which serve as primary factors responsible for impaired muscle function (Tesch et al 1978).

It has been argued that fatigue is probably a result of prolonged mechanical stimulation of nerve-endings in joints and tendons in which there is no accumulation of toxic products and that the first sense of fatigue occurs as a result of this (Frumerie 1913 as cited by Mutch and Bannister 1983). The mechanical alterations in gait patterns after prolonged jarring during running and the effect on the movement response cannot be overlooked. As a teaching assistant during undergraduate laboratory work at Rhodes University (August 1985) the author personally recorded energy expenditure increases of 10% and perceptions of exertion increases of some four points (from 11, fairly light to 15, hard) when gait patterns were deliberately altered (e.g. walking with a splint). When examining the effect of an altered gait pattern (limp or significant asymmetrical gait pattern) on the movement response (seen in added energy expenditure and increased RPE and pain), and the effect of further movement on the already altered gait pattern; what transpires can best be described as a circular negative spiral in movement response, which very quickly leads to the individual ceasing further activity as a result of pain limitations. Subjective responses from individuals support the arguments for biomechanical limitations to prolonged work performed of a jarring nature, such as continual running. Comments such as "my breathing is fine, I'm not tired but my knees hurt" were often heard.

Cadence was not measured in this study. However, subjects' subjective responses suggest there is a strong indication that the number of times a foot strikes the ground correlates with the perception of exertion (local differentiation of exertion - Pandolf 1982) and in the latter phase of an endurance activity would appear to correlate with the perceptions of pain and fatigue, resulting in the decision to cease activity. This would lend support to the argument that fatigue is probably a result of mechanical stimulation of nerve endings in joints and tendons. Therefore, from a biomechanical standpoint it may be argued that it is not the speed (intensity) per se which causes fatigue but the number of times the feet strike the ground. Thus, there may be an element of truth in the statement that "physiology is a sub-section of biomechanics" (Wall 1985) - implying that biomechanical factors are of prime importance in that they determine the physiological and psychological response.

Figures 27 to 32 illustrate the changes which occurred over time in the five psychological parameters measured. In essence all five parameters demonstrate fairly linear increases over the duration of the treatment conditions, irrespective of the intensity applied. The least linear response occurred with perceived thermal comfort. In short, RPE (general), RPE (legs), perceived thermal comfort, perceptions of fatigue and perceptions of pain show an increase in response over time. The perceptual response patterns observed warrant further discussion and clarification.

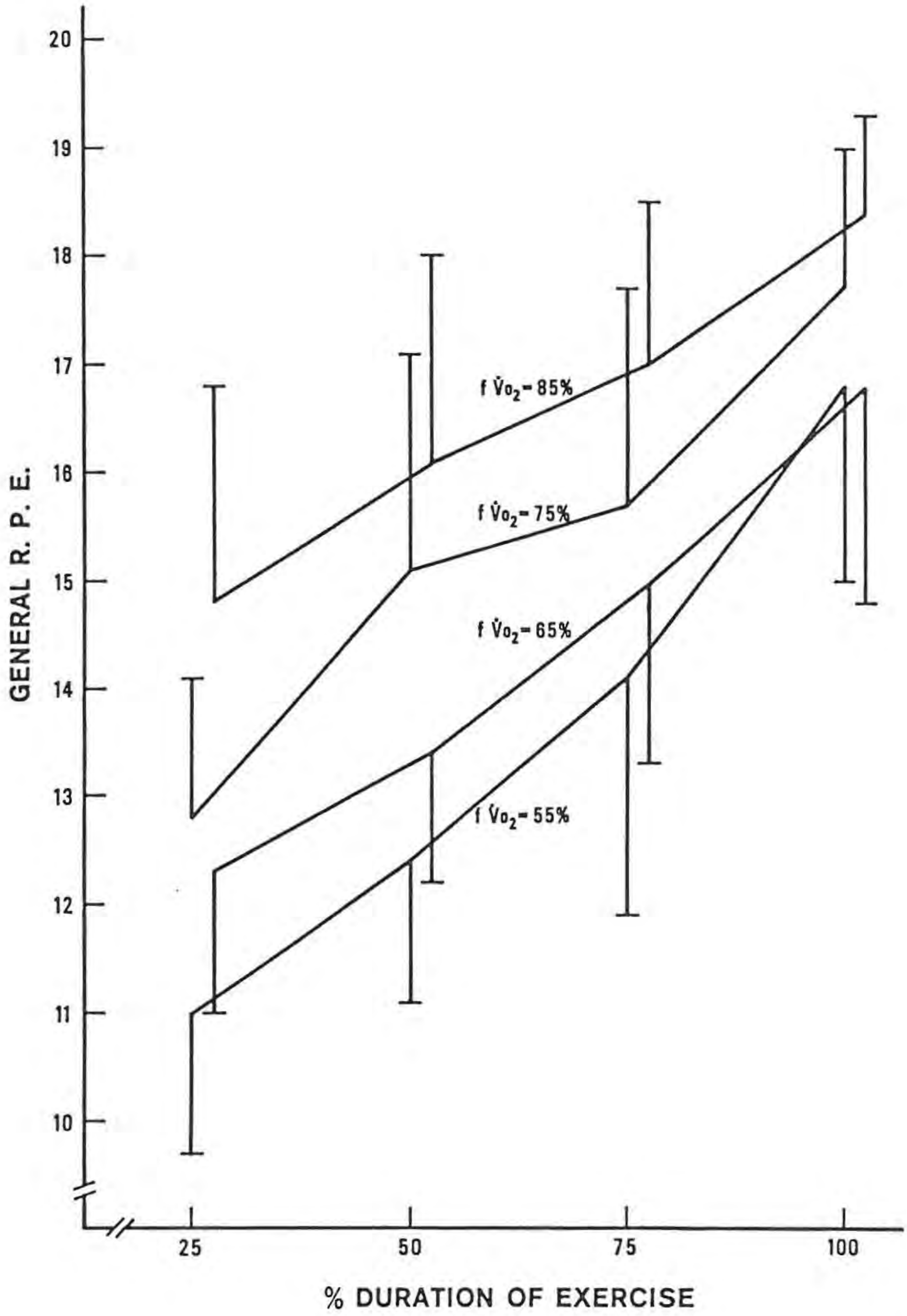

Figure 27: Mean and standard deviation general ratings of perceived exertion change over time (% duration of exercise) of 10 subjects exposed to different relative intensities ($_{f}VO_2$ max.).
(25% ≠ 50% ≠ 75% ≠ 100% $p<0,05$)

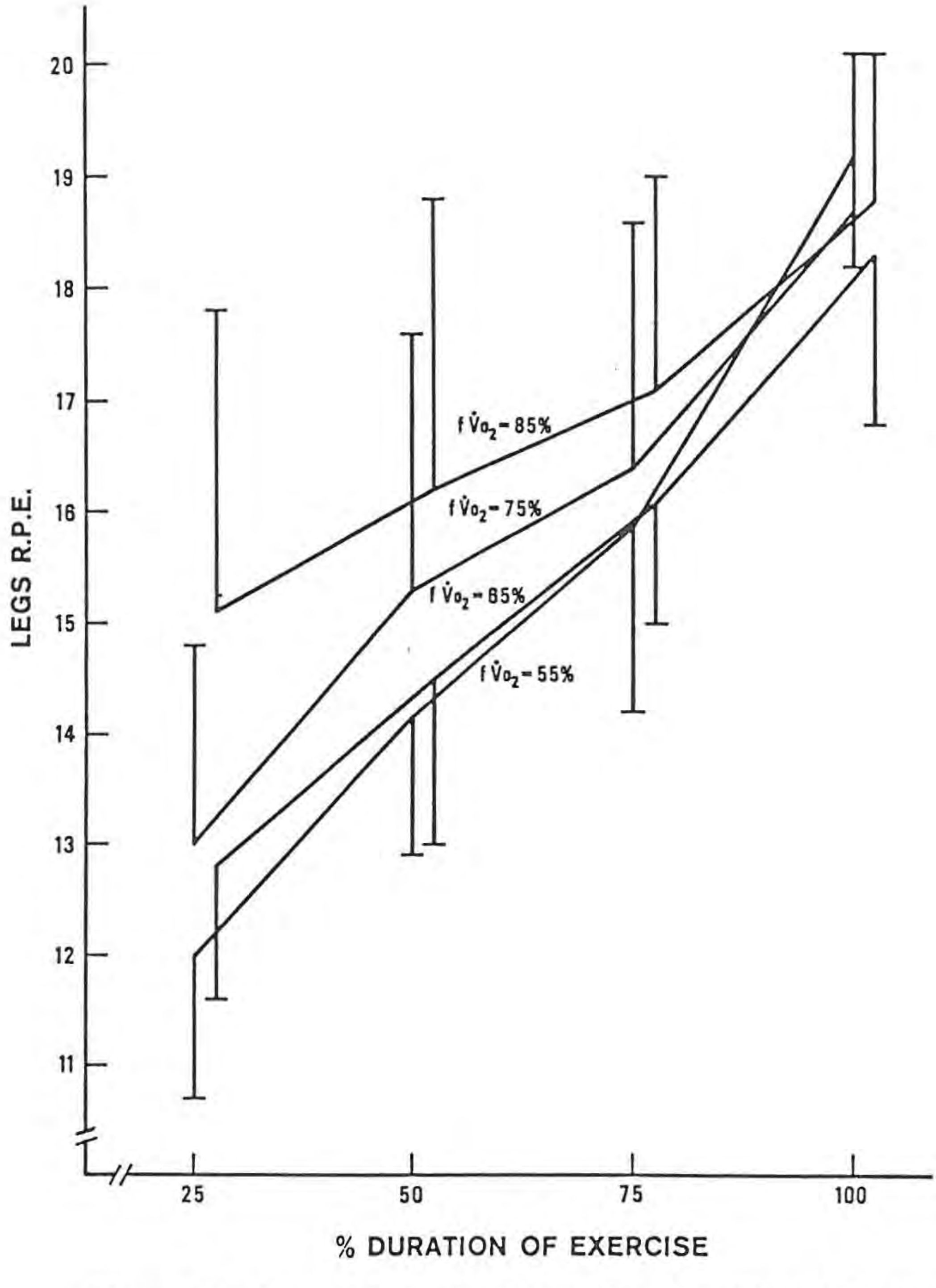

Figure 28 : Mean and standard deviation of ratings of perceived exertion (legs only) change over time (% duration of exercise) of 10 subjects exposed to different relative intensities ($_{f}VO_2$ max.).
(25% ≠ 50% ≠ 75% ≠ 100% $p<0,05$)

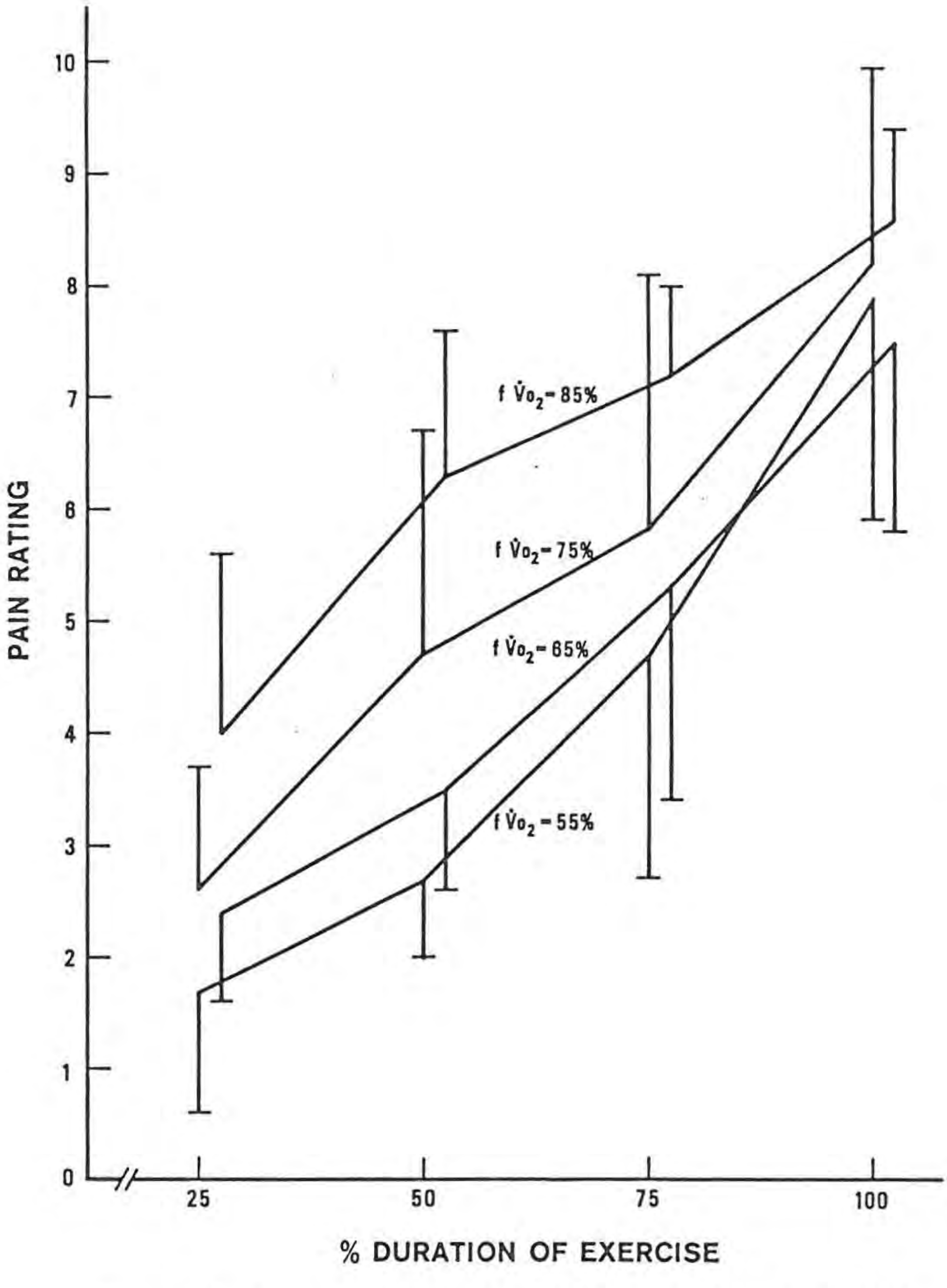

Figure 29: Mean and standard deviation of pain perception over time (% duration of exercise) of 10 subjects exposed to different relative intensities ($_f VO_2$ max.). (25% ≠ 50% ≠ 75% ≠ 100% $p<0,05$)

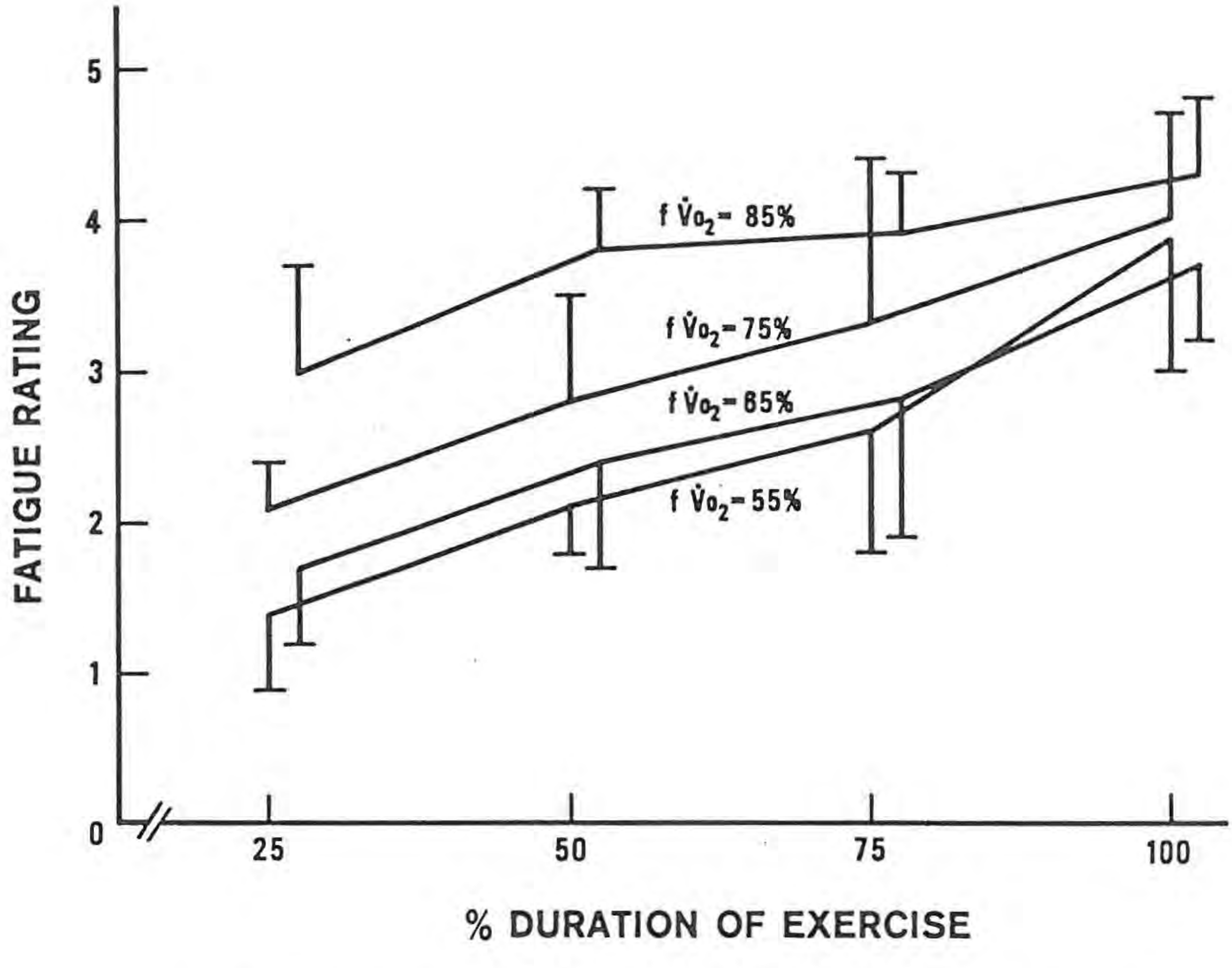

Figure 30: Mean and standard deviation ratings of fatigue change over time (% duration of exercise) of 10 subjects exposed to different relative intensities ($_fVO_2$ max.).
(25% ≠ 50% = 75% ≠ 100% $p<0,05$)

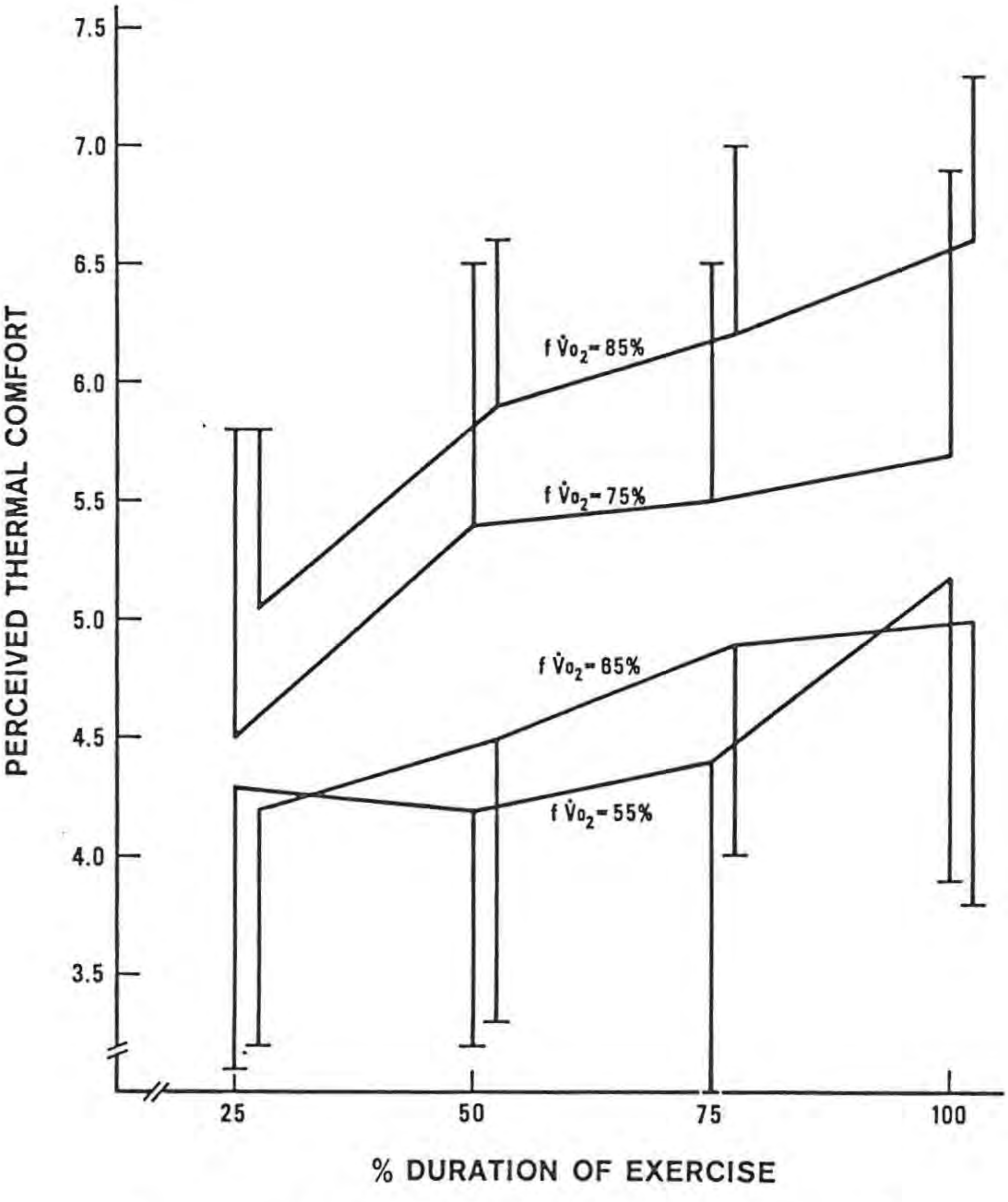

Figure 31 : Mean and standard deviation ratings of perceived thermal comfort change over time (% duration of exercise) of 10 subjects exposed to different relative intensities ($_{f}VO_2$ max.).

(25% = 50%; 25% ≠ 75%; 50% = 75% = 100% p<0,05)

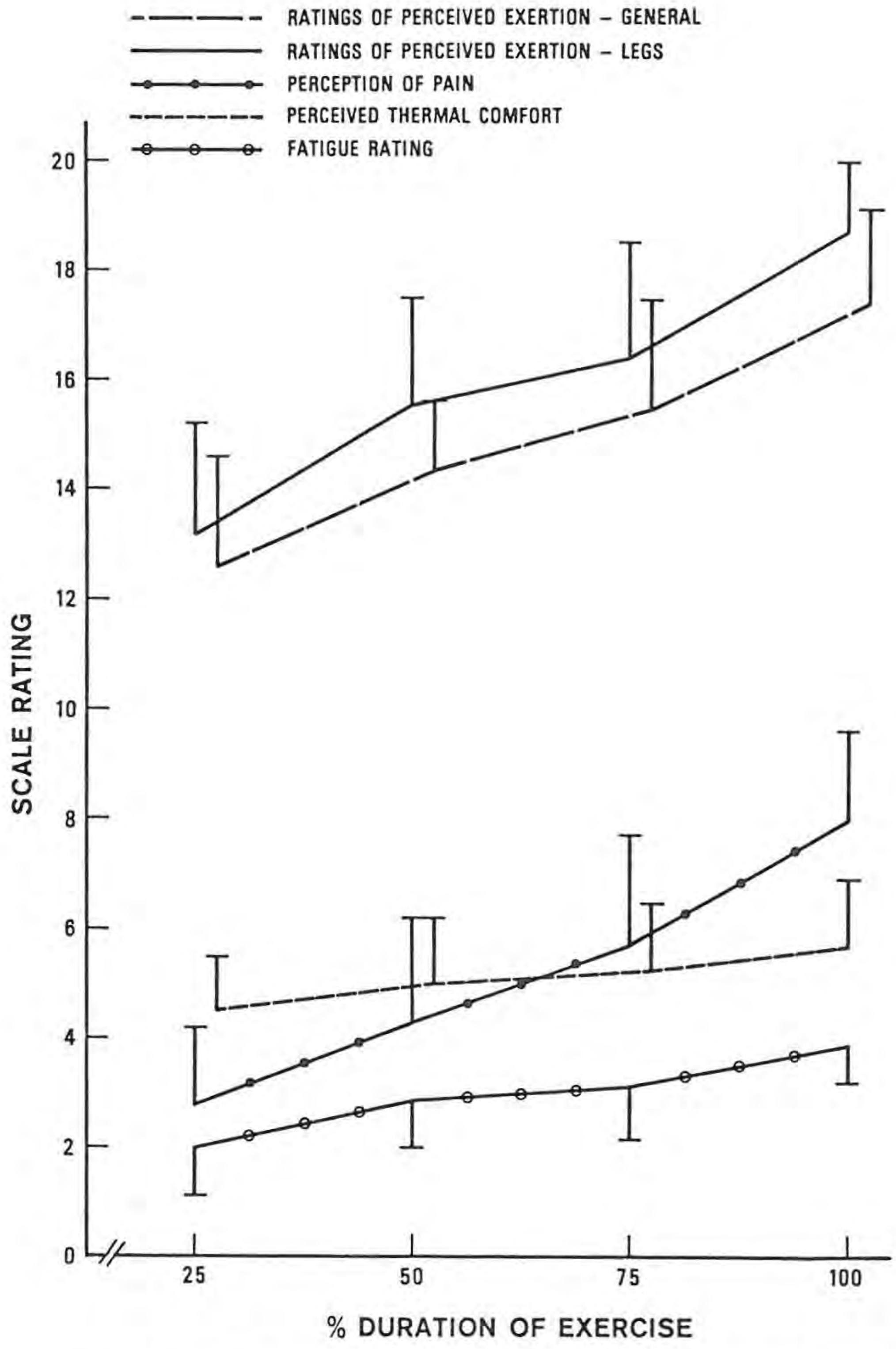

Figure 32 : Mean and standard deviation psychological responses to various rating scales change over time (% duration of exercise) of 10 subjects, all intensities combined.

(RPE General : 25% ≠ 50% ≠ 75% ≠ 100% $p<0,05$)
(RPE Legs : 25% ≠ 50% ≠ 75% ≠ 100% $p<0,05$)
(Pain : 25% ≠ 50% ≠ 75% ≠ 100% $p<0,05$)
(Thermal Comfort : 25% = 50%; 25% ≠ 75%; 50% = 75% = 100% $p<0,05$)
(Fatigue : 25% ≠ 50% ≐ 75% ≠ 100% $p<0,05$)

Before proceeding with this discussion the reader should note the occurrence of artifact in experimental research using human subjects. Artifact in this sense is defined by Boring (1969) as "extraneous conditions - for the most part social in nature - that affect the experimental variables." What is being referred to here has commonly become known as the "Hawthorne Effect" (Schneider 1976) i.e. subjects change when they know they are being studied or given attention. In-so-far as a subject cares about the outcome of a research study, his perception of his role and of the hypothesis being tested may become a significant determinant of his behaviour. Subjects may actively process their impressions toward the development of some interpretive hypothesis, one that will lead them to adopt a response strategy that may distort resulting data. Factors having influence are the experimenter/subject interaction, for example, the results of a given experiment may be influenced in some measure by the expectations of the experimenter. Further, subjects seek to validate their psychological adequacy i.e. the maintenance or enhancement of their self esteem (Boring 1969).

Another point to note is the potential error due to the inherent inadequacy of introspection. Self reports are descriptions of the self, and, in psychological terms these are not the same as the phenomenal self. A self-report is the product of a person's total phenomenal field i.e. self perception and the situation in which the individual is involved. The perceptual field is complex, made up of meanings of events past, present and future. To access the perception, direct attention should be given to the dynamics of perception behind the behavioural manifestation. The self report however, gives an important insight into the feelings of the individual - often reflecting accurate descriptions of the feelings existing (Boring 1969).

How we function in any given situation will be dependent upon how we perceive ourselves and how we perceive the situation in which we are involved. Humans are insatiably engaged in a continual attempt to achieve an adequate self (Combs et al 1976). Of necessity, accessing the limits to prolonged physical work demanded the examination of perceptual factors. This was done as adequately as possible with the perceptual measuring tools available, and the results obtained need to be integrated with known facts related to personality and motivational influences.

An important fact to note in relation to perception and workload is that it is not what the individual is doing but what he thinks he is doing that determines the nature of psychological response. RPE is an indication of the physical strain under which a subject is working. Figure 27 illustrates the increase in RPE (general) over time, giving a clear indication that subjects perceived the work load as becoming increasingly more difficult, despite the fact that they were working at a constant relative intensity. This supports similar findings by Noble et al (1973) where RPE's increased over time when workload was held constant. There is a known relationship of RPE and heart rate (Mihevic 1981). When all intensities were combined RPE correlated at 0,69 ($p < 0,05$) with heart rate. Logically then the increasing heart rates over time are correlated with the increasing RPE's.

The mean ventilatory threshold established in this study has already been reported at 77% of VO_2 max. An interesting observation is that the mean RPE (general) at 75% $_{f}VO_2$ max. at the beginning of the exercise condition is 13 i.e. somewhat hard. This is in agreement with the findings of Purvis and Cureton (1981) who established that when working at or very close to the anaerobic threshold subjects respond with a rating of 13 for RPE. As the task progresses in duration subjects may respond with cognitive pacing i.e. the unpleasant consequences of fatigue may be delayed by suppressing subjective estimates of tiredness (Rejeski and Ribisl 1980). This usually occurs when subjects have a goal, or an expected task duration. However cognitive mediation cannot compete with strong internal cues and this is evident in the increased RPE over time. Of significance is the fact that upon cessation of exercise, irrespective of the treatment condition worked at, the mean RPE's reported were statistically the same ($p<0,05$). This reflects a convergence indicative of the agreement between subjects with respect to the intensity of exertion at which they decide to cease work.

This convergence applies to all the psychological parameters measured where at the point of cessation of exercise, irrespective of the intensity, there was no statistically significant difference ($p<0,05$) in the intensity of psychological response recorded.

If the convergence is visually scanned (Figure 28 which illustrates RPE (legs)), clearly the overall convergence and the absolute intensity is greater than that for RPE (general) especially when viewed in the light of the correlation between RPE (legs) and perception of pain, where $r = 0,98$. RPE (legs) correlates at 0,43 with heart rate, much lower than the correlation between RPE (general) and heart rate (0,69 $p<0,05$). This is true also for the correlation between breathing frequency, and RPE (general) and breathing frequency and RPE (legs), where r = 0,81 and 0,62 ($p < 0,05$) respectively. Bearing these relationships in mind it is expedient to recall Pandolf's (1982) assertion that when a particular physiological cue is markedly altered over others the resultant sensation can easily dominate the overall RPE. When the exercise mode is considered this assertion appears to be quite logical in that the prime sensations of pain as subjectively reported by subjects, were experienced in the legs.

Clinical pain assessment questionnaires such as the McGill Pain Questionnaire (Melzack 1975) consist primarily of three major classes of word descriptors i.e. sensory, affective and evaluative, and are used by patients to specify subjective pain experience. It is evident that the word "pain" refers to a variety of qualities that are characterised under a single linguistic label, and not to a specific single sensation that varies only in intensity (Melzack 1975). In this regard the pain rating scale used in this study has it's limitations. However, when the correlations of pain perception with physiological and psychological parameters are examined, the usefulness of the scale becomes apparent. (See Table VIII, correlation matrix). Further, heart rate change over time (Δ HR 25% to 100% duration) has a correlation of 0,5 with pain perception. Pain perceptions increase relatively linearly over time (r = 0,89); and where general ratings of discomfort may be easily biased local discomfort ratings are more reliable (Kuorinka 1983). The convergence referred to earlier is clearly apparent in Figure 29 illustrating the pain responses recorded. Again, this serves to indicate the agreement between subjects with respect to the intensity of pain perception at which the decision is made to cease work.

Figure 30 illustrates the recorded ratings of fatigue. The response is relatively linear over time and demonstrates close convergence. The ratings correlate very highly with RPR (general) at 0,99; RPE (legs) at 0,94; perceived thermal comfort at 0,85, and perceived pain at 0,97 ($p<0,05$). It would appear that in this regard there is a great deal of similarity in what the different scales appear to measure. The comment by Borg (1982) that in his opinion perceived exertion is the single best indicator of physical strain would appear valid. However, if such high correlations are to be found between RPE and other scales, the choice of rating scale to be used would be determined by the nature of work and psychological response measure desired. For example, RPE could be used in high intensity work, perceived thermal comfort in heat tolerance tests, perceived fatigue in endurance tests and perceived pain in pressure tolerance experiments.

The mean body temperature derived at the cessation of exercise correlates with the recorded perceptions of thermal comfort at 0,52 ($p < 0,05$). Figure 31 illustrates the changes in perceived thermal comfort over time and Figure 32 illustrates the mean psychological responses of the five rating scales used and the changes over time. Here the four treatment intensities have been combined. All the slopes are fairly linear and demonstrate an upward trend i.e. an increase in intensity of psychological response over time. The interrelationships are reported in Table VIII as correlations.

The question of the relative contribution of each measured parameter, whether physiological or psychological, remains. One manner of addressing this vexing problem is to compute ratios of convergence for each of the parameters. Thus the coefficient of variation of responses mid-way through the treatment conditions was expressed over the coefficient of variation of responses at cessation of exercise. A ratio was computed thus:

$$\frac{\text{CV at 50\% Duration}}{\text{CV at 100\% Duration}}$$

This ratio expresses the convergence or non-convergence of responses toward the end of the exercise. To illustrate, if the coefficient of variation is greater mid-way through the exercise than at cessation a ratio greater than one will be recorded. The higher the ratio above one the greater the convergence i.e. the greater the inter-subject agreement on the intensity of response. This logic is extended thus: the parameter demonstrating the highest convergence, or agreement amongst subjects as to intensity of response, is likely to be the parameter of most importance.

Table VII records the convergence ratios computed at each treatment intensity for the five physiological and five psychological parameters measured, and the overall mean ratios. When these means were ranked the importance of psychological response variables was in the order:

1) RPE (legs) 2) Pain	Local factors
3) RPE (general) 4) Fatigue 5) Perceived thermal comfort	General (central) factors

This convergence or agreement upon psychological response accords with the two-factor model of RPE propounded by Ekblom and Goldbarg (1971), where the factors contributing to the ratings of perceived exertion are divided into local and central mediators. Thus it appears that local factors such as RPE of the legs and perceptions of pain contribute most to the decision to cease activity. This concurs with subjective comments made by subjects during the course of this study where pain limited cessation of exercise is indicated as a function of biomechanical limitations.

The ranked convergence means indicating the order of importance of the physiological variables was as follows:

1) R
2) Vi
3) Vt
4) Vf
5) HR

Again, this order appears quite logically self evident. The respiratory exchange ratio is indicative of the fuel substrate utilized and as such is least under conscious control. Further, consider that if all subjects pushed themselves to a point of severe fatigue; with glycogen depletion occurring, leading to a preference for fat metabolism, a substantial agreement in physiological response, namely respiratory exchange ratio, should occur. This appears to be the case. Combustion of fat would require greater amounts of oxygen, as would increasing muscle fibre recruitment and temperature regulation (Astrand and Rodahl 1977). The need for oxygen will to a large extent, determine the ventilatory and heart rate responses. The low variation (high convergence) in R values, would suggest the same for the volume of oxygen required for fuel combustion, this subsequently determining the volumed of inspired air. The volume of inspired air is determined by both depth and rate of breathing (McArdle _et al_ 1981), and it appears that in this study greater variation occurred in the frequency of breathing than in the depth of breathing. Finally, heart rate would appear to be open to the greatest variation due to such factors as age, state of training and the efficiency of oxygen transport and utilization (Astrand and Rodahl 1977).

Table VII : Derived Ratios of Convergence (coefficient of variation at 50% of duration/coefficient of variation at 100% duration of activity), Mean Ratios of Convergence and Ranking of parameter in order of importance.

Intensity	Measured Parameter									
(% VO_2 max.)	HR	Vi	Vf	V̇t	R	RPE(g)	RPE(l)	PTC	Pain	Fat
55	0,5	1,2	1,3	1,1	2,9	0,9	1,95	1,1	1,0	0,6
65	1,3	1,1	0,7	0,95	0,97	0,7	1,3	1,1	1,1	2,2
75	1,0	1,2	0,93	0,96	0,98	1,7	2,0	0,97	1,99	1,6
85	0,86	0,93	0,83	0,94	0,97	2,3	2,32	1,1	2,21	0,9
Mean Ratio	0,91	1,1	0,94	0,99	1,46	1,4	1,89	1,1	1,6	1,3
Ranking	10	6	9	8	3	4	1	6	2	5

The importance of the interrelationship of the above factors should not be overlooked. For example, a coefficient of multiple correlation of 0,94 was obtained when a regression analysis was done for % VO_2 max. against HR, Vf, R, RPE (general), RPE (legs), PTC, pain, fatigue, mean body temperature and endurance time. In addition the close interrelationship evident amongst the measured physiological and psychological parameters is reflected in the correlation matrix (Table VIII).

Table VIII : Correlation matrix for measured parameters (all intensities combined).

HR	Vf	R	RPE(G)	RP(L)	PTC	PAIN	FAT
1	.88	.79	.69	.43	.87	.55	.68
0	1	.54	.81	.62	.89	.71	.77
0	0	1	.16	-.12	.51	-.01	.18
0	0	0	1	.95	.85	.98	.99
0	0	0	0	1	.68	.98	.94
0	0	0	0	0	1	.79	.85
0	0	0	0	0	0	1	.97
0	0	0	0	0	0	0	1

The athleticism and psycho-social mileau of the subjects in this study is reflected in the personality traits recorded after the Maudsley Personality test. The majority of the subjects are extroverted (see Table IX), this being an accepted character trait of athletic individuals (Cratty 1973, Hendry 1975). The general consensus is that extroverts are better able to withstand pain and are more persistant at tasks than individuals highly neurotic (Petrie 1960, Lynn and Eysenck 1961, Ryan 1976). However, the results of this study indicate that endurance time to exhaustion is negatively correlated with extroversion (mean r = -0,26 for four intensities). This would be in agreement with the findings of Morgan (1972) that marathon runners tend to be introverted. It is clear that a great many factors influence response style, personality being but one of them. Therefore the role of personality factors should be seen in context, that is, as a contributory confounding factor in work performance. The nature of the task at hand may well determine the importance which will be attached to personality factors. For example, the military may be regard personality as critical in the choice of select personnel, as opposed to the importance to be attached to the role of personality for common labourers tasks. In this ergonomically oriented study the role of personality appears not to be significant in view of the close agreement (convergence) in psychological responses recorded, the nature of the task (manual work) and the insignificant correlation between personality type and endurance time to exhaustion.

Table IX : Maudsley Personality Inventory Scores Recorded.

Subject	PC	GD	AH	AJ	AL	DM	LR	SR	AS	MW	$\bar{X}$	σ
Extroversion	-1	6	2	6	6	0	6	4	0	2	3,1	2,8
Neuroticism	-4	1	0	-2	-2	0	4	-4	-2	0	-0,9	2,4

The fatigue cluster analysis of the pre- and post-test Physical Activity Questionnaire (Weiser <u>et al</u> 1973) yielded interesting results (Appendix N). The difference between pre- and post-test Likert scale ratings (1-5) were calculated for each adjective and the mean difference for each of the four clusters recorded for each treatment intensity. It is asserted that the greater the difference between pre- and post-test scores the greater the contribution of the adjective in question to the total body perception, and the subsequent decision to cease activity. This reasoning is extended to the importance to be attached to each cluster of adjectives (Weiser _et al_ 1973).

Figure 33 is an illustrative example of the change in response established between ratings of each adjective prior to and after treatment condition 55% VO_2 max. The pattern demonstrated is typical of the responses recorded for the other intensities. Table X summaries the mean differences between pre-and post-test responses for each of the clusters at each relative intensity. This is graphically illustrated in Figure 34. The most important clusters contributing toward the sensation of fatigue and the subsequent decision to stop working are Task Aversion and General Fatigue. An analysis of variance (Ferguson 1981) indicated no significant difference between these two clusters and a very high correlation (0,96) exists between the two. Weiser _et al_ (1973) reported a moderate correlation between Task Aversion and General Fatigue. Next in order of importance is Leg Fatigue, and Thirst contributes the least to the overall sensation of fatigue. That Thirst plays a minor role is not surprising in that subjects were free to drink whilst working except at 85% VO_2 max. when they breathed continuously through the mouthpiece. The Thirst cluster reflects this fact in that Thirst becomes more predominant at 85% VO_2 max. in terms of pre-to post-test differences in rating. Initially, the fact that the cluster Leg Fatigue played less of a role was considered surprising, especially in view of the local perception of pain and the RPE (leg) ratings. However, this apparent difference is a function of the adjective choice making up this cluster, which includes adjectives such as panting and numbness - where little pre- to post-test difference was recorded.

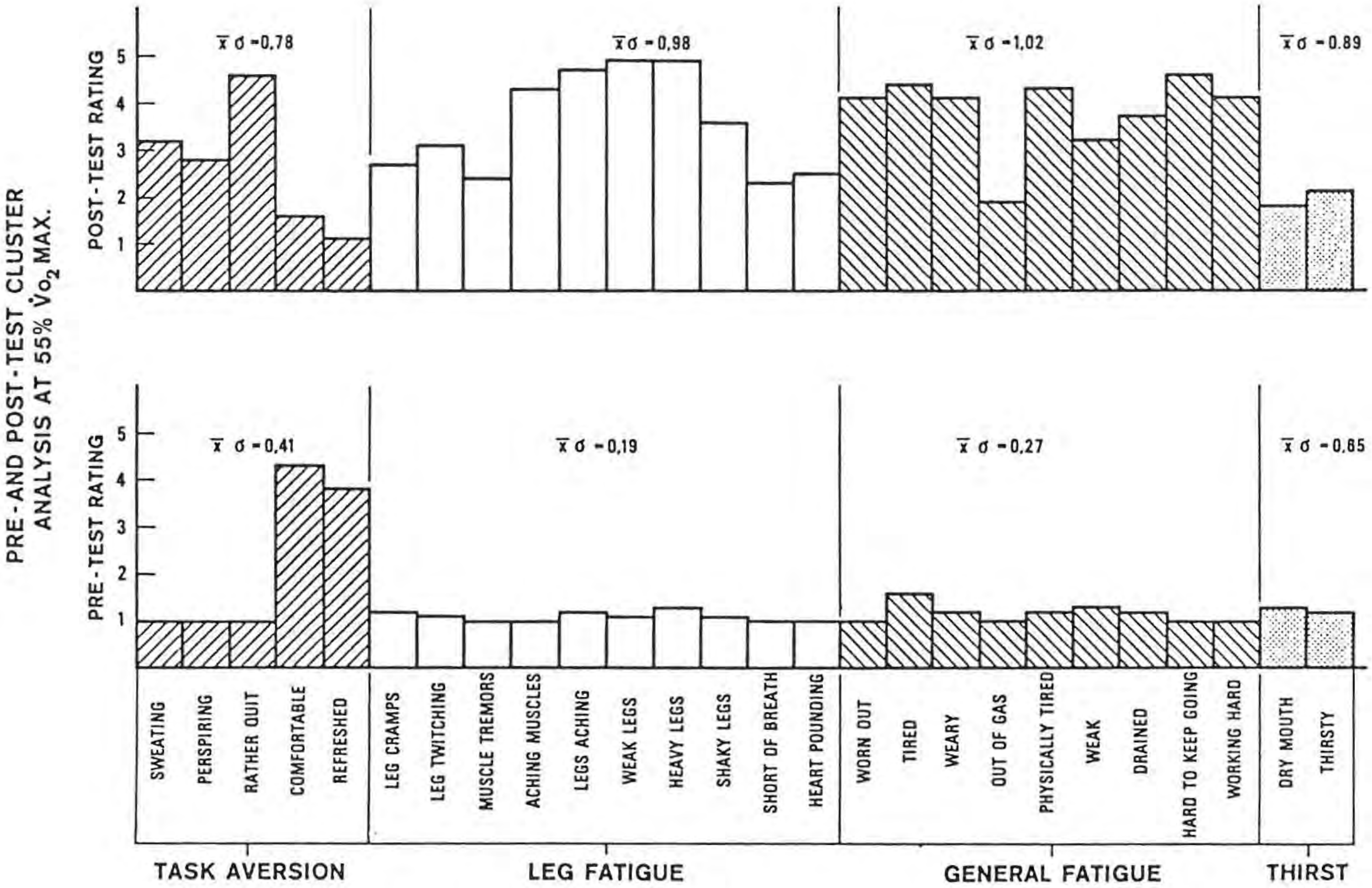

Figure 33: Mean Pre-and Post-test responses to adjectives on the cluster analysis at 55% VO_2max. These trends are representative of the responses at the other relative intensities, namely 65%, 75% and 85% VO_2max.

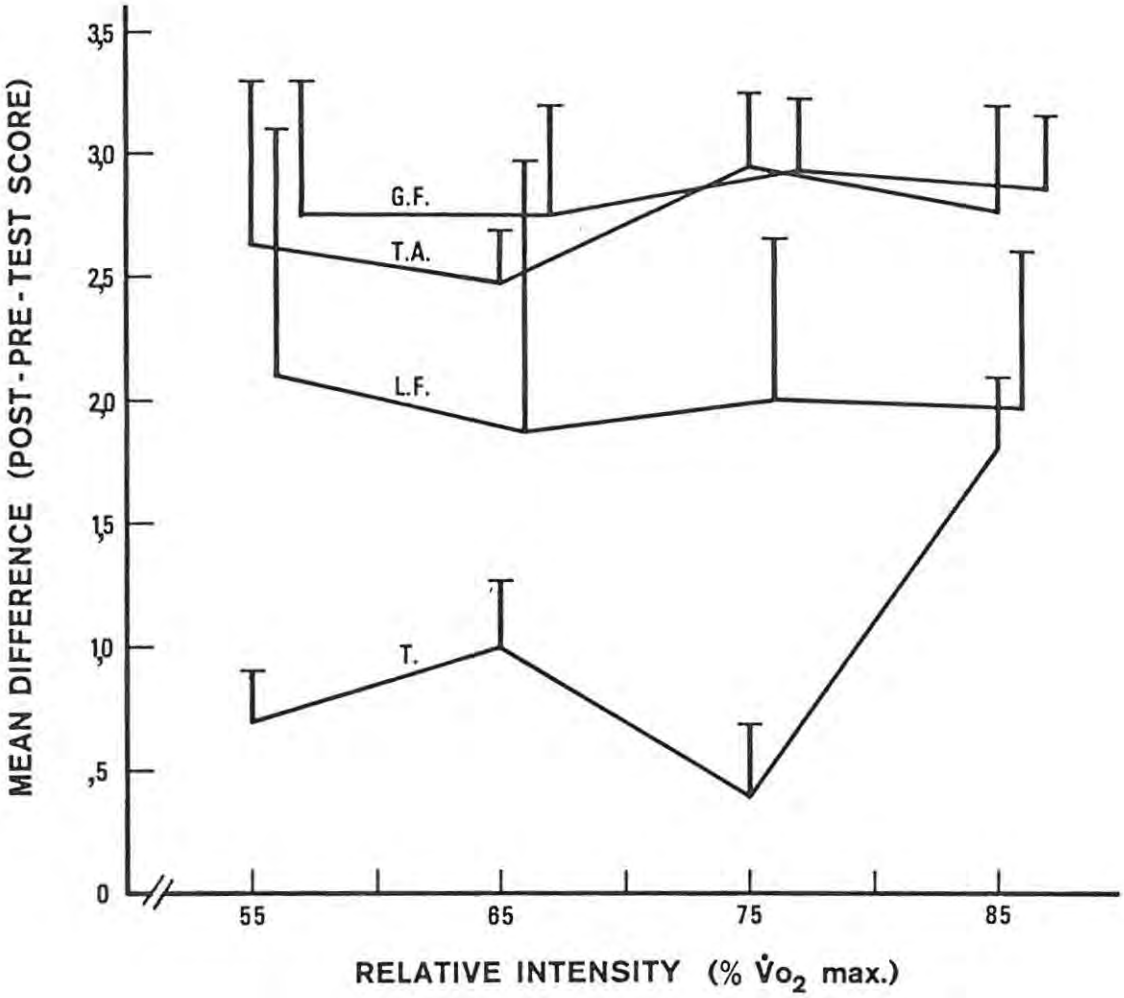

Figure 34: Mean and standard deviation absolute mean differences in pre-to post-test response on the adjective cluster analyses for the four clusters General Fatigue (GF), Task Aversion (TA), Leg Fatigue (LF) and Thirst T)

(GF = TA; GF ≠ LF ≠ T; TA = LF; TA ≠ T; LF = T p<0,05)

Table X : Summary of the mean pre- to post-test difference in response for the adjective clusters, at each relative intensity. Absolute data for 10 subjects

Intensity (% VO_2 max)	Task Aversion	Leg Fatigue	General Fatigue	Thirst
55	2,6	2,1	2,8	0,7
65	2,5	1,9	2,8	0,1
75	2,9	2,0	2,9	0,4
85	2,8	1,8	2,9	0,2

The importance of the high relationship between General Fatigue and Task Aversion must be stressed. Clearly as subjects become progressively more fatigued they find the task becomes more distasteful. This contributes to the decision to cease activity. It is here that the question of motivation arises. As a subject perceives the task as more demanding on one hand, and further perceives lack of control over outcomes on the other (Broadbent 1979) the decision is made to cease the task. This reflects the subjects' unwillingness to continue with a task which has become so stressful that further coping mechanisms (e.g. cognitive pacing and rationalisation) are no longer possible. In essence, the scenario parallels the General Adaptation Syndrome of Selye (1956) of alarm, resistance and exhaustion. It is at this end point that motivational tools as aids to performance, such as music (Anshel and Marisi 1978) and videos no longer have application. The test room may be judged as serious and impersonal (Espe and Schulz 1983) and the task so distasteful that the only outcome is to cease the activity. The task is simply no longer considered attractive, even though it may be an entirely novel experience which is approached with fervour (Broadbent 1979).

As an aid to explaining the importance of the role of motivational factors, the author is fortunately able to refer to the performance of three subjects who run the prestigious 90 kilometer Comrades ultramarathon after they had taken part in this study. On average the three subjects in question completed their last treatment condition in this study two to three weeks prior to the Comrades. Thus, there was little, if any change in training status between taking part in the study and their ultra-distance run. Table XI compares the average speed of run, the duration of the run and approximate average percentage of VO_2 max. worked at during Comrades; with the same factors during the 55% VO_2 max. condition. The average speed for both the 55% condition and Comrades is essentially the same, as is the mean relative intensity worked at, that is, approximately 55% VO_2 max. (The Comrades relative intensity for each subject is estimated from the VO_2 value during the max. VO_2 test at the speeds in question, and the VO_2 values during the 55% relative intensity treatment condition as well as the average Comrades velocity). Strikingly apparent is the discrepancy in working times, the average run being 1,9 times longer than during this study. The motivational forces at play warrant further examination.

Table XI : Comparison of 3 subject's mean speeds, relative intensities, and endurance times between treatment condition 55% relative intensity and the Comrades marathon, indicating the increase in endurance times due to motivational factors.

Subject	$\bar{X}$ Speed ($km.hr^{-1}$)		$\bar{X}$ Relative intensity		Endurance Time (Min)		Comrades Time / 55% Time
	55%	Comrades	55%	Comrades	55%	Comrades	
AH	9,9	9,4	55	54	358	570	1,6
SR	8,1	8,4	55	56	335	639	1,9
MW	9,0	8,8	55	53	255	608	2,4
$\bar{X}$	9,0	8,9	55	54	316	606	1,9
σ	0,9	0,5	0	1,5	54	34,6	0,4
CV	10,0	5,6	0	2,8	17,1	5,7	21

Only average velocity has been reported for the Comrades run. In reality runners tend to run faster at a higher relative intensity, but in an intermittent fashion, i.e. with walks interspersed with running. However, the ambient weather conditions (dry temperature peak of 30^{o}c. and wind), and the hilly terrain over which subjects ran made the Comrades a far more strenuous activity than the 55% relative intensity condition where the average dry bulb temperature was 18,7^{o}c, and subjects ran on the level. Why then, did the subjects, on average, run for 1,9 times longer than the 55% relative intensity condition, in more adverse conditions?

The answer must lie in a combination of perceptual characteristics and motivation. Thus the goal (finish Comrades) which becomes the end point of behavioural movement, is determined by a unique motive hierarchy in interaction with environmental incentives (Forgus _et al_ 1979). If the psychological expression, performance = ability x motivation is considered, with the three subjects concerned demonstrated they had the ability to finish Comrades. If the motivational components are expanded as suggested by Campbell and Pritchard (1976) then it is necessary to examine why the individual chooses to expend effort, why he chooses to expend a particular degree of effort, and why the individual persists with the task. Obviously running Comrades is goal directed behaviour and this behaviour can be explained in terms of achievement dynamics (Atkinson 1957). Here the concern is with the motivation to achieve success and avoid failure. The incentive value of succeeding at Comrades is very high. It is a prestigious event carrying high peer group approval and affording status in the athletic community. There is a low incentive value attached to failing to finish Comrades for it would mean an individual could not join an "elitest" fraternity. Thus individuals who approach the Comrades would do so with a high expectancy belief of success; a high instrumentability component reflecting the belief that successful performance will result in a particular outcome; and a high positive valence belief component reflecting the high value the individual attaches to completing the Comrades (Barling 1983). Thus an interaction occurs between both the intrinsic and extrinsic motivational forces (Calder and Stow 1975). The high cognitive belief component coupled with the extrinsic reward and satisfaction will determine the effort to perform successfully.

In contrast to the above scenario the relative intensity treatments in this study carried no such high incentives to motivation. Further, where subjects were motivated to such an extent at Comrades as to be prepared to endure considerable pain, this was not the case during the 55% relative intensity. No extrinsic rewards were offered in this study, yet the effort expended is reflected in the physiological and psychological responses recorded. This is confirmed by the reduction in absolute speeds which was necessary to keep subjects at the desired relative intensities (average drop in speed from start to finish 2 $km.hr^{-1}$); as well as the drop in respiratory exchange ratios from start to finish and the close convergence of this parameter, indicative of glycogen depletion and elevated fat metabolism in all subjects.

An extremely important fact to note is that subjects were asked to exercise to a point of subjective discomfort at which they were no longer willing to continue. This was done in view of the fact that the study was oriented in an ergonomics direction i.e. an examination of the chronic work related effects and not only short-term traumatic effects. To illustrate, the subjects who ran Comrades had great difficulty walking the following day. This is highly undesirable in a work situation where performance must be sustainable on a day to day basis. It has been demonstrated that man can sustain continuous physical work for up to 100 hours (Thomas and Reilly 1975). However, the subject in their study practised for 3 months prior to the experiment at the three exercise modes used, namely walking, cycling and rowing. Further, the intensity was such as to only elicit a mean heart rate of 84 $beats.min^{-1}$ (range 73 to 103). Continuous prolonged physical work of this nature results in fatigue which requires extended rest periods before the work can be resumed.

Subjects were asked at the end of their relative intensity run to estimate the duration of their run. The results of this time estimation were that 5% of the responses were a correct estimation of the endurance time to within two minutes; 28% of the responses were above the actual endurance time and the majority of responses (66,7%) were estimates below the actual performed endurance time. This concurs with the findings of extroverts reducing sensory input (Petrie 1960) in that a significant percentage of the responses are indicative of a perceptual characteristic which "slows down" the actual passing of time i.e. time is perceived as passing more slowly than in reality. When related to motivation it would appear logical that if a high valence is placed upon a particular goal (e.g. Comrades) then a perceptual strategy of sensory dampening would be applied by an individual to cognitively downplay the negative aspects of the activity. The reverse may well be true, that is, it may be expedient to augment the perception in order to "escape" the aversive stimulus, either consciously or unconsciously. A cognitive coping strategy (Ladouceur and Carrier 1983) is undoubtedly applied by individuals when experiencing the stress of prolonged physical work irrespective of intensity, and in particular when an endeavour is made to counteract the aversive effects of pain.

Subjects were also asked at the end of the treatment condition whether or not they felt pressed for time. Eighty seven percent of the responses indicated no time pressure whilst thirteen percent indicated a sense of time pressure. This appears unrelated to the mood state at the end of the tests. The pre- to post-test response to the rating of mood state of either agitated, indifferent or relaxed, was analysed. A positive change was regarded as a change from agitated or indifferent to relaxed. Thirty one percent of the change was in this direction. A negative change was regarded as a change from either indifferent or relaxed, to agitated. Twenty eight percent of the change was in this direction. Forty one percent of the time there was no change in the mood state reported. This data appears inconclusive in that approximately the same percentages were found for positive shifts as were for negative shifts. This could be significant in the light of the experimental nature of testing. To explain, subjective changes of mood following the completion of the Comrades marathon are unequivocally positive i.e. a sense of relief and inner self-satisfaction. Other than relief, there was no logical reason during the experiment for subjects to feel great satisfaction at completing a task which had no highly desired outcome attached thereto.

The above may be related to the findings on subjective performance. When asked to subjectively rate their endurance time performance in relation to that of their fellow subjects 61,5% indicated a performance of average, 30,8% above average and 7,7% below average. The reasons for this slant toward average and above average may lie in the personality characteristics of the individuals who are generally extroverted and have a tendency toward competitive type A behaviour. Alternately these findings may be a function of the fact that subjects had no previous experience of such experimental treatment conditions and the novelty of the experience may have made such an evaluation difficult.

An attempt has been made in this text to integrate the complex and diverse nature of factors contributing as limits to prolonged physical work. The interrelationship of the measured psychological variables has been established unequivocally in the high coefficient of multiple correlation (0,94) recorded. No such statement can be made with regard to other contributory factors such as motivation; though implicit in the understanding of limits to prolonged work is the great importance of a variable such as motivation which is difficult to measure empirically. The difficulties facing the integrative human movement researcher are summarised by Whiting (1975):

> "In the practise of drawing sections together as a whole text, a problem arises which illustrates one of the central characteristics of human movement study: all should be first and none last. That is, men moving are multifactorial organisms with such factors integrating with each other within the man, between men and in the relationships between men and the inanimate environment. This poses problems for the scholar, who can no longer be restricted by the defined boundaries such as molecular biology, psychology, physiology, aesthetics etc. within which to study separate aspects of human existence, for they are not separate in the life situation. It poses problems also 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 reader's growing awareness

elicits for him the synthesis into this multidimensional whole".

Having discussed in turn various aspects related to the endurance performance recorded in this study as well as the physiological and psychological limits to prolonged physical work, it seems appropriate to complete the discussion by drawing together some of the salient points related to the relative intensities examined. Each of the relative intensities examined is excessive for occupational activities of a chronic repetitive nature. The findings of this study concur with those of Astrand and Rodahl (1977) in that intensities of 50% VO_2 max. and above are sustainable for a full day (e.g. Comrades Marathon) but result in severe fatigue. Such activities therefore, cannot be performed on a daily basis continually (except in the highly conditioned athlete) and if attempted will be to the detriment of physical status. Although not directly examined in this study, the 35% relative intensity propounded by Saha et al (1979) as an acceptable workload for ergonomics purposes, would appear to be logically sound. It is important to note that endurance times are greatly influenced by population characteristics such as age, sex, nutritional state, state of training, personality and motivational variables (Brouha 1953).

In determining acceptable workloads for ergonomics purposes, an important consideration should be the reduction of fatigue and promotion of endurance capacity. This can be achieved by giving attention to some of the following methods: a) reducing the workload and work stress, for example by greater mechanisation; b) attaining optimal positioning of the body, nature of motion and speed of motion

- thereby reducing mechanical load and physiological cost; c) reducing the heat load; d) implementing adequate rest periods; e) ensuring adequate nutrition and fluid replacement; f) ensuring optimal selection of workers; g) applying an equitable reward system thus enhancing motivational approach to the task due to expectancy x instrumentality x valence; and finally, h) measuring energy cost, and measuring subjective response through the use of psychological rating scales, at the very least promoting a "Hawthorne effect".

CHAPTER 5

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

AIMS OF STUDY

This study sought to examine the physiological and psychological limitations to prolonged work performed at different relative intensities, through the use of an eclectic integrative methodology. Questions addressed aimed at explaining why man elects to cease prolonged physical work at a specific point in time. Further the study aimed at elucidating inter-subject differences in factors limiting prolonged work, as well as possible intra-subject variance over time in this respect.

It was hypothesized that there would be no difference in the factors limiting prolonged work performed at the relative intensities 55%, 65%, 75% and 85% of maximal aerobic capacity. Further, it was hypothesized that there would be no difference in the physiological and psychological responses of subjects at 25%, 50%, 75% and 100% of their endurance time at each of the above relative intensities.

METHODS

Ten volunteer male caucasian subjects, mean age 26,3 $\pm$3,7years, mass 72,2 kg $\pm$7,0 and stature 176,8 cm $\pm$6,6 undertook a direct measurement of VO_2 max. upon the treadmill, yielding a mean VO_2 max. of 60,0 $ml.kg^{-1}.min^{-1}$($\pm$ 7,9). Thereafter subjects were randomly exposed to each of four different relative intensities, expressed as percent of

VO_2 max, namely 55%, 65%, 75% and 85%, where they exercised to a point of subjective discomfort at which they no longer were willing to continue. Throughout each treatment condition measures of VO_2, R, Vi, Vf, Vt, HR, RPE (general), RPE (legs), perceived thermal comfort, perceived pain and perceived fatigue were recorded. Upon cessation of exercise mean body temperatures and sweat rates were calculated. Pre- and post-test questionnaires employed an adjective cluster analysis in order to examine the contribution of these clusters toward the sensation of fatigue. The results were analysed using Single Variable Statistics, 2 factor Analyses of Variance, One Independent Variable Regression techniques and Ratios of Convergence. A 0,05 level of significance was chosen.

RESULTS

1) Work times to exhaustion recorded for the relative intensities (% VO_2 max.) 55%, 65%, 75% and 85%, namely 243 minutes $\pm$70; 159 minutes $\pm$ 37; 96 minutes $\pm$25 and 23 minutes $\pm$8 respectively, are within the range reported by earlier researchers.

2) A regression equation was developed to predict endurance times to exhaustion when working at a known relative intensity between 55 and 85% of VO_2 max. thus:

$$\% \ VO_2 \ max. = 117{,}8 + (-\ 10{,}6 \times LN\ (time))$$

$$where\ r = -\ 0{,}91$$

The high correlation coefficient indicates the predictive significance, and the high degree of variance in one factor accountable for in the other. The equation only applies to the range of relative intensities examined in this study.

3) A linear relationship was found between increases in work rates and increases in the physiological parameters of metabolism, namely heart rate, respiratory exchange ratio, inspired minute ventilation, breathing frequency, tidal volume, blood pressure, mean body temperature and sweat rates.

4) In close agreement with the physiological findings, the psychological parameters measured also demonstrated increases with increases in work intensity. Thus, RPE (general), RPE (legs), perceptions of pain, thermal comfort and fatigue ratings increase as a function added worked rate, though not as linearly as with physiological measures of metabolism.

5) Both physiological and psychological variables measured indicated significant ($p<0,05$) changes over time at all intensities examined. Summarised, heart rate and breathing frequency increased over time, whilst respiratory exchange ratio and tidal volume decreased over time. This concurs with earlier research findings. All psychological parameters measured demonstrated significant ($p< 0,05$) increases in rated intensity over time.

6) Ratios of convergence ranked the recorded physiological change over time in accordance with the known importance of each contributing factor. The same technique ranked psychological variables measured, lending support to the greater contribution of local factors in the overall gestalt of perceived exertion and fatigue, in agreement with subject's subjective reports, and concurring with such findings in the literature.

7) High intercorrelations were found between psychological rating

scales, suggesting the use of the scale considered most applicable to the task at hand and the psychological response measure required.

8) The close interrelationship evident amongst the physiological and psychological parameters measured is reflected in the high coefficient of multiple correlation of 0,94 established when a regression analysis was done (all intensities combined), for relative intensity against heart rate, breathing frequency, respiratory exchange ratio, RPE(general), RPE(legs), perceived thermal comfort, perceived pain, perceived fatigue, mean body temperature and endurance time.

9) Endurance time was found to be negatively correlated with extroversion (r =-0,26). This is not significant but is in agreement with earlier research findings. Extroverts demonstrated reduction in sensory input as illustrated by the under-estimation of endurance time. This too, is in accord with earlier research findings.

10) Fatigue cluster analysis indicated that the most important clusters contributing toward the sensation of fatigue and subsequent decision to cease work were Task Aversion and General Fatigue (r = 0,96 followed by Leg Fatigue and Thirst. This concurs with earlier research findings.

11) Variables such as motivation which are difficult to measure empirically, undoubtedly play a major role in work performance as demonstrated by the difference between Comrades ultramarathon times and those recorded for the 55% relative intensity condition.

CONCLUSIONS

1) The findings of this study are in accord with the statement of Broadbent (1979) in that any hope of measuring the effects of prolonged work must lie in studying the organisation of the whole behaviour and not in looking at particular parts of it. Whilst Grandjean (1969) maintains that there is no practical physiological objective test of fatigue which can be used in industry with success, the findings of this study strongly suggest the use of a pertinent subjective rating scale to access the state of the operator (worker). Further, relative intensity (percent of maximal working capacity) appears a valid tool for use in prolonged work studies due to its high predictive capacity for endurance performance time ($r = -0,91$).

2) The relative intensities applied in this study established endurance times within the range reported by earlier researchers. Severe fatigue results if longer durations are attempted, and workloads considerably below 55% VO_2 maximum are indicated as acceptable workloads for an eight hour working day.

3) Convergence rankings and subjective reports lend support to the greater contribution of local factors in the overall gestalt of perceived exertion, pain and fatigue, with biomechanical factors strongly indicated as limiting prolonged work.

4) Motivation, the task at hand and an attainable goal are important considerations in prolonged work performance.

Hypothesis One : Tentative Acceptance

The findings of this study lead one to tentatively accept the null hypothesis ($p < 0,05$) as follows:
There is no difference in the psychological factors limiting prolonged work performed at the relative intensities 55%, 65%, 75% and 85% of maximum aerobic capacity.

Hypothesis Two : Tentative Acceptance of Alternate Hypothesis

The findings of this study lead one to tentatively accept the alternate hypothesis ($p \leq 0,05$) as follows:
There is a difference in the physiological and psychological response of subjects at 25%, 50%, 75% and 100% of endurance time at each of the the relative intensities, both in direction and in intensity of response.

RECOMMENDATIONS

1) In agreement with earlier researchers, relative intensities (percent of maximal aerobic capacity) are recommended for use in studies examining prolonged physical work capacity, this being a standardised, objective and sound physiological basis to determine optimal levels of work output.

2) The use of category rating scales is recommended in psychological and ergonomics investigations of prolonged physical work. Such techniques access the confounding cognitive and subjective components at play in the complex gestalt which sets limits to prolonged physical work output.

3) Future researchers in this field would be advised to concentrate on two important limits to prolonged physical work, namely:

i) Biomechanical limitations; specifically the contribution of stress and strain caused by the continual pounding of the feet on a hard surface, though this could be generalised to postural strain and vibratory stress. In prolonged running tasks therefore, examination of the interplay between cadence, time and distance is suggested.

ii) Motivational limitations: It is suggested that a study be designed with sufficient subject numbers to examine differential motivational responses and prolonged work performance. For example, comparisons between high and low need achievers; intrinsic and extrinsic motivational strategies such as differential reward systems; and manipulation of expectancy-value theory postulates.

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APPENDIX 'A'

RHODES UNIVERSITY

DEPARTMENT OF HUMAN MOVEMENT STUDIES

INFORMED CONSENT FORM

Project: "An investigation of the Psychogenic Limitations to Prolonged work Performed at Different Relative Intensities."

The project you are about to take part in is research work for a Master's degree. The project supervisors are Mr. B. Goslin and Prof. J. Charteris, and they may be approached for further information should you so desire.

The study aims at investigating both the physiological and psychological limits to prolonged physical work. The "optimal" level of energy expenditure for the endurance type work activities of man and the complex nature of the limits to prolonged work remains an enigma. The purpose of this study is to elucidate this complex interplay of factors in an attempt to define the relative importance and contribution of each. In so doing, it is hoped that the question - "what makes man stop working?" may be answered. The results of the investigation could be applied in industrial ergonomics with regard to work intensity, duration and frequency for optimal performance, as well as in sport endurance activities.

The following will be required of you:

1) Measures of your mass, height, age, body fat percentage and other pertinent variables.
2) A measure of baseline personality characteristics (extroversion/introversion) obtained via a short 12 item

questionnaire.

3) A direct VO_2 max. test upon the treadmill (to exhaustion) during which various physiological (HR, Vt etc.) and psychological (ratings of perceived exertion) measures will be obtained.

4)

i) Thereafter, you will be required to report to the laboratory on four separate occasions to undertake a run on the treadmill at one of FOUR different relative intensities.

ii) You will not be informed of these intensities, though they will be well within your capability, and you will be required to make yourself available for a maximum period of SEVEN hours each time you report, as the duration of the exercise bout will be unknown.

iii) You will not be allowed to monitor the time duration of your exercise bout and will be required to work up to a point at which you feel so discomforted that you under normal circumstances voluntarily terminate your effort.

iv) You will be allowed a five minute rest period each hour upon the hour in order to relieve yourself should you so desire. Further, you will be allowed to eat and drink fluids freely, and will have the choice listening to music of your choice or viewing a videofilm of your choice.

v) You will be required to wear the same running shoes throughout the duration of the study.

vi) You are requested to refrain from heavy exhaustive exercise on the day before a treadmill bout and to refrain from eating a heavy meal or drinking fluid with a caffeine content, within two hours before commencement of exercise.

5) Various physiological and psychological measures will be obtained throughout the study. These include, a brief pre and post test questionnaire, measures of heart rate, blood pressure, oxygen consumption, breathing frequency, oral and skin temperature, sweat rate and the like ; measures of ratings of perceived exertion, pain, fatigue and perceived thermal comfort. You will be informed as to how to respond to the rating scales.

You are informed of the possible risks involved.

i) Falling or slipping on the treadmill

ii) Muscle strain and residual muscle soreness

iii) Psycho-physiological discomfort e.g. elevated heart rate, blood pressure, ventilation rate, sweating, tiredness, boredom and the like.

The actual risks involved are considered to be less than those encountered for example in endurance running outdoors, due to the even surface (treadmill) and the controlled environment and continuous monitoring of vital signs.

You are assured of complete confidentiality and anonymity with regard to the use of data obtained. Kindly note that data obtained may be stored and used (anonymously) for a different purpose in the future without obtaining further consent.

N.B. Your attention is drawn to the fact that your participation is entirely voluntary and that you may withdraw/stop your participation at any stage throughout thge study, either physically or by verbal communication.

Benefits to yourself:

You will be given feedback in the form of your direct VO_2 maximum measurement, which is an indication of your cardiorespiratory fitness. You will experience an awareness of how hard you are able to work as well as what it is like to work at different levels within your capacity. You will also find out how long you are able to sustain work at a specific intensity once the study is completed. There is potential for the learning experience i.e. exposure to equipment methods and protocol, as well as the potential for "self-knowledge".

You will be informed of the basic finding of the study and the conclusions reached. Bear in mind that you will be contributing to the greater body of knowledge with regard to endurance - type physical work, and that the findings of the study have potential use in ergonomics and in sport, to the possible benefit of society.

Thank you,

Stafford Rorke

APPENDIX 'B'

RHODES UNIVERSITY

DEPARTMENT OF HUMAN MOVEMENT STUDIES AND PHYSICAL EDUCATION

SUBJECT CONSENT FORM

I, ______________________________________ having

been fully informed of the nature of the research entitled:

____

(TITLE OF RESEARCH)

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

(At this point you should explain, in writing, the following:

1) Brief, explicit description of all procedures the subject personally will participate in.

2) Clear explanation of potential risks and benefits)

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.

APPENDIX 'C'

NAME .... CHRISTIAN NAMES ....

AGE .... SEX .... OCCUPATION ....

N = E = ? =

Instructions

Here are some questions regarding the way you behave, feel and act. After each question there is a "Yes," a "?" and a "No".

Try and decide whether "Yes" or "No" represents your usual way of acting or feeling; then put a circle round the "Yes" or "No." If you find it absolutely impossible to decide, put a circle round the "?", but do not use this answer except very occasionally. Work quickly, and don't spend too much time over any question; we want your first reaction, not a long drawn-out thought process! The whole questionnaire shouldn't take more than a few minutes. Be sure not to omit any questions. Now go ahead, work quickly, and remember to answer every question. There are no right or wrong answers, and this isn't a test of intelligence or ability, but simply a measure of the way you behave.

1.	Are you happiest when you get involved in some project that calls for rapid action?	Yes	?	No
2.	Do you sometimes feel happy, sometimes depressed, without any apparent reason?	Yes	?	No
3.	Does your mind often wander while you are trying to concentrate?	Yes	?	No
4.	Do you usually take the initiative in making new friends?	Yes	?	No
5.	Are you inclined to be quick and sure in your actions?	Yes	?	No
6.	Are you frequently "lost in thought" even when supposed to be taking part in a conversation?	Yes	?	No
7.	Are you sometimes bubbling over with energy and sometimes very sluggish?	Yes	?	No
8.	Would you rate yourself as a lively individual?	Yes	?	No
9.	Would you be very unhappy if you were prevented from making numerous social contacts?	Yes	?	No
10.	Are you inclined to be moody?	Yes	?	No
11.	Do you have frequent ups and downs in mood, either with or without apparent cause?	Yes	?	No
12.	Do you prefer action to planning for action?	Yes	?	No

(From : Eysenck 1958)

APPENDIX 'D'

RATINGS OF PERCEIVED EXERTION

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 1962)

APPENDIX 'E'

Standard Instruction Read to Subjects for Eliciting RPE

"You will now see in front of you a scale which contains numbers from 6 to 20. This scale is used to translate into numbers your feelings of exertion while exercising. The range of numbers represents a range of feelings from "No exertion at all" (No 6) to "Maximal exertion" (No 20). In order to help you select a number which corresponds to your subjective feelings every other number has an attached verbal expression - for example, 7 is associated with feelings of Very Very Slight Exertion while 19 is associated with feelings of Very Very Hard Exertion. Your goal is to rate your feelings which are caused by the work and not the work itself. These feelings should be general, that is, about the body as a whole. You will not be asked to specify the feeling but select a number which most accurately corresponds to your perception of your total body feeling. Keep in mind there are no right or wrong numbers. Use any number you think is appropriate."

(From Noble et al 1973, Medicine and Science in Sports Vol 5, No 2 p 117.)

APPENDIX 'F'

PERCEIVED THERMAL COMFORT

1 COLD

2 COOL

3 SLIGHTLY COOL

4 NEUTRAL

5 SLIGHTLY WARM

6 WARM

7 HOT

(From : Gagge et al 1967)

APPENDIX 'G'

PAIN PERCEPTION

0	NORMAL
1	
2	UNCOMFORTABLE
3	
4	VERY UNCOMFORTABLE
5	
6	PAINFUL
7	
8	VERY PAINFUL
9	
10	EXTREMELY PAINFUL

(From : Morgan and Horstman 1978)

APPENDIX 'H'

FATIGUE SCALE

0	NONE
1	JUST NOTICEABLE
2	MODERATE
3	SEVERE
4	VERY SEVERE
5	INTOLERABLE

(From : Smith 1968)

APPENDIX 'I'

PRE-TEST QUESTIONNAIRE

This is a brief questionnaire considered necessary to examine some of the factors related to your participation in this study. Please be as honest as possible in replying and do not dwell upon any question for too long - simply report how you feel. Circle appropriate responses.

1) During the past week has the amount of sleep you have had been ....
   Less than normal   Normal   More than normal
2) Hours of sleep last night? ....
3) Do you feel well rested?   Yes   No
4) During the past week have you been eating normally?   Yes   No
5) Time of last meal? .... normal   big   small?
6) Any illness or injuries during the past two weeks?
   Yes   No
   If yes, please elaborate
7) Are you on any medication?   Yes   No
   If yes, please elaborate
8) Is there any reason you should not participate in this experience?
   Yes   No
9) Do you have the time available to undertake this experiment?
   Yes   No
10) Do you have any pressing engagement to attend immediately after this experiment?   Yes   No
11) Did you postpone/cancel any engagement to be present for this experiment?   Yes   No
12) Did this upset you or any other party?   Yes   No
13) How would you describe your present emotional state?
    CALM   INDIFFERENT   AGITATED
14) With regard to the anticipated exercise would you regard yourself as ...
    NOT MOTIVATED   INDIFFERENT   MOTIVATED

15) Please rate the following on a scale from 1 = absent to 5 = severe, for your present state.

	1	2	3	4	5
perspiring					
weak legs					
refreshed					
thirsty					
numbness					
out of gas					
leg twitching					
sweating					
dry mouth					
tired					
heavy legs					
short of breath					
comfortable					
leg cramps					
hard to keep going					
panting					
legs aching					
weak					
working hard					
muscle tremors					
rather quit					
hard to breathe					
drained					
shaky legs					
weary					
aching muscles					
heart pounding					
worn out					
physically tired					

APPENDIX 'J'

<u>Post-Test Questionnaire</u>

Please complete this questionnaire as honestly as possible describing how you felt at the point in time when you decided to stop exercising.

1) Please rate the following on a scale from 1 = absent to 5 = severe, for the moment you stopped exercising.

	1	2	3	4	5
perspiring					
weak legs					
refreshed					
thirsty					
numbness					
out of gas					
leg twitching					
sweating					
dry mouth					
tired					
heavy legs					
short of breath					
comfortable					
leg cramps					
hard to keep going					
panting					
legs aching					
weak					
working hard					

muscle tremors

rather quit

hard to breathe

drained

shaky legs

weary

aching muscles

heart pounding

worn out

physically tired

2) How long do you think you have been going? Hours ______

Minutes______

3) If you reached 7 hours and were stopped by the researcher how much longer do you think you would have continued of your own free will? Hours______

Minutes______

4) If this had been a life or death situation, or one of great incentive, how much longer do you think you could have continued at this intensity?

Hours______

Minutes______

5) Do you feel pressed for time now? Yes No

6) How would you rate your present state now?

RELAXED INDIFFERENT AGITATED

7) In terms of your own subjective and personal expectations how would you rate your performance?

below average average better than average

APPENDIX "K"

PILOT TESTING RESULTS

85% RELATIVE INTENSITY

	Endurance Time Seconds		HR Beats.min^{-1}		RPE (general)		RPE (legs)		ORAL T 0°C		BODY MASS KG		SYSTOLIC BP mm Hg	
Subject	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2
1	1714	1875	188	197	18	19	19	20	37,4	37,3	0,5	0,25	175	180
2	1695	1690	180	175	19	19	20	19	36,2	36,4	0,8	0,7	150	145
3	885	865	187	183	18	18	17	18	37,5	36,8	0,9	0,7	180	190
$\bar{x}$	1431	1476	188	185	18,3	18,7	18,7	19	37,0	36,8	0,7	0,6	168	172
σ	473	538	9	11	0,6	0,6	1,5	1,0	0,7	0,5	0,2	0,3	16	24
CV	33	36,4	4,8	6,0	3,1	3,1	8,2	5,3	1,9	1,2	28,4	47,2	9,5	13,7
$P<0,05$	1 = 2		1 = 2		1 = 2		1 = 2		1 = 2		1 = 2		1 = 2	

APPENDIX " K"

APPENDIX 'L'

TABLE XII : RAW DATA : CONDITION : 55% RELATIVE INTENSITY, 25% OF DURATION

SUBJECT	HR Beats $.min^{-1}$	Vi ℓ. min^{-1}	Vf Breaths $.min^{-1}$	Vt ℓ. min^{-1}	R	SPEED km. hr^{-1}	VO_2 $ml.kg^{-1}$ $.min^{-1}$	RPE GENERAL	RPE LEGS	PTC	PAIN	FATIGUE
PC	146	48,52	40	1,21	,9	-	56,5	12	12	5	3	2
GD	157	64,77	46	1,41	,97	12,18	55,1	12	14	4	3	2
AH	145	48,78	44	1,11	,92	11,21	54,6	11	11	5	1	1
AJ	144	55,7	40	1,39	,92	9,7	56,2	9	13	5	2	2
AL	148	53,38	48	1,11	,88	9,88	54,7	11	12	5	2	1
DM	145	60,78	44	1,38	,98	9,01	56,0	11	11	3	1	1
LR	148	39,68	26	1,53	,94	7,24	55,2	9	10	4	1	1
SR	147	44,42	26	1,71	,95	9,51	54,8	11	12	4	1	1
AS	140	62,32	38	1,64	,86	11,68	54,1	11	11	2	0	1
MW	143	59,48	46	1,29	,9	–	57,8	13	14	6	3	2
$\bar{x}$	146	53,78	40	1,38	,92	10,05	55,5	11	12,0	4,3	1,7	1,4
σ	5	8,29	8	,21	,04	1,6	1,11	1,3	1,3	1,2	1,1	,5
CV	3,5	15,41	20	15,2	4,34	15,92	2,0	11,8	10,8	27,9	64,7	35,7

TABLE XIII : RAW DATA : CONDITION : 55% RELATIVE INTENSITY, 50% OF DURATION

SUBJECT	HR Beats $.min^{-1}$	Vi ℓ. min^{-1}	Vf Breaths $.min^{-1}$	Vt ℓ. min^{-1}	R	SPEED km. hr^{-1}	VO_2 $ml.kg^{-1}.min^{-1}$	RPE GENERAL	RPE LEGS	PTC	PAIN	FATIGUE
PC	144	51,87	42	1,42	,92	-	55,9	12	14	4	3	2
GD	154	64,85	50	1,3	,9	12,4	56,1	12	14	3	3	2
AH	148	46,89	36	1,3	,84	10,59	55,8	12	13	5	2	2
AJ	144	53,64	36	1,49	,89	9,42	55,8	10	15	5	3	2
AL	147	57,6	54	1,07	,88	9,54	56,4	12	12	5	2	2
DM	147	56,53	58	0,97	,86	8,00	55,7	15	16	4	4	3
LR	148	39,81	36	1,11	,9	7,22	56,6	13	15	4	3	2
SR	152	41,58	28	1,49	,84	8,21	54,8	12	13	4	2	2
AS	140	62,51	34	1,84	,86	11,60	56,1	13	14	2	2	2
MW	149	51,39	46	1,12	,86	-	54,8	13	16	6	3	2
$\bar{x}$	147	52,67	42	1,29	,88	9,62	55,8	12,4	14,2	4,2	2,7	2,1
σ	4	8,23	10	,26	,03	1,81	0,60	1,3	1,3	1,1	,7	,3
CV	2,72	15,63	23,81	20,16	3,41	18,81	1,07	10,48	9,16	26,19	25,93	14,29

TABLE XIV : RAW DATA : CONDITION : 55% RELATIVE INTENSITY, 75% OF DURATION

SUBJECT	HR Beats $.min^{-1}$	Vi $\ell.min^{-1}$	Vf Breaths $.min^{-1}$	Vt $\ell.min^{-1}$	R	SPEED $km.hr^{-1}$	VO_2 $ml.kg^{-1}.min^{-1}$	RPE GENERAL	RPE LEGS	PTC	PAIN	FATIGUE
PC	158	54,36	44	1,24	,89	-	57,7	14	15	5	3	3
GD	162	63,92	48	1,33	,86	11,79	54,3	17	17	6	8	4
AH	150	47,52	48	0,99	,83	9,73	54,5	15	15	5	3	2
AJ	148	52,94	36	1,47	,85	9,33	54,4	10	18	5	6	2
AL	166	54,51	50	1,09	,88	9,44	54,7	13	13	4	3	2
DM	150	51,22	50	1,02	,83	8,36	53,9	16	17	5	5	3
LR	148	36,67	34	1,08	,88	6,64	58,6	16	18	3	7	4
SR	154	41,4	24	1,73	,84	8,05	55,4	14	15	3	4	2
AS	140	61,76	32	1,84	,86	11,56	56,1	13	14	2	2	2
MW	151	51,79	42	1,23	,82	-	55,8	13	17	6	6	2
$\bar{x}$	153	51,61	41	1,3	,85	9,36	55,53	14,1	15,9	4,4	4,7	2,6
σ	8	8,28	9	,29	,02	1,73	1,57	2,0	1,7	1,4	2,0	,8
CV	5,23	16,04	21,95	22,31	2,35	18,48	2,83	14,18	10,69	31,82	42,55	30,77

TABLE XV : RAW DATA : CONDITION : 55% RELATIVE INTENSITY, CESSATION OF ACTIVITY

SUBJECT	HR Beats $.min^{-1}$	Vi ℓ. min^{-1}	Vf Breaths $.min^{-1}$	Vt ℓ. min^{-1}	R	SPEED km. hr^{-1}	Δ SPEED Start to Finish	VO_2 $ml.kg^{-1}$ $.min^{-1}$	RPE GENERAL	RPE LEGS	PTC	PAIN	FATI-GUE	MEAN BODY TEMP 0°C	ENDUR-ANCE TIME min	ABSOLUTE SWEAT RATE $1.nr^{-1}$	RELATIVE SWEAT RATE $1.m^2$	BP mm.Hg
PC	158	51,92	52	1,00	,84	-	-	54,8	18	20	6	9	5	35,2	202	,7	,4	130/ 80
CD	166	63,33	48	1,32	,85	11,76	-0,54	55,2	19	20	6	10	5	34,2	193	,9	,4	145/80
AH	150	48,55	38	1,28	,85	9,86	-1,52	55,1	17	18	6	4	3	34,8	358	,6	,4	140/80
AJ	148	56,62	40	1,42	,85	9,28	-0,47	55,8	13	20	5	9	4	33,9	202	,7	,4	140/90
AL	166	52,71	50	1,05	,84	8,62	-2,91	53,9	16	19	5	8	4	35,2	166	,7	,4	160/80
DM	157	57,2	54	1,06	,85	8,11	-2,78	55,9	18	19	6	8	4	35,0	321	,8	,4	140/80
LR	156	43,48	38	1,14	,83	7,06	-1,73	58,8	19	20	4	9	5	33,6	200	,6	,3	140/80
SR	157	42,7	28	1,66	,82	7,9	-2,42	56,6	17	18	6	7	3	34,2	335	,6	,4	110/70
AS	140	62,2	40	1,55	,83	11,3	-0,65	55,3	16	18	2	5	2	34,4	196	,8	,4	150/70
MW	154	51,21	48	1,07	,83	-		54,5	15	20	6	10	4	35,5	255	,6	,3	140/70
$\overline{X}$	155	52,99	44	1,26	,84	9,24	-1,63	55,59	16,8	19,2	5,2	7,9	3,9	34,6	243,0	0,7	,4	140/78
σ	8	7,02	8	,23	,01	1,66	-1,01	1,36	1,9	,9	1,3	2,0	,9	,6	70.0	0,1	,04	13/6
CV	5,16	13,25	18,18	18,25	1,19	17,97	61,96	2,45	11,31	4,69	25,0	25.32	23,08	1,73	28,8	14,29	10.0	9,28/7,69

TABLE XVI : RAW DATA : CONDITION : 65% RELATIVE INTENSITY, 25% OF DURATION

SUBJECT	HR Beats $.min^{-1}$	Vi $\ell.$ min^{-1}	Vf Breaths $.min^{-1}$	Vt $\ell.$ min^{-1}	R	SPEED km. hr^{-1}	VO_2 $ml.kg^{-1}$ $.min^{-1}$	RPE GENERAL	RPE LEGS	PTC	PAIN	FATIGUE
PC	160	59,4	36	1,65	,97	11,14	66,6	13	12	4	3	2
GD	167	80,48	54	1,49	,93	14,15	65,2	13	14	4	3	2
AH	161	54,71	40	1,37	,96	12,71	63,0	13	13	6	2	2
AJ	150	60,02	42	1,43	,91	10,85	65,2	12	13	5	3	2
AL	145	62,09	40	1,55	,93	11,68	63,0	13	13	4	2	1
DM	144	68,5	58	1,18	,88	10,6	67,4	14	14	5	2	2
LR	165	46,72	47	1,3	,96	8,64	64,8	10	11	3	2	2
SR	160	48,65	30	1,62	,94	10,89	65,0	12	13	3	2	1
AS	151	77,76	46	1,69	,91	13,55	64,8	11	12	3	1	2
MW	178	63,96	52	1,23	,91	12,67	63,9	12	12	5	4	1
$\bar{x}$	158	62,23	45	1,45	,93	11,7	63,09	12,3	12,7	4,2	2,4	1,7
σ	11	11,11	9	,18	,03	1,62	5,89	1,2	,9	1,0	,8	,5
CV	6,96	17,85	20	12,4	3,22	13,85	9,34	9,75	7,09	23,81	33,33	29,41

TABLE XVII : RAW DATA : CONDITION : 65% RELATIVE INTENSITY, 50% OF DURATION

SUBJECT	HR Beats $.min^{-1}$	Vi $\ell.$ min^{-1}	Vf Breaths $.min^{-1}$	Vt $\ell.$ min^{-1}	R	SPEED km. hr^{-1}	VO_2 $ml.kg^{-1}$ $.min^{-1}$	RPE GENERAL	RPE LEGS	PTC	PAIN	FATIGUE
PC	160	58,12	38	1,53	,94	11,01	63,9	13	13	4	3	2
GD	167	74,8	48	1,56	,91	14,03	65,0	14	15	3	3	3
AH	162	61,08	44	1,39	,86	12,71	66,4	15	15	6	4	3
AJ	155	69,82	52	1,34	,92	11,28	64,4	12	17	6	5	3
AL	153	70,25	50	1,4	,92	11,69	65,8	14	15	5	3	2
DM	148	63,33	58	1,09	,82	9,67	65,4	15	16	6	4	3
LR	165	45,08	38	1,19	,92	8,41	64,2	14	15	4	4	3
SR	161	52,63	34	1,55	,95	10,81	64,0	13	14	3	3	2
AS	151	78,94	42	1,88	,95	13,59	64,6	12	13	4	2	2
MW	178	65,53	48	1,32	,92	12,88	62,5	12	12	4	4	1
$\bar{x}$	160	63,76	45	1,43	,91	11,6	64,62	13,4	14,5	4,5	3,5	2,4
σ	9	10,24	7	,22	,04	1,75	1,1	1,2	1,5	1,2	,9	,7
CV	5,63	16,06	15,56	15,38	4,39	15,09	1,70	8,96	10,34	26,67	25,71	29,17

TABLE XVIII : RAW DATA : CONDITION : 65% RELATIVE INTENSITY, 75% OF DURATION

SUBJECT	HR Beats $.min^{-1}$	Vi $\ell.min^{-1}$	Vf Breaths $.min^{-1}$	Vt $\ell.min^{-1}$	R	SPEED $km.hr^{-1}$	VO_2 $ml.kg^{-1}.min^{-1}$	RPE GENERAL	RPE LEGS	PTC	PAIN	FATIGUE
PC	160	65,94	48	1,37	,93	10,7	64,5	15	15	4	4	2
GD	169	70,2	48	1,46	,92	13,67	63,9	18	19	5	8	4
AH	162	53,23	44	1,21	,81	11,43	63,1	15	15	6	4	3
AJ	160	67,37	52	1,3	,89	10,44	65,9	12	19	6	8	4
AL	156	70,22	54	1,3	,92	11,82	65,4	14	15	5	4	2
DM	157	69,94	62	1,13	,8	10,12	65,2	16	16	6	5	3
LR	168	44,24	38	1,16	,85	7,85	64,2	17	18	5	8	4
SR	165	56,67	32	1,77	,93	10,73	66,1	15	15	3	4	2
AS	154	79,76	50	1,6	,89	13,03	65,4	14	16	4	3	2
MW	178	67,59	52	1,3	,91	12,87	64,1	14	13	5	5	2
$\bar{x}$	163	64,52	48	1,36	,89	11,3	64,78	15,0	16,1	4,9	5,3	2,8
σ	7	10,25	8	,2	,05	1,7	0,97	1,7	1,9	,9	1,9	,92
CV	4,29	15,89	16,67	14,7	5,62	15,04	1,50	11,33	11,8	18,36	35,85	32,86

TABLE XIX : RAW DATA : CONDITION : 65% RELATIVE INTENSITY, CESSATION OF ACTIVITY

SUBJECT	HR Beats $.min^{-1}$	Vi ℓ. min^{-1}	Vf Breaths $.min^{-1}$	Vt ℓ. min^{-1}	R	SPEED km. hr^{-1}	SPEED Start to Finish	VO_2 $ml.kg^{-1}$ $.min^{-1}$	RPE GENERAL	RPE LEGS	PTC	PAIN	FATIGUE	MEAN BODY TEMP 0°C	ENDURANCE TIME min	ABSOLUTE SWEAT RATE $l.hr^{-1}$	RELATIVE SWEAT RATE $l.m^2$	BP mm.Hg
PC	160	68,99	54	1,28	,91	10,81	- 0,55	65,5	18	19	4	8	4	34,6	143	,5	,3	120/70
GD	170	81,84	58	1,41	,93	13,66	- 0,87	63,8	19	20	5	9	4	34,3	148	1,2	,6	165/80
AH	166	57,66	48	1,2	,81	11,69	- 1,12	64,6	16	17	6	4	3	34,3	218	,8	,4	150/80
AJ	160	67,46	50	1,35	,88	10,53	-0,94	64,1	12	20	6	8	4	34,1	160	,9	,5	140/80
AL	157	74,47	48	1,55	,92	11,81	-0,47	67,2	16	16	6	5	3	34,7	116	,9	,4	145/75
DM	163	70,44	74	0,95	,88	9,8	-2,49	67,9	18	19	6	8	4	35,6	229	,9	,5	160/70
LR	170	49,69	34	1,46	,87	7,78	-1,28	65,3	19	19	4	9	4	34,3	138	,6	,3	160/70
SR	167	54,81	38	1,44	,84	9,68	-1,57	61,8	18	19	3	8	4	33,7	150	,8	,5	140/80
AS	154	76,8	44	1,75	,85	13,01	-0,66	62,6	17	18	4	8	3	35,0	158	1,4	,7	160/80
MW	178	69,77	56	1,25	,92	12,98	-0,08	64,3	15	16	6	8	4	34,0	126	,5	,3	150/70
$\overline{X}$	165	67,19	50	1,36	,88	11,2	- 1,0	64,71	16,8	18,3	5	7.5	3,7	34,4	159	,85	,45	149/76
σ	7	10,17	11	,22	,04	1,8	- ,7	1,87	2,2	1,5	1,2	1,7	,5	,55	37	,3	,1	13,5/5
CV	4,24	15,14	22,0	16,18	4,55	16,07	70,0	2,89	13.09	8,19	24,0	22,67	13,51	1.59	23,3	35,29	22,2	9,1/6,6

TABLE XX : RAW DATA : CONDITION : 75% RELATIVE INTENSITY, 25% OF DURATION

SUBJECT	HR Beats $.min^{-1}$	Vi $\ell.$ min^{-1}	Vf Breaths $.min^{-1}$	Vt $\ell.$ min^{-1}	R	SPEED km. hr^{-1}	VO_2 $ml.kg^{-1}$ $.min^{-1}$	RPE GENERAL	RPE LEGS	PTC	PAIN	FATIGUE
PC	166	68,27	42	1,63	,96	12,43	76,2	12	13	4	1	2
GD	181	88,37	46	1,92	,98	15,84	73,3	13	13	3	2	2
AH	161	70,84	44	1,61	,97	-	76,7	13	13	7	3	2
AJ	156	76,61	42	1,82	,96	12,5	76,1	13	13	5	3	2
AL	156	79,79	56	1,42	,96	13,46	75,6	13	13	4	2	2
DM	165	82,75	50	1,66	,93	-	75,4	10	9	3	3	2
LR	176	56,72	40	1,42	,95	9,27	76,4	12	12	4	3	2
SR	172	71,94	44	1,63	,99	12,44	74,5	15	16	4	4	3
AS	168	101,6	46	2,2	,98	15,47	74,8	14	14	5	1	2
MW	182	80,6	54	1,49	1,0	14,68	72,7	13	14	6	4	2
$\bar{x}$	168	77,75	46	1,68	,97	13,3	75,17	12,8	13	4,5	2,6	2,1
σ	9	12,17	5	,24	,02	2,1	1,34	1,3	1,8	1,3	1,1	,3
CV	5,36	15,65	10,87	14,39	2,06	15,79	1,78	10,16	13,85	28,89	42,31	14,29

TABLE XXI : RAW DATA : CONDITION : 75% RELATIVE INTENSITY, 50% OF DURATION

SUBJECT	HR Beats $.min^{-1}$	Vi $\ell.$ min^{-1}	Vf Breaths $.min^{-1}$	Vt $\ell.$ min^{-1}	R	SPEED km. hr^{-1}	VO_2 $ml.kg^{-1}$ $.min^{-1}$	RPE GENERAL	RPE LEGS	PTC	PAIN	FATIGUE
PC	168	69,28	42	1,65	,96	12,54	74,4	13	14	4	2	2
GD	181	102,22	58	1,76	1,02	15,84	72,6	17	17	5	7	4
AH	163	70,52	46	1,53	,96	-	75,5	14	14	7	3	2
AJ	160	84,01	56	1,5	,96	12,55	75,7	14	14	5	5	2
AL	157	79,09	52	1,52	,98	13,37	72,2	17	17	6	5	3
DM	169	80,37	56	1,44	,94	-	73,6	12	11	5	4	3
LR	176	51,18	34	1,51	,89	9,01	72,8	18	19	6	8	4
SR	172	59,54	36	1,65	,93	11,92	73,9	16	17	4	6	3
AS	168	105,22	54	1,95	,99	15,14	75,5	14	15	5	2	2
MW	182	81,52	64	1,27	,93	14,62	74,1	16	15	7	5	3
$\bar{x}$	170	78,3	50	1,58	,96	13,1	74,03	15,1	15,3	5,4	4,7	2,8
σ	8	16,91	10	,19	,04	2,16	1,26	1,9	2,3	1,1	2,0	,8
CV	4,71	21,59	20,0	12,03	4,17	16,49	1,70	12,58	15,03	20,37	42,55	28,57

TABLE XXII : RAW DATA : CONDITION : 75% RELATIVE INTENSITY, 75% OF DURATION

SUBJECT	HR Beats $.min^{-1}$	Vi ℓ. min^{-1}	Vf Breaths $.min^{-1}$	Vt ℓ. min^{-1}	R	SPEED km. hr^{-1}	VO_2 $ml.kg^{-1}.min^{-1}$	RPE GENERAL	RPE LEGS	PTC	PAIN	FATIGUE
PC	165	71,27	48	1,48	,9	12,41	76,4	15	15	5	3	2
GD	181	103,91	62	1,68	,98	15,92	74,2	19	14	6	9	5
AH	173	74,8	46	1,63	,98	-	74,5	15	15	7	4	2
AJ	168	87,5	50	1,75	,95	12,22	76,9	15	18	7	8	4
AL	158	75,53	50	1,47	,97	13,36	71,8	18	19	6	8	4
DM	169	81,22	56	1,45	,92	-	76,9	13	13	5	5	3
LR	176	55,79	34	1,64	,89	8,79	75,4	17	18	5	8	4
SR	175	69,47	44	1,58	,93	12,05	78,1	17	18	4	6	4
AS	168	94,58	46	2,06	,94	15,31	76,7	15	16	5	3	2
MW	182	80,79	60	1,35	,93	14,51	74,1	13	13	5	4	3
$\bar{x}$	172	79,49	50	1,61	,94	13,07	75,5	15,7	16,4	5,5	5,8	3,3
σ	7	13,58	8	,2	,03	2,26	1,86	2	2,3	1,0	2,3	1,1
CV	4,05	17,08	16,0	12,42	3,19	17,29	2,46	12,74	14,02	18,18	39,66	33,33

TABLE XXIII : RAW DATA : CONDITION : 75% RELATIVE INTENSITY, CESSATION OF ACTIVITY

SUBJECT	HR Beats .min^{-1}	Vi ℓ. min^{-1}	Vf Breaths .min^{-1}	Vt ℓ. min^{-1}	R	SPEED km hr^{-1}	Δ SPEED Start to Finish	VO_2 ml.kg^{-1} .min^{-1}	RPE GENERAL	RPE LEGS	PTC	PAIN	FATI-GUE	MEAN BODY TEMP 0°C	ENDUR-ANCE TIME min	ABSOLUTE SWEAT RATE 1.hr^{-1}	RELATIVE SWEAT RATE 1.m²	BP mm.Hg
PC	163	71,53	46	1,56	,86	12,02	- 1,41	77,6	17	19	4	4	3	34,6	94	1,1	,6	130/70
GD	181	100,92	58	1,74	,97	15,81	-0,13	73,9	19	20	6	10	5	34,7	58	1,4	,8	180/70
AH	175	76,73	48	1,6	,97	-	-	74,3	19	19	7	10	5	34,2	95	1,0	,6	170/80
AJ	168	89,25	58	1,54	,94	12,6	NIL	74,8	16	19	7	9	4	35,7	155	1,0	,5	210/90
AL	165	81,44	56	1,45	,94	13,57	-0,17	76,6	18	19	6	8	4	34.6	83	,9	,4	160/50
DM	170	80,14	64	1,25	,89	-	-	75,3	18	19	7	8	4	36.0	96	1,4	,8	160/40
LR	176	56,09	38	1,48	,89	8,92	-1,32	77,0	19	20	4	9	4	34,6	102	,8	,4	180/70
SR	175	68,93	44	1,57	,93	12,00	-1,13	78,5	18	19	5	7	4	34.4	80	1,0	,6	160/70
AS	168	103,99	54	1,93	,94	15,16	-0,78	75,8	18	18	5	8	4	35,5	100	1,6	,8	175/75
MW	184	86,14	66	1,31	,9	14,41	-0,60	76,1	15	15	6	9	3	35.4	95	1,0	,6	150/80
$\overline{X}$	172	81,52	53	1,54	,92	13,06	- ,7	75,99	17,7	18,7	5,7	8,2	4	34,9	96	1,1	,6	168/70
σ	8	14,5	9	,2	,04	2,2	- ,6	1,47	1,3	1,4	1,2	1,75	,7	,6	25	,3	,15	21/15
CV	4,65	17,79	16,98	12,99	4,35	16,85	85,7	1,93	7,34	7,49	21,05	21,34	17,5	1,72	26,0	27,27	23,0	12,5/21,4

TABLE XXIV : RAW DATA : CONDITION : 85% RELATIVE INTENSITY, 25% OF DURATION

SUBJECT	HR Beats $.min^{-1}$	Vi ℓ. min^{-1}	Vf Breaths $.min^{-1}$	Vt ℓ. min^{-1}	R	SPEED km. hr^{-1}	VO_2 $ml.kg^{-1}$ $.min^{-1}$	RPE GENERAL	RPE LEGS	PTC	PAIN	FATIGUE
PC	178	89,19	40	2,23	1,01	16,5	85,5	17	18	6	2	3
GD	190	120,53	56	2,15	1,03	16,52	86,6	15	15	4	5	3
AH	184	92,14	46	2,00	1,18	-	84,6	15	16	6	4	3
AJ	172	96,59	54	1,79	,96	13,73	85,2	14	13	5	3	3
AL	183	106,73	56	1,91	1,25	17,5	86,0	17	18	5	7	4
DM	181	105,74	56	1,89	1,03	-	89,3	12	11	4	3	2
LR	182	79,44	38	2,09	1,18	12,43	86,9	11	11	6	2	2
SR	180	79,75	50	1,6	1,1	-	85,1	17	18	5	4	3
AS	182	96,16	50	1,94	1,09	-	85,81	15	15	5	4	3
MW	192	95,32	54	1,77	1,07	-	83,9	15	16	5	6	4
$\overline{x}$	182	96,16	50	1,94	1,09	15,34	85,81	14,8	15,1	5,1	4	3
σ	6	12,52	7	,19	,09	2,15	1,52	2,0	2,7	,7	1,6	,7
CV	3,29	13,02	14,0	9,79	8,26	14,02	1,77	13,51	17,88	13,72	40,0	23,33

TABLE XXV : RAW DATA : CONDITION : 85% RELATIVE INTENSITY, 50% OF DURATION

SUBJECT	HR Beats $.min^{-1}$	Vi ℓ. min^{-1}	Vf Breaths $.min^{-1}$	Vt ℓ. min^{-1}	R	SPEED km . hr^{-1}	VO_2 $ml.kg^{-1}.min^{-1}$	RPE GENERAL	RPE LEGS	PTC	PAIN	FATIGUE
PC	178	89,33	44	2,03	,98	–	87,0	18	18	7	4	4
GD	190	119,01	54	2,2	,97	16,66	85,7	17	18	5	7	4
AH	184	90,17	46	1,96	1,06	–	86,2	14	13	7	6	4
AJ	172	92,93	56	1,66	,96	13,49	83,9	15	15	5	5	3
AL	178	103,64	52	1,99	1,14	–	82,0	18	19	5	7	4
DM	184	100,93	56	1,8	,97	–	85,3	16	14	6	7	4
LR	185	75,98	36	2,11	1,08	11,79	84,7	13	12	6	5	3
SR	180	80,67	46	1,75	1,00	–	85,4	18	19	6	8	4
AS	183	95,07	50	1,92	1,02	–		16	16	6	6	4
MW	194	102,99	58	1,78	1,06	–	82,7	17	18	6	8	4
$\bar{x}$	183	95,07	50	1,92	1,02	13,98	84,79	16,2	16,2	5.9	6,3	3,8
σ	6	12,37	7	,17	,06	2,5	1,54	1,8	2,6	,7	1,3	.4
CV	3,28	13,01	14,0	8,85	5,88	17,88	1,82	11,11	16,05	11,86	20,64	10,53

TABLE XXVI : RAW DATA : CONDITION : 85% RELATIVE INTENSITY, 75% OF DURATION

SUBJECT	HR Beats $.min^{-1}$	Vi ℓ. min^{-1}	Vf Breaths $.min^{-1}$	Vt ℓ. min^{-1}	R	SPEED km. hr^{-1}	VO_2 $ml.kg^{-1}$ $.min^{-1}$	RPE GENERAL	RPE LEGS	PTC	PAIN	FATIGUE
PC	179	84,03	40	2,1	,95	-	85,3	19	19	7	6	4
GD	190	117,67	56	2,1	,95	16,72	83,9	17	18	6	8	4
AH	185	92,81	50	1,86	1,07	-	86,3	14	13	7	6	4
AJ	174	102,84	56	1,84	,96	14,35	88	15	16	5	7	3
AL	178	97,45	54	1,8	1,09	-	82,0	18	19	5	7	4
DM	186	102,29	60	1,7	,95	-	85,1	17	16	7	8	4
LR	185	71,99	38	1,89	1,04	11,02	82,1	18	16	7	7	4
SR	180	77,68	52	1,49	,97	-	82,3	18	19	6	8	4
AS	184	94,64	52	1,84	1,00	-	-	17	17	6	7	4
MW	198	105,04	60	1,75	1,04	-	83,2	17	18	6	8	4
$\bar{x}$	184	94,64	52	1,84	1,00	14,03	84,36	17,0	17,1	6,2	7,2	3,9
σ	7	13,7	8	,18	,05	2,86	1,94	1,5	1,9	,8	,8	,3
CV	3,80	14,48	15,39	9,78	5,00	20,38	2,29	8,82	11,11	12,9	11,11	7,69

TABLE XXVII : RAW DATA : CONDITION : 85% RELATIVE INTENSITY, CESSATION OF ACTIVITY

SUBJECT	HR Beats $.min^{-1}$	Vi $\ell.$ min^{-1}	Vf Breaths $.min^{-1}$	Vt $\ell.$ min^{-1}	R	SPEED km. hr^{-1}	Δ SPEED Start to Finish	VO_2 $ml.kg^{-1}$ $.min^{-1}$	RPE GENERAL	RPE LEGS	PTC	PAIN	FATI-GUE	MEAN BODY TEMP 0°C	ENDUR-ANCE TIME min	ABSOLUTE SWEAT RATE $l.hr^{-1}$	RELATIVE SWEAT RATE $l.m^2$	BP mm.Hg
PC	180	91,0	54	1,69	,92	16,45	-	86,6	19	20	7	7	4	35,8	29	1,4	,8	145/80
CD	190	119,54	62	1,93	,93	16,6	- 2,63	85,1	19	20	6	10	5	35,2	28	1,1	,6	190/70
AH	185	94,31	50	1,89	1,03	-	-	84,0	17	17	7	8	5	35,2	15	1,2	,6	190/70
AJ	174	97,83	54	1,81	,93	13,84	- 1,54	88,3	17	17	5	8	4	36,0	35	1,4	,7	180/100
AL	180	107,84	66	1,63	1,11	-	-	81,4	19	20	6	9	5	35,8	14	2,4	1,2	190/85
DM	187	103,26	68	1,56	,94	-	-	87,9	18	17	7	8	4	36,9	28	1,5	,8	190/70
LR	185	75,9	42	1,81	1,01	11,13	- 2,04	86,2	20	19	7	9	4	35,3	15	2,4	1,3	180/70
SR	182	81,28	56	1,45	,97	-		81,1	19	20	7	9	4	35,2	15	1,6	,9	170/70
AS	185	98,45	59	1,69	,99				18	19	7	9	4	25,7	22	1,6	,9	180/77
MW	198	115,05	76	1,51	1,03	-		83,4	18	19	7	9	4	26,2	15	1,6	,9	180/75
$\overline{X}$	185	98,45	59	1,7	,99	14,5	_2,07	84,9	18,4	18,8	6,6	8,6	4,3	25,7	23	1,6	,9	180/77
σ	7	13,78	10	,16	,06	2,58	-0,55	2,47	,9	1,3	,7	,8	,5	.6	8	,4	,2	14/10
CV	3,78	13,99	16,95	9,41	6,06	17,8	26,6	2,91	4,89	6,92	10,61	9,3	11,63	1,68	34,5	25,0	22,22	7,8/12,9

APPENDIX 'M'

SUMMARY OF MEAN ENVIRONMENTAL CONDITIONS

55% RELATIVE INTENSITY				
Subject	Pb mm.Hg	Td 0°C	Tw 0°C	Rel.Hum. %
PC	715,6	19,5	14,5	55
GD	712,0	17	14	65
AH	716,9	18	15	71
AJ	717,7	17	12,5	56
AL	715,4	18	14	53
DM	717,7	20	16	64
LR	716,5	17	13	61
SR	718,4	20	17	64
AS	718,6	16	12,5	64
MW	720,7	19,5	16	68
$\bar{x}$	717,03	18,2	14,5	62,1
σ	2,15	1,46	1,55	5,8

65% RELATIVE INTENSITY				
Subject	Pb mm.Hg	Td 0°C	Tw 0°C	Rel.Hum %
PC	717,1	16,5	14	65
GD	711,6	20	15	52
AH	715,7	18,5	15,5	63
AJ	722,0	17	14	65
AL	720,7	19,5	16	67
DM	718,2	19,5	17	68
LR	722,3	18,5	15	67
SR	721,6	17,5	15	65
AS	717,6	16	12	59
MW	719,4	17	13	56
$\bar{x}$	718,57	18	14,7	62,7
σ	3,4	1,4	1,5	5,3

75% RELATIVE INTENSITY				
Subject	Pb mm Hg	Td 0°C	Tw 0°C	Rel.Hum %
PC	714,7	20	13,5	44
GD	723,6	18	15	62
AH	717,4	18,5	15,5	71
AS	724	17,5	14,5	70
AL	722,7	19,5	14,5	56
DM	711,9	21	15	49
LR	718,2	20	15	56
SR	717,3	17	14,5	65
AS	720,5	17	14	61
MW	719,2	20	17,5	68
$\bar{x}$	718,6	18,9	14,9	60,2
σ	4,39	1,43	1,1	8,9

85% RELATIVE INTENSITY				
Subject	Pb mm Hg	Td 0°C	Tw 0°C	Rel.Hum %
PC	723,5	20,5	17,5	73
GD	721,0	17,5	14,0	66
AH	717,0	19,0	15,5	67
AJ	722,2	20,5	15,0	53
AL	723,5	20,5	17,5	73
DM	723,5	20,5	17,5	73
LR	715,4	18,0	14	53
SR	715,1	20,5	15,5	56
AS				
MW	723,5	20,5	17,5	73
$\bar{x}$	722,2	19,7	16	65,2
σ	3,56	1,2	1,5	8,9

APPENDIX 'N'

TABLE XXVIII

PHYSICAL ACTIVITY QUESTIONNAIRE

CLUSTER ANALYSIS - PRE-AND POST-TEST RESPONSE ie (PRE-/POST 1/5)

CONDITION : 55% RELATIVE INTENSITY

CLUSTER	TASK AVERSION					LEG FATIGUE													GENERAL FATIGUE									THIRST	
Subject	Sweating	Perspiration	Rather Quit	Comfortable	Refreshed	Leg Cramps	Leg Twitching	Muscle Tremors	Aching Muscles	Legs Aching	Weak Legs	Heavy Legs	Shaky Legs	Short of Breath	Panting	Hard to Breathe	Heart Pounding	Numbness	Worn Out	Tired	Weary	Out of Gas	Physically Tired	Weak	Drained	Hard to Keep Going	Working Hard	Dry Mouth	Thirsty
PC	1/3	1/3	1/5	4/1	3/1	1/3	1/4	1/1	1/5	1/5	1/5	1/5	1/4	1/1	1/1	1/1	1/3	1/1	1/5	1/5	1/5	1/1	1/5	1/2	1/5	1/5	1/5	2/1	1/1
GD	1/5	1/4	1/5	5/1	5/1	1/2	1/4	1/4	1/5	1/5	1/5	1/5	1/4	1/5	1/3	1/3	1/4	1/3	1/5	3/5	1/5	1/5	1/5	1/5	1/5	1/5	1/5	1/3	1/3
AH	1/2	1/2	1/5	4/2	4/1	1/1	1/1	1/2	1/4	1/4	1/5	1/5	1/3	1/1	1/1	1/1	1/1	1/3	1/5	2/5	2/5	1/5	1/5	2/4	2/4	1/4	1/4	3/1	3/1
AJ	1/3	1/3	1/3	5/2	5/2	2/5	1/5	1/3	1/3	3/4	1/5	2/5	1/3	1/2	1/2	1/2	1/3	1/4	1/3	1/3	1/3	1/3	1/3	1/3	1/3	1/5	1/2	1/2	1/3
AL	1/2	1/2	1/5	5/1	3/1	1/5	1/5	1/5	1/5	1/5	1/5	1/5	1/5	1/3	1/2	1/2	1/2	1/3	1/4	1/4	1/4	1/3	1/4	1/2	1/3	1/4	1/4	1/1	1/1
DM	1/3	1/3	1/3	5/4	5/1	1/4	1/3	1/2	1/5	1/5	1/5	1/5	1/5	1/2	1/3	1/3	1/3	1/1	1/3	1/5	1/4	1/3	1/4	1/3	1/3	1/4	1/3	1/2	1/3
LR	1/2	1/2	1/5	4/1	3/1	1/1	1/1	1/1	1/4	1/5	1/5	2/5	1/3	1/1	1/1	1/1	1/1	1/1	1/5	2/5	2/4	1/1	2/5	2/3	1/5	1/5	1/5	1/2	1/1
SR	1/3	1/3	1/5	4/1	3/1	2/2	2/3	1/3	1/4	1/5	1/5	1/5	1/4	1/3	1/3	1/3	1/3	1/2	1/5	1/5	1/5	1/5	1/5	1/5	1/5	1/5	1/5	1/3	1/3
AS	1/4	1/3	1/5	2/2	2/1	1/1	1/1	1/1	1/4	1/4	2/4	2/4	2/1	1/1	1/2	1/1	1/2	1/1	1/3	3/4	1/4	1/1	2/4	2/2	2/2	1/4	1/4	1/1	1/3
MW	1/5	1/3	1/3	5/1	5/1	1/3	1/4	1/2	1/4	1/5	1/5	1/5	1/4	1/4	1/1	1/2	1/3	1/2	1/3	1/3	1/2	1/2	1/3	1/3	1/2	1/5	1/4	1/2	1/2
TOTAL	10/32	10/28	10/46	43/16	38/11	12/27	11/31	10/24	10/43	12/47	11/49	13/49	11/36	10/23	10/19	10/19	10/25	10/21	10/41	16/44	12/41	10/29	12/43	13/32	12/37	10/46	10/41	13/18	12/21
$\overline{X}$ DIFFERENCE	2,2	1,8	3,6	2,7	2,9	1,5	2,0	1,4	3,3	3,5	3,8	3,6	2,5	1,3	0,9	0,9	1,5	1,1	3,1	2,8	2,9	1,9	3,1	1,9	2,5	3,6	3,1	0,5	0,9
$\overline{X}$ DIFFERENCE $\overline{X}$			2,64								2,1												2,8					0,7	

TABLE XXIX

PHYSICAL ACTIVITY QUESTIONNAIRE

CLUSTER ANALYSIS - PRE- AND POST-TEST RESPONSE ie (PRE-/POST- 1/5)

CONDITION : 65% RELATIVE INTENSITY

CLUSTER	TASK AVERSION					LEG FATIGUE													GENERAL FATIGUE									THIRST	
Subject	Sweating	Perspiration	Rather Quit	Comfortable	Refreshed	Leg Cramps	Leg Twitching	Muscle Tremors	Aching Muscles	Legs Aching	Weak Legs	Heavy Legs	Shaky Legs	Short of Breath	Panting	Hard to Breathe	Heart Pounding	Numbness	Worn Out	Tired	Weary	Out of Gas	Physically Tired	Weak	Drained	Hard to Keep Going	Working Hard	Dry Mouth	Thirsty
PC	1/4	1/4	5/5	4/1	1/1	1/1	1/1	1/1	1/5	1/5	1/4	1/4	1/2	1/1	1/2	1/1	1/2	1/1	1/4	2/4	1/4	1/2	1/4	1/2	1/4	1/5	1/4	1/2	1/2
GD	1/3	2/3	1/5	5/3	5/1	1/2	1/3	1/3	1/5	1/5	1/5	1/5	1/4	1/3	1/3	1/3	1/3	1/2	1/4	1/4	1/4	1/5	1/4	1/3	1/4	1/5	1/5	3/2	2/1
AH	1/3	1/3	2/4	3/2	3/1	1/1	1/1	1/2	1/4	1/5	1/4	1/5	1/3	1/1	1/1	1/1	2/2	1/3	2/4	2/5	2/5	2/5	2/4	2/4	2/4	1/5	1/4	1/2	1/2
AJ	1/3	1/3	1/2	5/3	5/3	2/5/	2/5	1/2	2/3	2/5	2/5	2/5	1/4	1/2	1/2	1/2	1/2	2/4	1/4	2/2	1/3	1/3	2/4	1/2	2/3	1/4	1/2	1/2	1/3
AL	1/4	1/4	1/2	5/2	5/2	1/2	1/3	1/2	1/3	1/3	1/4	1/4	1/3	1/3	1/2	1/2	1/3	1/4	1/4	1/4	1/3	1/4	1/4	1/3	1/3	1/3	1/3	1/2	1/2
DM	1/5	1/4	1/5	3/2	5/4	1/2	1/3	1/2	1/5	1/5	1/5	1/5	1/5	1/3	1/2	1/2	1/3	1/4	1/5	1/5	1/4	1/4	1/5	1/4	1/4	1/4	1/4	1/2	1/3
LR	1/4	1/3	1/4	5/2	2/1	1/1	1/1	1/1	1/5	1/5	1/5	1/5	1/3	1/1	1/1	1/1	1/1	1/1	1/2	2/4	2/4	1/5	1/4	1/3	1/2	1/5	1/5	1/1	1/2
SR	1/3	1/3	1/5	4/1	4/1	1/2	1/2	1/2	1/5	1/5	1/5	1/5	1/3	1/3	1/2	1/3	1/3	1/2	1/5	1/5	1/5	1/5	1/5	1/5	1/5	1/5	1/5	1/2	1/3
AS	1/4	1/4	1/5	4/2	3/1	1/1	1/1	1/1	1/4	1/3	1/4	1/4	1/3	1/2	1/2	1/2	1/2	1/1	1/4	1/4	1/4	1/3	1/4	2/2	1/3	1/5	1/4	1/1	1/2
MW	1/4	1/4	1/5	5/1	5/1	2/3	2/4	1/3	3/5	2/5	2/5	2/5	2/4	1/4	1/1	1/3	1/4	1/2	1/3	1/4	1/3	1/4	1/3	1/3	1/3	1/5	1/4	1/4	1/3
TOTAL	10/37	11/35	15/42	43/19	38/16	12/20	12/24	10/19	13/44	12/46	12/46	12/47	11/34	10/23	10/18	10/20	11/26	11/24	11/39	14/41	12/39	11/40	12/41	12/31	12/35	10/46	10/40	12/20	11/23
$\bar{X}$ DIFFERENCE	2,7	2,4	2,7	2,4	2.2	0,8	1.2	0,9	3,1	3,4	3,4	3,5	2,3	1,3	0,8	1.0	1,5	1,3	2,8	2.7	2,7	2,9	2,9	1,9	2,3	3.6	3.0	0,8	1,2
$\bar{X}$ DIFFERENCE $\bar{X}$			2,48							1,89													2,76					0,1	

TABLE XXX

PHYSICAL ACTIVITY QUESTIONNAIRE

CLUSTER ANALYSIS - PRE- AND POST-TEST RESPONSE ie (PRE-/POST- 1 / 5)

CONDITION : 75% RELATIVE INTENSITY

CLUSTER	TASK AVERSION					LEG FATIGUE													GENERAL FATIGUE									THIRST	
Subject	Sweating	Perspiration	Rather Quit	Comfortable	Refreshed	Leg Cramps	Leg Twitching	Muscle Tremors	Aching Muscles	Legs Aching	Weak Legs	Heavy Legs	Shaky Legs	Short of Breath	Panting	Hard to Breathe	Heart Pounding	Numbness	Worn Out	Tired	Weary	Out of Gas	Physically Tired	Weak	Drained	Hard to Keep Going	Working Hard	Dry Mouth	Thirsty
PC	1/4	1/4	1/4	5/1	3/1	1/1	1/1	1/1	3/5	2/4	1/3	3/5	1/3	1/2	1/1	1/1	1/2	1/1	1/4	2/3	3/5	1/3	1/4	1/3	1/4	1/3	1/4	3/1	4/2
GD	3/5	3/5	1/5	3/2	3/1	1/1	1/1	1/5	1/5	1/5	2/5	2/5	1/4	1/2	1/2	1/2	1/4	1/1	3/5	3/5	1/5	1/4	1/5	1/3	1/5	1/5	1/5	2/1	1/1
AH	1/3	1/3	2/5	3/1	4/1	1/1	1/1	1/5	1/5	1/5	1/5	2/4	2/2	2/4	1/1	1/1	1/1	1/2	3/5	3/5	1/2	4/5	2/5	3/5	3/5	2/5	1/4	3/1	3/1
AJ	1/4	1/5	1/4	5/1	5/4	1/5	1/5	1/3	1/5	1/4	1/4	1/4	1/4	1/3	1/3	1/3	2/4	1/4	1/4	1/4	1/4	1/4	1/4	1/4	1/4	1/4	1/5	1/3	2/3
AL	1/3	1/3	1/5	5/2	5/1	1/4	1/5	1/4	1/4	1/5	1/4	1/4	1/4	1/3	1/3	1/3	1/3	1/4	1/5	1/5	1/4	1/4	1/5	1/4	1/5	1/4	1/4	1/2	1/3
DM	1/5	1/5	1/4	5/1	5/1	1/3	1/2	1/2	2/4	1/4	1/4	1/4	1/4	1/3	1/3	1/4	1/4	1/2	1/4	1/5	1/4	1/4	1/4	1/4	1/4	1/4	1/4	1/3	1/3
LR	1/3	1/3	1/4	5/1	4/2	1/4	1/1	1/1	1/5	1/5	1/5	1/5	1/4	1/1	1/1	1/1	1/1	1/3	1/3	1/4	1/4	1/5	1/4	1/3	1/4	1/5	1/5	2/2	2/3
SR	1/4	1/4	1/5	4/1	3/1	1/2	1/2	1/3	1/3	1/5	1/5	1/5	1/3	1/4	1/5	1/4	1/5	1/2	1/5	2/5	1/5	1/5	2/5	1/5	1/5	1/5	1/5	1/2	1/3
AS	1/4	1/4	1/5	4/2	4/1	1/1	1/2	1/1	2/3	1/3	1/4	1/4	1/5	1/2	1/3	1/3	1/3	1/2	1/4	2/5	1/4	1/3	1/5	2/2	2/3	1/4	1/5	3/2	2/2
MW	1/4	1/4	1/4	5/1	5/1	1/2	1/2	1/2	1/3	2/3	2/3	2/2	1/2	1/4	1/1	1/3	1/3	1/2	1/3	1/2	1/3	1/4	1/3	1/2	1/2	1/4	1/4	1/3	1/3
TOTAL	12/39	12/40	11/45	44/13	41/14	10/24	10/25	10/26	14/42	12/43	12/42	15/42	11/35	11/28	10/23	10/25	11/30	10/23	14/42	17/43	12/40	13/41	12/44	13/38	13/41	11/43	10/45	18/20	18/24
$\overline{X}$ DIFFERENCE	2,7	2,8	3,4	3,1	2,7	1,4	1,5	1,6	2,8	3,1	3,0	2,7	2,4	1,7	1,3	1,5	1,9	1,3	2,8	2,6	2,8	2,8	3,2	2,5	2,8	3,3	3,5	0,2	0,6
$\overline{X}$ DIFFERENCE $\overline{X}$			2,94									2,06											2,92					0,4	

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TABLE XXXI

PHYSICAL ACTIVITY QUESTIONNAIRE

CLUSTER ANALYSIS - PRE- AND POST-TEST RESPONSE ie (PRE-/POST- 1 / 5)

CONDITION : 85% RELATIVE INTENSITY

CLUSTER	TASK AVERSION					LEG FATIGUE													GENERAL FATIGUE									THIRST	
Subject	Sweating	Perspiration	Rather Quit	Comfortable	Refreshed	Leg Cramps	Leg Twitching	Muscle Tremors	Aching Muscles	Legs Aching	Weak Legs	Heavy Legs	Shaky Legs	Short of Breath	Panting	Hard to Breathe	Heart Pounding	Numbness	Worn Out	Tired	Weary	Out of Gas	Physically Tired	Weak	Drained	Hard to Keep Going	Working Hard	Dry Mouth	Thirsty
PC	1/5	1/5	1/5	4/1	4/1	1/1	1/4	1/1	1/5	1/4	3/4	4/4	1/3	1/4	1/4	1/4	2/4	1/2	1/5	2/5	1/5	1/5	2/5	1/4	1/5	1/5	1/5	1/5	1/4
GD	1/4	1/4	1/5	5/1	5/1	1/5	1/3	1/3	1/4	1/4	1/4	1/5	1/4	1/5	1/4	1/4	1/5	1/3	1/4	1/4	1/5	1/5	1/4	1/5	1/5	1/4	1/5	1/2	1/1
AH	1/3	1/3	1/5	4/1	4/1	1/1	1/1	1/1	1/1	1/3	1/4	1/4	1/3	1/5	1/5	1/4	2/4	1/4	1/4	1/5	2/4	1/5	1/5	1/3	1/5	1/4	1/5	3/4	3/5
AI	1/5	2/5	1/3	4/4	3/2	1/2	3/2	1/2	1/2	1/2	3/3	3/2	1/2	1/3	1/2	1/3	1/3	1/2	2/4	3/4	2/3	3/3	3/3	2/3	2/3	1/4	1/4	1/2	4/2
AL	1/3	1/3	1/5	5/1	5/1	1/4	1/4	1/4	1/5	1/5	1/5	1/5	1/5	1/5	1/5	1/5	1/5	1/5	1/5	1/5	1/5	1/5	1/5	1/5	1/5	1/5	1/5	1/4	1/4
DM	1/4	1/4	1/5	4/2	2/2	1/2	1/2	1/2	1/3	1/2	1/2	1/2	1/2	1/4	1/3	1/4	1/4	1/2	1/4	1/4	1/4	1/4	1/4	1/3	1/4	1/4	1/4	1/5	1/5
LR	1/5	1/5	1/5	5/1	2/1	1/1	1/1	1/1	1/1	1/3	1/3	2/3	1/2	1/5	1/4	1/4	1/5	1/3	1/5	2/4	1/4	1/4	1/5	1/3	1/4	1/5	1/5	1/2	1/2
SR	1/5	1/5	1/5	4/1	3/1	1/2	1/2	1/3	1/3	1/4	1/4	1/5	1/3	1/4	1/4	1/5	1/5	1/2	1/5	2/5	1/5	1/5	2/5	1/5	1/5	1/5	1/5	1/3	1/3
AS																													
MW	1/5	2/5	1/5	3/1	5/1	1/2	1/3	1/2	1/4	1/5	1/4	1/5	1/3	1/5	1/2	1/4	2/5	1/2	1/4	1/3	1/2	1/4	1/4	1/3	1/4	1/5	1/5	2/5	1/4
TOTAL	9/39	11/39	9/43	38/13	33/11	9/20	11/22	9/19	9/28	9/31	13/33	15/35	9/27	9/40	9/33	9/37	12/40	9/25	10/40	14/39	11/37	11/40	13/40	10/34	10/40	9,41	9,43	12/32	14/30
$\overline{X}$ DIFFERENCE	3,0	2,8	3,4	2,5	2,2	1,1	1,1	1,0	1,9	2,2	2,0	2,0	1,8	3,1	2,4	2,8	2,8	1,6	3,0	2,5	2,6	2,9	2,7	2,4	3,0	3,2	3,4	2,0	0,16
$\overline{X}$ DIFFERENCE $\overline{X}$			2,8									1,8										2,9						0,18	

APPENDIX 'O'

PRE AND POST–TEST QUESTIONNAIRE - SUMMARY OF RESPONSES

55% RELATIVE INTENSITY

	TIME ESTIMATION CORRECT (Y), ABOVE (+), BELOW	TIME PRESSURED YES (Y), NO (N)	MOOD STATE RELAXED (R) INDIFFERENT (I) AGITATED (A)			SUBJECTIVE PERFORMANCE AVERAGE (A) ABOVE (+) BELOW (-)
SUBJECT			PRE	POST	CHANGE	
PC	C (within 1 min.)	N	I	I	0	A
GD	-	N	I	R	+	+
AH	-	N	R	I	-	+
AJ	-	N	R	A	-	A
AL	-	N	I	I	0	A
DM	-	N	I	I	0	+
LR	-	N	I	R	+	A
SR	-	N	A	R	+	+
AS	-	N	I	I	0	A
MW	-	N	R	R	0	A
TOTALS	-9; 1 C.	10 N	NET CHANGE		+	6 A; 4 +.

65% RELATIVE INTENSITY

SUBJECT			PRE	POST	CHANGE	
PC	+	N	R	I	-	A
GD	-	Y	I	R	+	+
AH	+	Y	I	R	+	+
AJ	+	N	R	R	0	+
AL	+	Y	I	I	0	A
DM	C (2 minutes)	N	R	R	0	A
LR	-	N	I	I	0	A
SR	-	N	I	A	-	-
AS	-	N	R	I	-	A
MW	-	N	I	I	0	-
TOTALS	5 -; 4 +; 1C.	7 N; 3 Y.	NET CHANGE		-	5A; 3+; 2-.

75% RELATIVE INTENSITY

SUBJECT	TIME ESTIMATION	TIME PRESSURED	MOOD STATE PRE	POST	CHANGE	SUBJECTIVE PERFORM.
PC	-	N	I	I	0	A
GD	-	N	R	A	-	A
AH	-	N	R	R	0	+
AJ	-	N	R	I	-	A
AL	C (1 minute)	N	I	R	+	+
DM	-	N	R	R	0	A
LR	-	N	I	R	+	+
SR	C (o)	N	I	R	+	A
AS	-	N	R	I	-	A
MW	-	N	I	R	+	A
TOTALS	8 -; 2 C.	10 N	NET CHANGE		+	7 A; 3+.

85% RELATIVE INTENSITY

SUBJECT	TIME ESTIMATION	TIME PRESSURED	MOOD STATE PRE	POST	CHANGE	SUBJECTIVE PERFORM.
PC	-	N	A	R	+	A
GD	-	N	I	R	+	-
AH	C (o)	N	R	A	+	A
AJ	+	Y	R	R	0	A
AL	-	N	I	A	-	A
DM	+	N	R	R	0	A
LR	-	Y	R	R	0	A
SR	+	N	I	A	-	+
AS	NOT TESTED					
MW	+	N	I	R	+	+
TOTALS	4 -; 4 +; 1 C.	7 N; 2 Y.	NET CHANGE		0	6 A; 2 +; 1 -.

GRAND TOTALS

TIME ESTIMATION	TIME PRESSURED	MOOD STATE	SUBJECTIVE PERFORM.
26 - OR 66,7% 5C OR 12,8% 8 + OR 20,5%	34N OR 87,2% 5Y OR 12,8%	12 + OR 30,8% 11 - OR 28,2% 16 OR 41,0%	24A OR 61,5% 12+ OR 30,8% 3- OR 7,7%

APPENDIX 'P'

DEPARTMENT OF
HUMAN MOVEMENT STUDIES
and
PHYSICAL EDUCATION

Dear

May I take this opportunity of thanking you for your participation as a subject in my Master's Thesis entitled "An investigation of the Contribution of Psychogenic Factors Limiting Prolonged Work Performed at Different Relative Intensities".

As promised the following data and summary of findings may be of interest:

	Measure	Your value	Group average
1	Age (years)		26,3
2	Stature (cm)		176,8
3	Mass (kg)		72,2
4	Body fat (%)		11,9
5	Body Surface area (m^2)		1,9
6	Vo_2 maximum ($ml.kg^{-1}$ $min.^{-1}$)		60,0
7	Max Mets. (No. of times Resting Metabolism)		17,1
8	Anaerobic Threshold (% of max. VO_2)		77,8
9.	Speed at which 8 attained ($km.hr^{-1}$)		14 – 15

At the point of cessation of exercise the following values were recorded:

Where Y = your value and $\bar{x}$ = group average

HR = Heart Rate ($B.min^{-1}$)

Vi = Inspired volume of air ($1.min^{-1}$)

Vt = Breathing frequency (no. of breaths$\cdot min^{-1}$)

R = Respiratory Quotient (Ratio Co_2 to O_2 indicative of foodstuff being utilised 1 = carbohydrate 0,8 = fat etc.)

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RPE = Ratings of Perceived Exertion

PTC = Perceived Thermal Comfort

P = Pain Rating

F = Fatigue Rating

MBT = Mean Body Temperature ($0^{\circ}C$)

ASW = Absolute Sweat Rate ($l.min^{-1}$)

BP = Blood Pressure

T = Time of cessation of exercise (minutes)

Condition	HR		Vi		Vf		Vt		R		Gen RPE		Legs RPE	
(% Max.)	Y	$\bar{X}$	Y	$\bar{X}$	Y	$\bar{X}$	Y	$\bar{X}$	Y	$\bar{X}$	Y	$\bar{X}$	Y	$\bar{X}$
55%		155		52,9		44		1,3		0,84		16,8		19,2
65%		165		67,2		50		1,36		0,88		16,8		18,3
75%		172		81,5		53		1,54		0,92		17,7		18,7
85%		185		98,5		59		1,7		0,99		18,4		18,8

Condition	PTC		P		F		MBT		ASR		BP		T	
(% Max)	Y	$\bar{X}$	Y	$\bar{X}$	Y	$\bar{X}$	Y	$\bar{X}$	Y	$\bar{X}$	Y	$\bar{X}$	Y	$\bar{X}$
55%		5,2		7,9		3,9		34,6		0,7		140/78		243
65%		5,0		7,5		3,7		34,4		0,85		149/76		159
75%		5,7		8,2		4,0		34,9		1,1		168/70		96
85%		6,6		8,6		4,3		35,7		1,6		180/77		23

I have not yet completed a full analysis of the data, though the statistics and graphics done indicate clear differences in response across the different percentages of maximum, which is to be expected. More exciting however, is the way that the psychological measures closely mirror the physiological with significant changes occurring over time i.e. between 25%, 50%, 75% and 100% of endurance time.

As you are probably well aware, very often pain-limited cessation of exercise occurred, with subjects reporting no cardio-vascular limits. The reasons for this appear to be mechanical strain coupled with for example, lactate accumulation in the legs. However, the "teasing out" of the principle limiting factors is still to be done.

Once again, thank you for your most valuable contribution, without which my thesis would not have been possible. Please do not hesitate to contact me if you have any queries or suggestions with regard to this research.

Yours sincerely,

STAFFORD RORKE