PHYSIOLOGICAL AND PSYCHOPHYSICAL FACTORS IN THE RATING OF PERCEIVED EXERTION DURING UPHILL OVERGROUND AND TREADMILL RUNNING

BY

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ABSTRACT

The purpose of this study was to examine possible differences between the field and laboratory ratings of perceived exertion (RPE) when the performance and physiological measures for the two conditions were equated. Furthermore, the interactive effects of local, central and overall RPE were examined. Finally, the question of the potential effects of attitudes on RPE was addressed.

Eleven well-conditioned adult male marathon runners voluntarily participated in the study. After a period of treadmill habituation, biographical and anthropometric data were collected. This was followed by a $\dot{V}O_2$ max test and a speed-matching session at 70% of $\dot{V}O_2$ max to determine overground running speed at 3.8% and 7.5% grade. Subjects then completed an attitudinal questionnaire and ran 4km overground. Finally, the above test was repeated on the treadmill, with the gradient and running speed of the overground condition being replicated. Physiological measures and differentiated RPE were obtained during the final two sessions.

There were no physical environmental, task characteristic or performance differences between the overground and treadmill conditions. No heart rate or $\dot{V}O_2$ differences were observed between the two conditions, but $\dot{V}E$ was significantly elevated in the laboratory. Local and overall RPE were significantly higher in the laboratory than in the field, but there was no difference for central RPE. Attitudes were more favourable towards the field than towards the laboratory work task.

The results suggest that neither heart rate nor $\dot{V}O_2$ are major factors directly influencing the perception of exertion. $\dot{V}E$ however appears to be a potent central signal mediating RPE. The results also indicate that local factors play a more important role in the perception of exertion than was previously thought. Attitudes towards a work task could possibly mediate the self-reports of exertion. The findings of this study also suggest that RPE are influenced by cognition to a large degree. Finally, environmental cues, or the ambience of a particular working environment, can exert a substantial influence on RPE. Direct perceptual translations from laboratory to field situations may therefore be invalid.

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CHAPTER ONE

INTRODUCTION

The Study of human performance and perceived exertion during physical activity has been an area of considerable interest and research in recent years. During recent decades, students of human movement have become interested in how people feel, what aches and pains they have, and how difficult they perceive their work to be. There seems to be substantial agreement that the rating of perceived exertion (RPE) has many practical applications (e.g. such as in exercise prescription), and that what people *think* they are doing may well be more important than what they *are* doing (Morgan, 1973; Rejeski, 1981; Borg, 1982; Rejeski, 1985). That is to say, 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 (Morgan, 1973).

What however, is perceived exertion? It can probably best be defined as one's subjective rating of the intensity of the work being performed (Morgan, 1973). Alternatively, it can be described as a subjective self-report of energy expenditure using a specific scale for quantification (Carton and Rhodes, 1985). Borg (1973) states that perceived exertion is "the single best indicator of the degree of physical strain experienced". The product of perceived exertion involves the interactive configuration or processing of numerous input parameters elicited from the peripheral working muscles and joints, from the central cardiovascular and respiratory functions and from the central nervous system. The processing of these signals may include that of muscle and blood lactate, ventilatory minute volume, catecholamine production, blood glucose levels, muscle glycogen stores, personality structure, pain tolerance, past experiences and memory and opioid and neurotransmitter levels in the brain (Morgan, 1981; Borg, 1982). Accepting that all of the above input parameters can impinge on an individual's rating of perceived exertion, it can readily be appreciated that the psychophysical judgement is based on the integration, into a configuration, of the above signals. The product (perceived exertion), is based upon a psychophysiological process which is technologically inaccessible, but is readily available in terms of self-awareness. Therefore, while the psychophysical judgement normally represents a verbalised statement about cognitively integrated sensations, they involve much more than cognition or perception alone. The interaction between, and integration of, the input parameters mentioned earlier, should in fact be viewed as a Gestalt of perceived exertion (Morgan, 1981; Borg, 1982).

The relationship between ratings of perceived exertion and various physiological measures has been well established and documented (Frankenhauser *et al.* 1969; Mihevic, 1981; Carton and Rhodes, 1985), yet most studies in this field have persisted with attempts to identify the biological foundations of the process (Rejeski, 1981).

We have, however, seen that many factors influence RPE, and the subjective ratings of perceived exertion must therefore be viewed as a psychological complement to physiological responses during work. Accepting that RPE does not seem to be a function of a single physiological or psychological parameter, but that it seems to involve a complex and yet unresolved integration of several parameters (Pandolf *et al.*, 1972), the present study has not searched for a primary perceptual cue, as this would be a rather simplistic attempt to probe the complex psycho-biological dynamics of the exercise response. This investigation therefore adopted, and was guided by, the conceptual framework that contends that perceived exertion at any given moment represents a complex psycho-biological process driven by local (feelings of strain in the exercising muscles and joints) and central (sensations from the cardiopulmonary systems) factors, as well as affective and cognitive factors.

Borg (in Milhevic, 1981) proposed that for prolonged work, perceived exertion is most forcibly influenced by the adaptation of the circulatory system. In contrast to this, Ekblom and Goldbarg (1971) proposed a two-factor model. They suggested that local influences such as feelings of strain in the exercising muscles and joints, and central influences involving the cardiopulmonary system both contribute to the perception of exertion. However, it appears that when a particular cue is accentuated by either elevated rate, concentration or value over others it can dominate the overall rating (Pandolf, 1978). While work intensity, duration, amount of muscle mass involvement, environmental situation, age, sex, body composition and training status may alter the interplay of the two factors, recent research (Mihevic, 1981; Pandolf, 1982; Robertson, 1982) has indicated strong support for the influence of local factors, and cited increasing evidence that central factors do not play as important a role in the perception of exertion as was originally thought. Pandolf (1978; 1982) proposed an experimental model for studying local and central factors. This model suggests that undifferentiated ratings from Borg's category scale belong to a "superordinate" level, and that this integrative factor is not necessarily closely linked to the underlying physiological substrata. "Subordinate" or differentiated (local and central) ratings are however more closely related to discrete physiological sensations. This model allows comparison between local, central and overall perceived exertion. The present investigation therefore examined the interplay between these factors within the particular limits of the study.

Several investigators (Frankenhauser *et al.*, 1969; Pandolf *et al.*, 1972; Pandolf, 1978; Mihevic, 1981; Carton and Rhodes, 1985) have reported high correlations between measured physiological stress and subjects' ratings of perceived exertion in studies under somewhat artificial conditions in the laboratory. Very little appears to have been done to corroborate these findings in normal field conditions. Furthermore, it has been suggested (Smutok *et al.*, 1980; Purvis and Cureton, 1981) that RPE could be reliably used to self-prescribe exercise. Implicit in this is the assumption that RPE values achieved at a specific metabolic output in the laboratory will be consistent with RPE values at the same metabolic output in the field. The literature however indicates a wide difference of opinion about the validity of the extrapolation of treadmill information to the overground environment or *vice-versa* (Van Ingen Schenau, 1980). In addition to this, Pennebaker and Lightner (1980) have demonstrated that during exercise, external cues (e.g. terrain) do compete with internal cues (e.g. ventilation). In the field, where a myriad of social psychological forces impinge on the performer, the role of physiological feedback to RPE may well be reduced (Rejeski, 1981). Implicit in all the research to date is the assumption that RPE findings can validly be extrapolated to the field. This assumption has been made and accepted intuitively, without empirical foundation. This study therefore attempted to examine the applicability of laboratory RPE to field conditions.

STATEMENT OF THE PROBLEM

The problem addressed in this study was to examine the relationship between ratings of perceived exertion obtained in the field and ratings of perceived exertion obtained in the laboratory setting, when the overall performance and physiological measures for the two conditions were equated for a task of uphill running. Furthermore the study attempted to elucidate the interactive effects, and relative importance of differentiated and undifferentiated ratings of perceived exertion. In addition, the question of the effects of attitudes on the ratings of perceived exertion was addressed.

RESEARCH HYPOTHESES

The following hypothesis was proposed to enable a broad examination of the relationship between ratings of perceived exertion in the field and ratings of perceived exertion in the laboratory:

There are no differences between ratings of perceived exertion obtained in the field and ratings of perceived exertion obtained in the laboratory, when the overall performance and physiological measures are equated, when attitudes towards the condition are taken into account, and when the field conditions with respect to temperature and gradient are simulated on the treadmill. Stated statistically, the null hypotheses were:

a) $Ho : \mu_{L1} = \mu_{L2}$

Where μ_{L1} are the local ratings of perceived exertion obtained during field testing, and μ_{L2} are the local ratings of perceived exertion obtained during laboratory testing.

The alternative hypothesis was: $Ha = \mu_{L1} \neq \mu_{L2}$

b) $Ho = \mu_{C1} = \mu_{C2}$

Where μ_{C1} are the central ratings of perceived exertion obtained during field testing, and μ_{C2} are the central ratings of perceived exertion obtained during laboratory testing.

The alternative hypothesis was: Ha : $\mu_{C1} \neq \mu_{C2}$

c) Ho : $\mu_{01} = \mu_{02}$

Where μ_{01} are the overall ratings of perceived exertion obtained during field testing, and μ_{02} are the overall ratings of perceived exterion obtained during laboratory testing.

The alternative hypothesis was: Ha : $\mu_{01} \neq \mu_{02}$

DELIMITATIONS

Eleven male caucasian marathon runners volunteered to participate in this study. The subjects were tested on four separate occasions. In addition to this, those subjects with no prior treadmill experience were each habituated to treadmill running at various grades with twenty minutes of distributed practice. Body mass and four skinfold measurements were obtained from each subject. Maximal oxygen consumption was measured during a progressive, continuously increasing speed test. Subjects then ran on the treadmill at 70% of the maximal oxygen consumption, and at 3.8% and 7.5% grade to determine running speed at that grade and percentage of maximal oxygen consumption. This was followed by a road-run along a stretch of road with a known gradient, at the previously determined speed. The final session was a treadmill run, during which attempts were made to replicate the conditions of speed and grade that occurred in the field. The following data were collected: Oxygen consumption, Heart rate, pulmonary ventilation, differentiated and undifferentiated ratings of perceived exertion, and attitudes towards the field and laboratory conditions.

LIMITATIONS

The following limitations must be borne in mind while examining the implications and subsequent conclusions drawn from these experimental results.

1. The subjects were not randomly selected. The substantial time commitment and the nature of each subject's involvement meant that potential subjects were approached with an explanation of experimental procedures and a request for voluntary participation. Every attempt was made, however, to approach as broad a spectrum as possible of potential subjects from within the running community of Grahamstown.

2. The small sample tested prevents any generalizations being made with regard to ratings of perceived exertion responses. In addition, the number of subjects constitutes a limitation in that the data are insufficient to generate any conclusive results with respect to trend and factor analysis.

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

influences.

4. As subjects were not tested at the same time of day during each session, diurnal variation in exercise response may have affected the experimental results.

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

6. Perceived exertion, being a privately experienced event, can only be measured indirectly through the use of self-report techniques. As such, a rating of perceived exertion constitutes only a distal reaction.

7. From a psychophysical scaling standpoint, it is possible that the RPE scale may not be sensitive enough to permit fine distinctions between the levels of exercise stress or physiological strain which may be mediated by aerobic fitness.

8. One of the limitations in using psychophysical category scales is that researchers must presume that verbal categories are appraised in a similar manner by all subjects. Attempts were made to explain the use of ratings scales as fully as possible, and questions were encouraged.

9. Personality variables can affect the ratings of perceived exertion. Besides the attempts to access attitudes,

personality assessment was outside the scope of this study.

10. The gradient of the field run was simulated by averaging the gradient for the first half and second half of the run, and then replicating these mean gradients on the treadmill. It is possible that this may have affected physiological measures such as oxygen consumption and pulmonary ventilation.

CHAPTER TWO

REVIEW OF LITERATURE

INTRODUCTION

CONCEPTUAL CONSIDERATIONS IN RPE RESEARCH

Before addressing the conceptual problems with regard to the ratings of perceived exertion (RPE) there is a need to critically examine the nature of the broader framework into which RPE falls, namely that of Human Movement Studies.

Whilst recognising that neither the empirical, nor the conceptual method of investigating should be regarded as superior to the other (Best, 1978), this study assumes the logical priority of fundamental conceptual questions over empirical pragmatic issues. This assumption of logical priority is based on the utility of a clear conceptual base to act as a frame of reference for the scientific methods to be employed. What then is the conceptual base of Human Movement Studies upon which this research rests?

In an attempt to locate and define the boundaries of Human Movement Studies, Renshaw (1975) poses several questions: Is Human Movement an autonomous discipline or is it more appropriately viewed as a field of knowledge drawing on several distinct forms of thought? What contributes to an understanding of human movement? Is it a unitary mode of experience, or is it possible to identify some central distinguishing feature?

Addressing himself to questions such as those posed above, Whiting (1975) noted that research findings are inevitably fractionated to some extent, and it is seldom meaningful to apply such findings until they have been integrated into some conceptual whole. The nature of the conceptual structure into which this study's findings will be integrated therefore needs to be examined.

Charteris *et al.* (1976) have proposed a naturalistic, biologically based conceptual model, reconciling social, behavioural, physiological, anatomical and biomechanical domains. The "Centre M" model recognises the inseparable relationship between man and his movement, and, in an attempt to focus on man-in-motion (as opposed to man, when in motion), seeks infusion from widely diverse academic fields. The "Centre-M" has four foundational propositions, the first being that human movement must initially be comprehended in a dimension of time, the time-based levels ranging in a continuum from movement actually in progress through to study at the phylogenetic level. Foundational proposition two is concerned with the examination of the interaction between the moving organism and the environment through which it moves, while proposition three accepts that the essential humanity of the moving organism implies a psychosocial dimension of study. The fourth proposition holds that human movement is best elucidated by an interdisciplinary, holistic approach.

The above conceptual approach illustrates clearly the ubiquity and diversity of the field of human movement studies. The synthesis brought about by proposition four is not, however, without attendant problems. Are any of the fundamental propositions more important than the others? Must all the psycho-socio-physio-anatomico-aesthetic (etc.) perspectives be treated in every case when studying human movement? How does the writer decide on the hierarchical presentation of his findings within the conceptual framework?

With regard to the first question, Whiting (1975) and Charteris *et al.* (1976) agree that all the central characteristics (foundational propositions) of human movement study should be first and none last. That is, no one proposition is more important than the other three. Practical considerations, however, determine that a particular investigator's order will derive from his focus. In other words, it will derive from immediacy of need to the particular study within the concept, and not from importance. In answer to the second question, logic dictates that while an investigation in the study of man-in-motion may involve biophysical, physiological and psychosocial variables, solutions to problems should be attempted in terms of the most crucial factors pertaining in the particular circumstances (Charteris *et al.*, 1976). Very little can be done about the problem posed by question three, 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 (Whiting, 1975). All that can be done is to present an order that is as logical as possible, and to trust that the reader's growing awareness will elicit for him the synthesis into the multi-dimensional whole. As with the other two questions, as long as the constructs of the model are not violated, the immediacy to and perspectives of a particular study may determine the order of presentation.

Having established the conceptual framework of how to structure a focus in human movement, Charteris *et al.* (1976) proceeded with the more contentious issue of what to focus upon. The biological paradigm upon which the model is based leads us to accept that man is today demonstrably less unique than we have previously believed (Charteris, 1986b). The search therefore focussed on characteristically human movements. This exploration of the essence of the "Centre-M" yielded three characteristically human movement complexes, namely Locomotion, Manipulation and Communication. These categories encompass all human endeavours, and are pervasive in all areas of man's performance, often in combination. They appear to be very near or at the basis of human action as a construct (Charteris, 1986b).

In conclusion, the broadly anthropological, biologically based "Centre-M" model is concerned with the motor behaviour of a psycho-social being, an ethicising animal, a culture-creating and culture-dependent species; in short, with human-kind (Charteris, 1986b). The model shows us that a reductionist approach and an overemphasis on fractional information (as opposed to integrated information) turns man into a robotic machine, ignoring crucial factors in the determination of characteristically human movement. The model then is based on a liberal attitude towards the input of cognate disciplines. If we confine ourselves to the traditional insular approach to the study of human movement, we run the risk of losing our broad focus on the relationship between man and his movement, with all the attendant implications of this relationship.

How does an examination of RPE in a particular movement task fall into the conceptual framework outlined above? For the past few decades the study of perceived exertion during physical activity has been an area subject to considerable interest and research, and as an investigative tool, RPE have proved to be useful adjuncts for studies in exercise physiology (Carton and Rhodes, 1985). Researchers have become interested in how people feel, what aches and pains they have and how difficult they perceive their work to be, and it is important to be able to relate these subjective symptoms to objective findings. Borg (1982) states that "perceived exertion is the single best indicator of physical strain", and several researchers feel that from the standpoint of understanding participant behaviour, knowing what people *think* they are doing may well be more important that what they *are* doing (Morgan, 1973; Pandolf *et al.*, 1978; Rejeski, 1981).

Accepting the importance of RPE, we need to have a clearer understanding of what it is. RPE can be defined as one's subjective rating of the intensity of work being performed, and as such the concept offers a unique approach to the study of human movement (Morgan, 1973). Perceived exertion can also be seen as a psychological evaluation of the physical demands made on the body in any situation requiring physical effort (Scott, 1985), or as a subjective self-report of energy expenditure using a specific scale for quantification. It is evident even from the above simplistic definitions that RPE is an extremely complex phenomenon (Fleishman *et al.*, 1984).

This complexity makes it difficult to explain the exact nature of RPE. For example, despite considerable research on the topic, the mechanism(s) by which individuals perceive the intensity of exertion during exercise remains unknown (Purvis and Cureton, 1981). As a construct, RPE could intuitively be viewed as analogous to pain, but Morgan (1973) states that there is little evidence to support such a conclusion. Perception is involved in virtually everything we do. There must therefore be a coordination between what one perceives and what one does (Ryan, 1976). Although we have noted that the mechanisms by which one perceives exertion are largely unknown, it must be borne in mind that for a given individual there is a linear relationship between perceived exertion, work intensity and measures such as cardiac output, heart rate, oxygen consumption and ventilation. It is unclear whether any or all of these are perceived (Skinner *et al.*, 1973).

To date, much of research in the field of RPE has adopted a conceptual approach which has viewed the concept as primarily a perceptual process. Consequently interest in explicating the underlying mechanism, or primary cue, of this phenomenon has led to a broad base of physiological inquiry (Rejeski and Ribisl, 1980). It has, however, been demonstrated that the physiological correlates of RPE are multidimensional and situationally specific. Multiple physiological indices only account for about 65% of the variance in RPE (Rejeski and Ribisl, 1980). This estimate may in fact be inflated by the restrictions imposed on behaviour due to the altered social context inherent in the somewhat artificial conditions present in laboratory research. Clearly the dynamics of perceived exertion remain equivocal (Rejeski and Ribisl, 1980).

Morgan (1973) contends that a portion of the unexplained variance mentioned earlier might be dependent upon factors of a psychometric nature. It has also been reported (Rejeski and Ribisl, 1980; Rejeski, 1985), that factors such as perception, cognition, motivation and emotion play a part in ratings of perceived exertion. In view of the above, and bearing in mind the many potential physiological mediators of perceived exertion, it seems that a search to identify a primary cue is unrealistic in view of the multiple responses associated with this subjective experience.

Perceived exertion should therefore be viewed as a psycho-biological process (Morgan, 1973), i.e. RPE represents a Gestalt of total bodily inputs based upon factors such as heart rate, ventilation, lactate accumulation, catecholamine production, oxygen consumption, skin and core temperature, aches and pains in muscles and joints, as well as other factors such as personality structure, fitness, pain tolerance, past experience and probably opioid and neurotransmitter levels in the brain. Perceived exertion is thus based upon a psychophysiological process (Morgan, 1981), and the multi-faceted nature of the construct consequently emphasises the fact that a psychobiologic approach to human performance in general, and RPE specifically, is the most efficacious.

"Too often in research, convenience rather than the appropriate method dictates the type and operation of independent and dependent variables" (Rejeski, 1981). To maintain conceptual integrity in RPE research, the selection of variables should therefore be guided by the conceptual structure of the problem under investigation. In fact, the position adopted by the researcher is crucial, as the conceptual framework guiding the research will govern the kinds of questions which are asked and the ways in which the answers are sought (Morgan, 1981).

Accepting the multi-faceted nature of the RPE construct (Rejeski, 1981), it seems that researchers should employ a diverse (i.e. psychological and physiological) integration of theoretically meaningful variables, while remaining cognizant of the multidimensional nature of this construct. We have seen that there are strong philosophical, theoretical and empirical arguments favouring a psychophysiological approach over a physiologic or psychologic one (Morgan, 1981). Such a heuristic, interactionist approach conforms to the naturalistic, biologically-based conceptual model of man-in-motion presented earlier (Charteris *et al.*, 1976), and this model then provides the conceptual frame of reference for the empirical methods employed by the present research.

DEVELOPMENT AND THE USE OF RATING SCALES

One of the major and continuing debates among perceptual psychologists and physiologists relates to the preferred method to employ in obtaining psychophysical judgements (Morgan, 1981). As a basis for criteria in the assessment of human movement, subjective reactions have not until recently been seriously considered. The reason for this neglect in favour of the more readily definable physiological indicators is that these reactions have been difficult to define and measure (Gamberale, 1985). These fundamental difficulties are connected with the nature of the measurement itself. As a privately experienced event or sensation, perceived exertion can only be measured indirectly through the use of self-report techniques. This self-report thus only constitutes a distal reaction, and the extent to which this is a reflection of the proximal reaction, i.e. the reaction within the individual organism, relies very heavily on the adequacy of the measurement tool or procedure adopted. The applicability of subjective symptoms as criteria in the assessment of human movement will depend on factors affecting validity and reliability, e.g. how well the reaction correlates with work intersity and performance, and how well it correlates with the physiological and neurological events (Gamberale, 1985).

It has been suggested that no one single subjective reaction, measurement method or experimental strategy is more adequate than others in every condition and for all purposes (Gamberale, 1985). The arguments surrounding the choice of method in obtaining psychophysical judgements are complex, but it seems reasonable to propose that the scaling procedure one chooses should be determined by the question being asked (Morgan, 1973; 1981). In short, it seems unreasonable to argue that only one procedure should be adopted to answer all questions.

What techniques then are available to the researcher attempting to assess the subjective reactions to work? Borg (1962) originally investigated the growth of perceived exertion with increasing intensity using ratio-scaling procedures before adopting a category rating scale, and still today considerable controversy exists regarding the efficacy of ratio- and category-scaling procedures for psychophysical measurement (Mihevic, 1981). This review will examine the advantages and disadvantages of both with a view to determining the method best suited to answer the questions posed by this study.

Ratio - Scaling Techniques

For most sensory and perceptual dimensions, the functional relationship between subjective sensory or perceptual magnitude and the physical dimension being manipulated appears to approximate a power function (Borg, 1973; 1982; Gamberale, 1985). Power functions thus describe the perceptual variation with the physical intensity. The expression of such a power function in logarithmic terms results in a simple linear equation which, when plotted on log-log coordinates, constitutes a straight line. An exponent of greater than 1.0 indicates that the perceptual intensity is a positively accelerated function of the physical stimulus, while an exponent of less than 1.0 indicates that the function is negatively accelerated.

Various direct ratio-scaling methods have been used in psychophysical studies. One such method is *ratio-production*, in which subjects are asked to increase or decrease a certain variable stimulus until it is perceived to be a certain fraction or multiple of a standard stimulus (Borg, 1982). Put another way, the subject manipulates the physical stimuli to reflect a given subjective reaction. Generally, however, estimation methods such as *magnitude estimation* have been preferred in the study of perceptions of physical work (Mihevic, 1983). With this method, subjects are presented stimuli of different intensities and are asked to assign numbers to them in proportion to the perceived magnitude of each stimulus (Borg, 1982). As stated earlier, greater perceptual sensitivity is reflected in a higher perceptual exponent. For both of these direct-scaling methods the basic assumption is that subjects are able to match perceptions with numbers. Studies have supported the validity of this assumption, and the result is that the subjective scale obtained is a ratio scale (Gamberale, 1985).

Several investigators have indicated that the perceived intensity of muscular effort follows the psychophysical power law. Early ratio-estimation studies reported by Borg (1973) showed positively accelerated functions (1.6) for both long and short term work, and these findings are supported by later research (Carton and Rhodes, 1985), although Gamberale (1985) states that perceived effort depends not only on the duration of the work being performed, but also on the intensity. The exponent of the power function may also depend on the type of work being done (Gamberale, 1985). Interestingly, and with possible application to the role of ventilation in RPE, it has been suggested (Carton and Rhodes, 1985) that respiratory sensations are quantitatively assessed in a manner which is analogous to force application in the limbs. In summary, there is strong empirical evidence that perceived exertion is a positively accelerated function of the workload. Despite the inevitable interindividual differences, generally speaking, the exponent of the function will fall between 1.5 and 1.9, irrespective of the type of work performance or the muscle groups involved (Gamberale, 1985).

The positively accelerated RPE - Work load relationship identified by ratio-scaling is consonant with expectations derived from classical psychophysical theory (Morgan, 1981). Why then has this procedure not been universally adopted? Before answering this question, there is a need to examine the merits of category-scaling techniques.

Category - Scaling Techniques

To overcome the difficulties involved in ratio-scaling, Borg (1962) developed a 21-grade rating scale to determine perceived exertion, the odd numbers of this scale being anchored with verbal expressions. This scale was later shortened to the one used in this study (Appendix 1). Although the Borg scale is employed around the world, it is not acceptable to many classical psychophysicists (Morgan, 1981), and we therefore need to examine it more closely to justify its use in this study.

Ratings on Borg's (1962) original scale yielded high correlations (r = 0.8 and 0.9) with heart rate when work intensity was varied. When the scale was changed to a fifteen-point graded category scale, the RPE values followed the heart rates even more closely. Using this scale, RPE have been shown to be approximately one-tenth of exercise heart rates for healthy, middle aged men performing moderate to heavy exercise. In the new scale, the midpoint was lowered and some of the verbal expressions were changed. This compression to compensate for non-linearity slightly reduced the sensitivity of the scale (Carton and Rhodes, 1985), to the point where Mihevic (1983) has cast doubt on the ability of the scale in certain situations. Specifically, she has stated that the RPE scale may not discriminate between groups of high and low fit subjects working at low to moderate absolute exercise intensities despite differences in physiological strain.

Earlier it was noted that the equal ratios obtained with ratio-scaling techniques follow a geometric series resulting in a power function. In contrast, the equal intervals of the RPE scale follow an arithmetic series and yield a linear function describing the increment of perceived exertion with increasing work loads (Mihevic, 1983). The Borg scale is based on a correlation between perceived exertion and heart rate, and Borg (1973) has proposed that RPE are correlated with the actual stress (i.e. work load) and strain (i.e. heart rate). Furthermore, he states that the addition of a zero to the RPE value should yield a figure which approximates the exercising subject's heart rate. This close relationship was not however intended to be taken too literally, because the meaning of a certain heart rate value as an indicator of strain depends upon various factors such as age, exercise modality, environment and anxiety (Borg, 1982). For example, on any given day one may run and achieve a heart rate of 150 and feel "fine" with an RPE of 13, while on another day the same exertion may cause the runner to feel "bad" with an RPE of 17 as a result of physical and emotional negative factors (Borg, 1982).

Using this category-rating scale, Borg (1973; 1982) thus found that RPE is a linear function of the workload, but this should not be interpreted as conflicting with the results of the ratio-scaling psychophysical studies, in which perceived exertion was found to be a positively accelerated function of the workload. When RPE values are plotted to the corresponding values of heart rate of the workload, the form of the relationship obtained depends largely on the specific characteristic of the rating scale itself, i.e. the number of categories, the verbal definition, etc. The achievement of a linear relationship between RPE and workload was in fact one of the objectives in the construction and development of the scale. This objective was achieved by a careful choice of verbal categories (Gamberale, 1985), by lowering the mid-point of original 21 point scale and by compressing the lower degrees (Carton and Rhodes, 1985).

Choice of Scaling Technique

Ratio-scaling and category-rating scales have been examined. Ratio-scaling procedures provide ratios between exercise intensities or time periods without permitting absolute comparisons of these (Mihevic, 1983). Using ratio scaling procedures, RPE have been shown to grow as a positively accelerating function of exercise intensity. The subjective magnitude of a work bout therefore increases disproportionately as exercise intensity increases. In contrast, category scales require the subject to divide a perceptual continuum into equal intervals in correspondence with available adjectival or numerical descriptions. The observer is therefore forced to attend to intervals or differences rather than ratios (Mihevic, 1983). This facilitates interindividual comparisons among exercise intensities or time periods (Borg, 1973; Morgan, 1981; Borg, 1982).

Category scaling does however have inherent limitations. Firstly, a "ceiling" effect (Morgan, 1973) occurs as the subject approaches maximal levels of work, since all subjects are constrained by the upper limit of the scale in that they have to rate 19 or 20. Secondly, category scales fail to reflect the actual sensations perceived across a range of stimulus intensities. This means that category scales suggest that equal increments for a given stimulus are perceived as being the same at light, moderate and heavy work loads (Morgan, 1981), whereas it has been reported that in many different areas of physical work the subjective intensity grows according to a positively accelerated function with the workload (Borg, 1973). Such category scales are rank-order scales, and from their results it can only be stated that one subjective intensity is more "intense" than the other; however, neither the degree of intensity nor the position of zero intensity can be accurately determined (Borg, 1982).

In light of all the above, Gamberale's (1985) statement that no single subjective reaction, measurement method or experimental strategy is more adequate than others in every condition and for all purposes, seems sound. Morgan (1981) and Borg (1982) have both suggested that the scaling procedure adopted should be determined by the questions being asked. In other words, there is no one perfect scale for all kinds of subjective intensities in all kinds of situations, and different scales should be used depending on the purpose of the study (Borg, 1982).

There is however general agreement (Borg, 1973; Morgan, 1973, 1981; Mihevic, 1981; Borg, 1982; Gamberale, 1985) that the Borg scale should be used in most cases, as it has shown versatility, parsimony and validity (Gamberale, 1985). It correlates well with heart rate and its linearity makes it simple to use and makes it easy to perform intra- or extrapolations, bearing in mind the "true" positive acceleration of RPE (Borg, 1982). In some cases ratio-scaling techniques are more appropriate, for example when evaluating the growth of subjective sensations with increasing stimulus intensity (Mihevic, 1981). When however we want to make comparisons between work tasks or between individuals, particularly in clinical and applied settings, the category methods are preferable (Borg, 1973; Morgan, 1973; Pandolf, 1978; Mihevic, 1981; Morgan, 1981; Carton and Rhodes, 1985 and Gamberale, 1985).

THE PHYSIOLOGICAL BASIS OF RPE

Can perceptions of exertion be accounted for by concurrent physiological responses (Noble *et al.*, 1973b)? Since an increase in work results in concomitant physiological changes at both the "central" (cardiorespiratory) and "local" (muscular) levels, a logical and intuitive supposition is that subjects' perceptual ratings of work intensity covary with specific metabolic/neurologic functions (Rejeski, 1981). Considerable research has been directed to the identification of sensory cues which provide direct input into the "effort sense". Numerous physiological and neuromuscular parameters have been proposed as contributors to effort perception during physical activity (Carton and Rhodes, 1985), and much of the research in this area has focused on the identification of a primary cue underlying the construct (Mihevic, 1981). In attempting to find out how an individual perceives the exertion from the physical work being performed (Pandolf *et al.*, 1978), investigators have implicated a variety of physiological parameters as important perceptual cues during exercise (Mihevic, 1983). Moving from the earliest investigations which were primarily concerned with isolating cues that could be universally shown to dominate the cognitive evaluation of effort (Carton and Rhodes 1985), researchers have recognised that, in view of the well-documented interrelationships among physiological responses during exercise, and the integrated nature of perceived exertion, the search for a primary perceptual cue appears to represent a rather simplistic attempt to probe the complex psychobiological dynamics of the exercise response (Mihevic, 1981). Furthermore, although factors such as minute ventilation, blood lactate concentration, respiratory rate, heart rate, catecholamine release and oxygen consumption have been investigated and associated with perceived exertion (Skrinar *et al.*, 1983), the perceptual response to exercise must be evaluated in terms of various modifying variables, such as exercise intensity, exercise modality, steady-state *vs* progressive exercise, and exercise duration (Mihevic, 1981). This review focused firstly on the distinction between factors affecting the perceptions of effort which arise in the active muscles or joints (local/peripheral), and those which are manifested in a more generalised cardiopulmonary response (central), and secondly on the research attempting to identify the physiological parameters most important as cues for the perception of effort. Finally, the effect of other influences such as environment, training, relativisation of workload, work intensity, the critical work threshold, diurnal variation, exercise modality, and social and psychological factors on ratings of perceived exertion were examined.

Central *vs* Local Factors

Following the identification of physiological cues which purportedly affect the perception of exertion, attempts have been made to assess the relative contributions of central factors *vs* local factors to

RPE (Carton and Rhodes, 1985). Borg originally acknowledged that the perception of effort was dependent upon input from both the musculature and the circulatory system, and he proposed that, for prolonged work, perceived exertion is most forcibly influenced by the adaptation of the circulatory system (Mihevic, 1981). Noble *et al.* (1973a) agreed that perceived exertion is not always a function of metabolic equivalence alone, but also of the stress placed on local musculature in the accomplishment of the task. They concluded that an increase in mechanical resistance, and therefore, local muscular strain, must also affect ratings of exertion. Their statements are in agreement with those of Ekblom and Goldbarg (1971) who proposed a two-factor model, contending that perceptions of physical exertion should be evaluated in terms of local factors involving sensations of strain in the working muscles, and central factors involving perceptions of ventilatory and circulatory stress (Noble *et al.*, 1973a & b; Pandolf, 1978; Mihevic, 1981; Pandolf, 1982; Robertson, 1982; Skrinar *et al.*, 1983; Noble and Allen, 1984). Subsequently, research has supported the theoretical merit of treating RPE as a multi-faceted construct (Rejeski, 1981).

Robertson (1982) states that local factors are assumed to provide the primary sensory signals, while central factors act as an amplifier or gain modifier that potentiate the local signals in proportion to the aerobic metabolic demand. Ventilatory and circulatory adaptation occurs approximately 30 - 180 s after the start of exercise, and this corresponds with the initiation of the potentiating input of central factors.

According to Robertson (1982), the sensory monitoring of the above perceptual signals occurs on both conscious and unconscious levels. For example, while respiratory discomfort can be consciously perceived, heart rate is likely to be monitored on an unconscious level. While the monitoring mechanisms are not clearly understood, they probably involve a multi-factor response, such as signals discharged from: a) sensory functions in mechanoreceptors, baroreceptors and chemoreceptors; b) specific physiological responses to exercise; and/or c) corollary responses involving central nervous system regulation or integration of a number of physiological adjustments to exercise (Robertson, 1982).

Robertson's (1982) implication that central factors are additional to local factors is supported by other researchers. Pandolf (1978) states that the dominance of either local and or central factors in the subjective estimate of exertion appears in part to be related to the amount of active muscle mass employed by the particular type of work. Ekblom and Goldbarg's (1971) original proposal was that local factors dominate effort perception during work involving small muscle groups, but when large muscle groups are employed the effort perception would be complemented by central inputs (Carton and Rhodes, 1985). However, it has been shown that local components may still provide the most intense sensory stimulus (Pandolf, 1982; Noble and Allen, 1984; Carton and Rhodes, 1985).

This is particulary true of cycling exercise, where local and overall effort consistently overide central sensations (Carton and Rhodes, 1985). It could be hypothesised that the greater relative strain placed on the lower limbs is the cause of an increase in the perception of difficulty in the task, and this in fact contradicts Ekblom and Goldbarg's theory linking local RPE with small muscle mass activity and central RPE with large muscle groups (Rejeski, 1981). This statement would then be consistent with Pandolf's (1978) proposal that when a particular factor or psychological cue becomes accentuated by either elevated rate, concentration or value, it can dominate the overall rated perceived exertion. Several researchers have indicated strong support for the influence of local factors, citing increasing evidence that central factors do not play as important a role in the perception of exertion as was originally thought (Goslin and Rorke, 1986).

Borg acknowledged that the perception of effort was dependent upon input from both the musculature and the circulatory system (Mihevic, 1981), and Ekblom and Goldbarg (1971) hypothesised that central cues come from cardiopulmonary responses while local cues come from sensations of discomfort in the muscles and joints of the exercised body parts (Noble and Allen, 1984). In the perceived exertion literature, the following variables have been categorised as central factors: heart rate, oxygen consumption, respiration rate, minute ventilation, dyspnoea and hypoxia; while the following variables have been assigned to the category of local factors: local muscular discomfort, blood lactate, IEMG, mechanoreceptors and chemoreceptors, vanilmandelic acid, catecholamine excretion, proprioceptive factors, local fatigue, golgi tendon organ activity and feelings from the working muscles and joints (Pandolf, 1982). These classifications are usually unambiguous, but some caution must be exercised with regard to certain variables. For example, many of the hypothesised factors for signalling local effort, i.e. mechanoreceptor and Golgi tendon organ activity and sensations from muscle, tendon, skin, joints and ligaments are difficult to quantify (Pandolf, 1978). Also, the association between blood-borne stress hormones, specifically the catecholamines epinephrine and norepinephrine, and their contribution to the perception of exertion is not yet resolved (Skrinar *et al.*, 1983). Furthermore, although the experimental literature supporting central factors appears more extensive than the literature disputing these factors the majority of research done has used correlational data to illustrate the relationship between perceived exertion and the physiological variable in question (Pandolf, 1978). Another factor to consider is that although the use of the term "central" in the perceived exertion literature is not ambiguous, the use of the term in the broader physiological and psychological literature could lead to some confusion. In this case it would refer to central nervous system factors. For example, discussions of fatigue (a concept which is closely linked with effort perception), distinguish between central and peripheral fatigue, although here central refers to the central nervous system (Mihevic, 1981). Therefore, although this study uses the terms "local" and "central" as proposed by Ekblom and Goldbarg (1971), it is useful to be cognizant of the different meanings associated with these terms in the more general literature (Mihevic, 1981).

Differentiated Ratings of Perceived Exertion

To effectively distinguish between the magnitude of central and local cues, differentiated ratings of perceived exertion have been utilised (Pandolf, 1978; 1982). Pandolf (1978) proposed an experimental model which describes the levels of subjective reporting applicable to different types of physical activity. Rejeski (1981) reports research which found that leg fatigue scores were significantly related to EMG amplitude, and which found a significant correlation between cardiac distress and respiratory rate. These data provide construct validity to the division of undifferentiated RPE into local and central factors (Rejeski, 1981).

Pandolf's (1978) model makes the division possible and provides a framework for future research in this field. The model suggests that undifferentiated RPE from the Borg category rating scale is probably associated with the "superordinate" level of subjective reporting, and represents overall body responsiveness that results from the integration of various sensory cues having different perceptual weightings. At this level of subjective reporting, undifferentiated RPE is not necessarily closely related to the underlying physiological substrata (Pandolf, 1978; 1982). The model suggests that the interrelationships between subjective perceptual ratings and specific physiological responses to various types of work can be better defined and compared using "subordinate" differentiated ratings which appear to be in close promixity to the level of the "discrete symptoms" (Pandolf, 1978). Put another way, the physiological substrata constitute the most basic level upon which the ratings of perceived exertion rest. Discrete symptoms arise from these cues and they are further tied to specific subordinate and/or ordinate levels of organisation. There is both a vertical hierarchy among levels and a horizontal interrelationship of categories within specific levels. The "superordinate" (undifferentiated) level is the most general level of subjective assessment and most closely approximates Borg's original measure of RPE. The link/process between the physiological substrata and the superordinate level is probably best characterised by reciprocal causation (Rejeski, 1981). The model then encourages comparisons between local and central factors with further contrasts to the overall exertion (Noble and Allen, 1984). Acceptance of this model for research presupposes that, as a result of the multidimensional nature of RPE, it is critical that researchers provide experimental subjects with specific instructions about the use of exertional scales (Rejeski, 1981). Using Borg's category rating scale, subjects should be asked to indicate a "local" muscular rating from feelings of strain in the working muscles and joints, a "central" rating from sensations involving the cardiopulmonary systems, and an overall rating in which subjects can integrate the local and central feelings with whatever weightings they deem appropriate (Pandolf, 1978).

While research to date supports the concept of differentiated ratings of perceived exertion, it should be noted that not all variables can be neatly categorised. There is also some debate as to whether the nature of the task is an appropriate unit of analysis, or whether a within-task analysis is more efficacious (Rejeski, 1981). Also, although the model provides an integrative framework for conceptualising subjective reports of exertion, it implicitly assumes ultimate physiological roots for psychological dimensions such as motivation. Although not necessarily incorrect, this position is reductionist and ignores the influence of cognitive mediation, revealing direct limitations with regard to its explanatory and predictive power (Rejeski, 1981).

Despite these weaknesses, the model makes provision for the division of undifferentiated RPE into local and central factors (Rejeski, 1981) thereby encouraging comparisons between these components, with further contrasts to the overall exertion (Noble and Allen, 1984). The model also provides a framework for future research in the field of perceived exertion in that it treats RPE as a multi-faceted construct (Rejeski, 1981).

CENTRAL FACTORS AS SENSORY CUES FOR PERCEIVED EXERTION

Heart Rate

Much of the work supporting the importance of central systemic factors as critical for perceived exertion has been directed towards validation of Borg's proposal that perceived exertion covaries directly with heart rate (Mihevic, 1981). Numerous other studies have since demonstrated that under certain conditions there exists a strong linear relationship between the two variables (Pandolf, 1972; 1978; Carton and Rhodes, 1985). The majority of studies which support the influence of heart rate on perception of effort have been correlational in nature (Mihevic, 1981), and consequently the relationship has not been investigated in cause and effect terms (Pandolf, 1972). Therefore, while heart rate and RPE may be highly correlated, at no point has it been implied that the two variables are causally related (Carton and Rhodes, 1985). As stated earlier in the review, the Borg scale was specifically designed to follow the increasing work intensity in a linear fashion, and heart rate and RPE are probably indirectly related through their common dependence upon physical strain (Carton and Rhodes, 1985).

Pandolf (1978) reports several studies with regard to the above relationship and presents the following conclusions. Ratings of perceived exertion are closely related to heart rate responses during submaximal work and this relationship is "fairly linear" irrespective of the kind of work. Borg's original work yielded a correlation of $r = 0.85$ between the two measures, and since then correlation co-efficients ranging from $r = 0.42$ to 0.94 have been found for work such as treadmill walking, one- and two-limb exercise, lifting weights, pushing a wheelbarrow, riding a cycle ergometer and carrying external weights (Pandolf, 1978; Robertson, 1982). In addition to the above studies, a high correlation between heart rate and perceived exertion has been noted for both male and female subjects, for subjects of varying fitness levels and for both intermittent and continuous exercise (Carton and Rhodes, 1985).

Borg's original study involved responses to a task of cycle ergometry where exercise intensity increased progressively. The high correlation is therefore based on values obtained over the entire stimulus range. This relationship is much less substantial for a single exercise intensity; in fact correlations as low as $r = 0.40$ have been reported for individual exercise intensities (Mihevic, 1981). Mihevic (1981) states that the prediction of heart rate from perceived exertion applies most reliably at higher exercise intensities, and this is supported by Morgan (1981), who presents evidence that heart rate and RPE do not covary during light work. He also proposes that the failure of investigators to explain deviations from the HR = RPE X 10 formula is due to their implication that the relationship has a causal basis. His data refutes the notion of causality and indicates that RPE is not mediated by heart rate. Furthermore, he concludes that where a high correlation exists, it is probably due to the testing protocol. These conclusions have been supported by other researchers. Pandolf *et al.* (1978) found that, for negative work, a 10 $b.min^{-1}$ increase in heart rate was associated with a 0.5 increase in RPE. Other factors such as motivation, disease, endurance exercise, drugs, heat and type of exercise have also been shown to affect the linearity of the relationship (Rejeski, 1981). Carton and Rhodes (1985) concur that when exercise is performed under irregular conditions, the connection between heart rate and RPE can be disturbed. For example, it is possible to manipulate heart rate through the use of parasympathetic and sympathetic blocking agents without affecting RPE (Mihevic, 1981). This supports the conclusion that heart rate, *per se*, has little influence on RPE and is not a primary factor fundamental to effort sensation (Rejeski, 1981; Pandolf, 1982).

Robertson (1982) also states that a substantial amount of evidence questions heart rate as a direct central signal of exertion, and suggestes that it is unlikely that heart rate is consciously perceived during exercise. This conclusion is supported by the research of Pandolf *et al.* (1972), who attempted to examine the influence of heart rate on RPE during prolonged work coupled with environmental heat increases. The results indicated that subjective ratings of perceived exertion during prolonged continuous work do not follow alterations in heart rate when heat is used to increase the cardiac frequency. Thus, under the influence of heat, heart rate does not appear to be the perceptual stimulus utilised for arriving at ratings of perceived exertion. The authors conclude that RPE does not seem to be a function of a single physiological paramater such as heart rate, but seems to involve a complex and yet unresolved integration of several parameters. Noble *et al.* (1973a) showed that at the same heart rate, rated perceived exertion was higher for walking than for running. Their finding that the RPE intersection point occurs at a significantly lower velocity than the metabolic intersection point also suggests that the physiological variable of heart rate is not an exact mirror image of perceived exertion. Some factor or factors other than heart rate must then be operating in one or the other modes which serve as a basis for the perceptual differences (Noble *et al.*, 1973a). The authors conclude that heart rate, *per se*, is not the primary factor in rating the perception of exertion during work, and that other factors such as work load and oxygen consumption may more accurately reflect physiological strain, and therefore perceived exertion. In addition to the metabolic factors, the amount of stress placed on the local musculature utilised in the accomplishment of the task can affect the ratings of perceived exertion (Noble *et al.*, 1973a). Evidence from research into adaptations in RPE and heart rate following training also challenges the postulated relationship between these variables. Following an eleven week training programme, RPE remained the same while heart rate was reduced (Carton and Rhodes, 1985). In another study, researchers evaluated the perception of exertion during the physical training of sedentary elderly men and women. While heart rate responses decreased significantly at a given work intensity, the RPE remained unchanged. In addition to this it was found that, in terms of percent of maximal aerobic power (relative change), RPE was augmented after training (Pandolf, 1978).

While Borg (1973) was convinced that there is a fundamental relationship between a physiological indicator of physical stress such as heart rate and a psychological indicator such as RPE, other investigators dispute this. Robertson (1982) noted that HR does not provide strong central signals to the effort sense, and suggested that possibly other haemodynamic mechanisms such as cardiac output, stroke volume and blood pressure provide the central signals that have been less appropriately attributed to HR. Pandolf (1978) also concluded that heart rate, *per se*, is not a dominant factor in an individuals subjective rating of exercise stress. This conclusion regarding the relationship between the two variables is shared by Mihevic (1981), who feels that research suggests that perceived exertion is not dependent upon the perception of heart rate during exercise, since alterations in heart rate may be accompanied by compensatory mechanisms as a result of other haemodynamic alterations for the maintenance of cardiac output. Therefore, the total cardiovascular input to the effort sense may remain relatively constant. The perceptual importance of the cardiovascular input may thus be better evaluated when heart rate is experimentally manipulated and the responses of blood pressure, stroke volume and cardiac output are also evaluated. In conclusion, it has been demonstrated that the linear relationship of heart rate and perceived exertion across several exercise intensities is strong. However, the independence of heart rate and perceptual responses with pharmacological and environmental manipulations suggests that heart rate is not a major input for perceived exertion. It must be remembered that the RPE scale was originally designed to follow the heart rate response to increasing exercise intensity. The linear relationship between the two variables is therefore virtually inherent during progressive exercice under neutral conditions (Mihevic, 1981).

Hypnosis, Perception and Exercise Metabolism

Unique from a methodological perspective, studies reported by Morgan (1981) evaluated perceptual and metabolic responses to exercise by using hypnosis. In the first study by Morgan *et al.* (1973), subjects were administered suggestions of light, moderate and heavy work prior to and during work on a cycle ergometer. The pertubation of effort sense by hypnotic suggestion resulted in significantly different ratings of perceived exertion following suggestions of light and heavy work. Put differently, the observation that a given work task seems easier or more difficult under certain circumstances was fabricated under laboratory conditions. While oxygen consumption did not differ significantly between conditions, heart rate was significantly different under the conditions of light and heavy work suggestions. Suggestions of heavy work elicited a cardiac frequency that was 10 - 15 $b.min^{-1}$ greater than for the other conditions. Carbon dioxide production, respiratory exchange ratio and ventilatory minute volume were also greater when accompanied by hypnotic suggestions of heavy work, and this indicates that subjects were hyperventilating, attempting to ventilate at a rate and depth that would normally be required for the suggested heavier load. Morgan (1981) suggests that increases in perceived exertion are associated with elevated minute ventilatory volume rather than with cardiac frequency, since ventilatory distress is readily perceived whereas heart rate is not.

In a further, related study, Morgan *et al.* (1976) investigated reactions to a suggestion of uphill work. Suggestions of uphill work yielded a rating of perceived exertion value of 13.6, which was significantly higher than ratings for the other conditions. the results indicate that attempts to perturb effort sense were successful for suggestions of increased work, and the authors interpret this to mean that perception of effort is governed by one's cognition to a large degree. Therefore, thinking that work is more difficult than it actually is can result in elevated ratings of perceived exertion. Again the authors associated the alterations in subjective reactions with alterations in ventilatory responses. Morgan (1981) suggests that ventilation covaries in a direct manner with RPE, and he proposes that it is quite likely that ventilation serves as a primary cue in the perception of work cost.

From the above studies it appears that cognitive factors can influence ratings of perceived exertion. It is also obvious that cognition is mediated by personality structure and that this can therefore also affect the subjective reaction to work (see later). The perception of effort therefore is governed by both the physiological cost of the work performed and the working subject's cognitive appraisal. Effort sense is thus based upon the physiological cost, cognition (thinking), and perception (feeling) (Morgan, 1981). Acceptance of this lends support to the conclusion that RPE is a multi-faceted contruct (Rejeski, 1981).

Ventilatory Responses

In addition to the work by Morgan (1981) described above, numerous other studies also support the role of minute ventilation ($\dot{V}E$) and/or respiration rate (RR) as sensory cues which have an impact on the perception of effort.

Correlations ranging from r = 0.52 to 0.94 have been demonstrated between RPE and both $\dot{V}E$ and respiration rate (Robertson, 1982; Carton and Rhodes, 1985). Using a multiple regression analysis, investigators found that $\dot{V}E$ and RR were the first variables entered into an equation to predict RPE in neutral and hot environments (Robertson, 1982). In other words, $\dot{V}E$ and RR were the best physiological predictors of RPE in those specific environments (Carton and Rhodes, 1985). Further support for the role of ventilation in the perception of effort is provided by Messier *et al.* (1986), who proposed that alterations in RPE brought about by overstriding are more likely to be due to changes in ventilation than to changes in $\dot{V}O_2$.

Ventilatory sensations such as breathlessness and dyspnoea appear to be the only central signals consciously monitored by an exercising subject (Robertson, 1982). Working subjects are thus thought to be consciously aware of ventilatory volume, but it has been found that to significantly affect RPE, ventilatory volume had to change a minimum of 30 $l.min^{-1}$ (Rejeski, 1981). This conclusion is supported by Robertson (1982), who states that conscious monitoring of ventilatory discomfort may only become significant during higher respiratory rates. He cites research which demonstrates a strong correlation ($r = 0.94$) between respiration rate and subjective responses of ventilatory fatigue and discomfort when these subjective symptoms were expressed as a single index of cardiopulmonary stress. The conclusion drawn from these results is that afferent impulses from the respiratory apparatus are consciously monitored when a significant ventilatory response is required during exercise. This is supported by Carton and Rhodes (1985), who note that unlike heart rate or $\dot{V}O_2$, $\dot{V}E$ has afferent nervous system input. Mihevic (1981) concurs, and points out that the capacity of $\dot{V}E$ for conscious monitoring through the afferent signal distinguishes it from the other proposed physiological inputs for perceived exertion.

Mihevic (1981) has also provided support for Robertson's (1982) conclusions by suggesting that the role of ventilation as a perceptual cue is minimized at low - moderate exercise intensities. Drawing slightly different conclusions, Stamford and Noble (1974) proposed that ventilation was relatively unimportant as a cue for perceived exertion. The subjects in this study were however highly fit (average $\dot{V}O_2$ max 61.4 $ml.kg^{-1}.min^{-1}$), and it is possible that the work intensity (960 $kpm.min^{-1}$) may not have been sufficient to cause ventilatory distress. In another study involving red blood cell reinfusion, the data suggested an association between RPE and $\dot{V}E$, but only at 70% work intensity as opposed to 45% work intensity. From these results the author concluded that ventilation does not have a potent influence on RPE at low metabolic levels, but that as the metabolic rate increases, the intensity of the $\dot{V}E$ signal also increases. The strength of the ventilatory signal then may depend on the metabolic intensity achieved during the exercise task (Robertson, 1982). These conclusions have been supported by other research which has attempted to identify the relative intensity at which $\dot{V}E$ contributes significantly to effort perception. Consistent with the above theory, Robertson (1982) reports a study which at 45% of $\dot{V}O_2$ max found no RPE differences between normoxic and hypoxic conditions, but found that at 70% of $\dot{V}O_2$ max both $\dot{V}E$ and RPE were higher under the hypoxic conditions. Given that breathing hyperoxic gas mixtures during dynamic exercise causes $\dot{V}E$ and RPE to change as a reciprocal of that expected under hypoxic conditions, another study found that at a given aerobic fraction, both $\dot{V}E$ and RPE were significantly lower when breathing a hyperoxic as opposed to a normoxic gas mixture. Furthermore, when RPE was plotted as a function of $\dot{V}E$ for both the normoxic and hyperoxic conditions, a linear relationship was seen (Robertson, 1982). The above results suggest that $\dot{V}E$ was not associated with a potent sensory signal at lower metabolic rates, and add weight to the proposal that the onset of the ventilatory signal as a contribution to effort perception is related to the relative exercise intensity of the work being performed (Carton and Rhodes, 1985). Robertson (1982) suggests that at a critical metabolic rate falling between 45 - 70% of $\dot{V}O_2$ max, ventilatory function begins to contribute cues readily perceived as central signals. He notes that the point of onset of the central ventilatory signal falls near the lactate threshold. The emergence of $\dot{V}E$ as a central signal at this point may be linked to local factors associated with muscle lactate release, as isocapnic buffering of metabolic acidosis is initiated at the lactate threshold (Robertson, 1982). The above findings coincide with a proposal by Mihevic (1983) that local factors are more closely related to perceptual responses at low exercise intensities, while central factors such as ventilation more closely parallel the perceptual response at high intensities.

Some research has suggested that pulmonary ventilation may not be causally related to perceived exertion. Pandolf (1978) reports a study in which the investigations did not find a parallel response between $\dot{V}E$ and RPE when ventilatory drive was altered during exercise in a hyperoxic environment. Although rated perceived exertion was lowered, comparative $\dot{V}E$ values were unchanged (Pandolf, 1978). In other words, the researchers were unable to show that the reductions in RPE which were seen during hyperoxic conditions were reflected in similar decreases in ventilation. Interpretation of this finding is difficult however, since the incidence of decrements in ventilation as a consequence of breathing oxygen-enriched gases has been well established (Carton and Rhodes, 1985). The above results must therefore be interpreted with caution, since they are in contrast to the consistently reported decrements in ventilation observed for exercise during hyperoxia. Consequently the relationship of perceived exertion with ventilation based on the results of hyperoxic exercise treatments remains unclear (Mihevic, 1981). In another study, researchers found that inspiring small amounts of CO_2 resulted in increases in $\dot{V}E$ during exercise and that these changes were not paralleled by perceived exertion responses (Pandolf, 1978). The hyperventilatory state created in the study does not however simulate exercise-induced hyperventilation. Although differential ventilatory and perceptual responses were observed, there are clear differences in the physiologic conditions and ventilatory mechanisms of the two hyperventilatory conditions (Mihevic, 1981).

Carton and Rhodes (1985) state that the mechanisms which underlie the perception of ventilatory stress appear to be related to factors which originate from sensations within the chest wall. Robertson (1982) proposes that the mechanisms by which $\dot{V}E$ provides sensory signals during exercise may involve the neuromechanical and chemical regulatory processes that govern tidal volume and respiratory rate. During rest, ventilatory function is controlled by central and peripheral chemorecptors, but with the onset of exercise and the associated increase in ventilation, these sensory receptors respond to changes in lung volume, lung pressure and respiratory muscle tension, all of which are determined by the tidal volume (Robertson, 1982). Therefore, while ventilatory function at rest is regulated by chemoreceptors, during exercise, control of ventilation is partially assumed by mechanoreceptors in the chest wall, lungs and airways (Carton and Rhodes, 1985).

From all the above it can be concluded that individuals can readily perceive the sensations of volume, pressure and ventilation during breathing. Furthermore, the perception of peak exercise intensity has been demonstrated to be coincident with peak ventilation. A review of several studies provides consistent correlational support for the covariation of ventilation and respiration rate with effort perception (Mihevic, 1981). It appears that afferent impulses from the respiratory apparatus are consciously monitored when a significant ventilatory response is required, and the strength of the ventilatory signal may depend on the metabolic intensity achieved during the exercise task (Robertson, 1982). In conclusion, numerous reports support the role of minute ventilation and/or respiration rate as sensory cues which have an impact upon the perception of effort (Carton and Rhodes, 1985).

Metabolic Demand

A number of investigators have suggested that $\dot{V}O_2$ provides central signals of exertion during dynamic exercise, and correlation coefficients for the $\dot{V}O_2$/RPE relationship range from $r = 0.76$ to 0.97 (Pandolf, 1978; Robertson, 1982). These correlations have been found for continuous and intermittent work, for work involving load carriage and for both arm and leg work (Pandolf, 1978). Investigators agree that although the perception of effort is related to metabolic demand, there is no evidence that oxygen consumption is consciously monitored by the individual during exercise (Mihevic, 1981; Robertson, 1982; Carton and Rhodes, 1985). Robertson (1982) states that the mechanisms that regulate the transmission and intensity of this sensory signal are not clearly understood.

With regard to the origins of this central sensory signal, several studies have examined perceptual differences in terms of absolute and relative oxygen requirements. Activity level, body composition, exercise mode, environmental conditions and rate of work have been the independent variables in these studies, and while results have indicated differences in perceptual ratings at absolute exercise intensities, perceptual differences were frequently eliminated when relative exercise intensities (% $\dot{V}O_2$ max) were employed (Mihevic, 1981). Skinner *et al.* (1973) studied RPE in lean and obese young men, both on the treadmill and on the cycle ergometer. They found that while there were differences between lean and obese subjects when RPE was related to absolute $\dot{V}E$ and $\dot{V}O_2$, no differences were observed when work was relativised according to maximal values. RPE therefore appears to be most closely related to the proportion of maximal capacity required for a given work load (Skinner *et al.*, 1973). Previous work reported by the same authors supports the above conclusion. In this study, they found that although athletes perceived a submaximal work load to be easier than did sedentary subjects, no differences were observed when work was relativised according to a given percentage of maximal capacity. Robertson *et al.* (1979) provide further support for the above findings, suggesting that the strongest evidence supports the relative $\dot{V}O_2$ as the physiological process most likely associated with the sensory signal. Their study demonstrated that increases in maximal aerobic power following induced erythrocaemia may result in reductions in RPE for a given workload, but these reductions are abolished at comparable exercise intensities (Carton and Rhodes, 1985). Robertson *et al.* (1979) also demonstrated the dependence of RPE on the relative aerobic demand when perceptual comparisons were made between normoxic and hypoxic ambient environments. They found that at a given submaximal $\dot{V}O_2$, RPE were lower during normoxia than hypoxia. Bearing in mind that $\dot{V}O_2$ max was reduced during acute hypoxia, the reference $\dot{V}O_2$ represented a lower relative aerobic demand under the normoxic than the simulated altitude condition. Comparisons at a given percent of $\dot{V}O_2$ max revealed that RPE was the same for both normoxic and hypoxic conditions.

While much of the research indicates that differences in individuals' RPE for specific exercise modes or functional capacities are greatly reduced when relative exercise intensity is adopted as the unit of analysis, other reports have indicated that the relationship between RPE and $\dot{V}O_2$ may be spurious (Rejeski, 1981; Carton and Rhodes, 1985). In particular, some studies have reported that the functional relationship between RPE and relative exercise intensity is subject to distortion. Skinner *et al.* (1973) found that at a given $\dot{V}O_2$, work on a cycle ergometer was perceived to be harder than on a treadmill. Despite this however, the authors concluded that RPE is most closely related to the proportion of maximal capacity required to perform a given work load. In examining RPE in relation to positive and negative work, Pandolf *et al.* (1978) found that when similar climbing methods were compared at equivalent climbing rates, the RPE (like $\dot{V}O_2$ and heart rate) for positive work was greater than that for negative work. However, when negative work stepping climb was compared to positive work regular climb, the RPE did not differ significantly. Therefore, although much less stressful metabolically, negative work was perceived to be as equally stressful as positive work. The authors concluded that somatic sensations of muscular and articular discomfort, as well as awkwardness of position and movement, may have resulted in the markedly elevated RPE responses during negative work. Contrary to the research supporting the importance of relative aerobic demand as a determinant of RPE, the above results indicate that perceptions of exertion at similar metabolic levels are not necessarily equal. The authors suggest that $\dot{V}O_2$ is not a dominant factor in an individuals subjective rating of exercise stress, and they contend that local feelings of strain in the working muscles and joints can dominate the exertional perception to the extent that metabolically different levels of work are perceived to be equally stressful (Pandolf *et al.*, 1978). This conclusion is supported by Noble *et al.* (1973a), who state that perceived exertion is not always a function of metabolic equivalence alone, but also of the stress placed on the local musculature due to factors such as increased mechanical resistance.

Although the focus thus far has been on several studies which suggest that relative $\dot{V}O_2$ plays a critical role in setting the perception of exertion during dynamic exercise (Robertson, 1982), other investigations reviewed present experimental evidence suggesting that oxygen uptake, *per se*, is not the major factor in the signalling of effort during physical work (Pandolf, 1978). Furthermore, there is no evidence that $\dot{V}O_2$ is subject to conscious monitoring by an exercising subject (Mihevic, 1981; Robertson, 1982). While it is reasonable that perception of effort may be comparable across conditions at similar metabolic demands, relative exercise intensities based on $\dot{V}O_2$ max do not necessarily equate other physiological responses such as lactate production, ventilatory hyperpnea and catecholamine elevation, which are modified by fitness and training and may also have an impact on perceived exertion at moderate - high exercise intensities (Mihevic, 1981). This supports the conclusion that $\dot{V}O_2$, *per se*, is not consciously monitored, and it is more plausible that $\dot{V}O_2$, like heart rate, is indirectly related to RPE, since the input of certain physiological parameters such as $\dot{V}E$ and blood lactate are linked to relative metabolic demand (Carton and Rhodes, 1985). The fact that such a variety of physiological parameters are intimately linked to metabolic demand makes it possible that the impact of relative aerobic power as a perceptual cue is mediated by other, more readily monitored responses (Mihevic, 1981).

LOCAL FACTORS AS SENSORY CUES FOR PERCEIVED EXERTION

Classification of a physiological or muscular response as a local factor important for perceived exertion is based on the mediation of feelings of strain in the exercising muscles and joints. Amongst others, the following parameters have been identified as local factors which may provide sensory input for effort perception: lactate concentrations in the blood and muscles; Golgi tendon organ activity; and general muscle sensations (Mihevic, 1981). Pandolf (1982) however cautions against such neat categorisation by pointing out that many of these hypothesised factors signalling local effort would be nearly impossible to quantify truly. Early experiments showed that the peripheral component (local factors) stimulates the most robust sensory signal (Cafarelli, 1982). The present review attempts to examine this conclusion by analysing the results of several studies. As many of the studies in question have included measures of both local and central inputs for perceived exertion, relevant data from studies cited earlier are included or referred to in subsequent sections concerned with specific local factors.

Lactate Concentrations

Using a variety of exercise modalities, intensities, environmental conditions, fitness levels and continuous or intermittent exercise protocols, investigators have found strong correlations between RPE and blood lactate concentrations (Carton and Rhodes, 1985). Caution should however be exercised before drawing conclusions implying causality between blood lactate concentrations and RPE, due to the correlational nature of many of the studies in question (Pandolf, 1982). Unlike most of the parameters which have been suggested as primary cues influencing perceived exertion, blood lactate during incremental exercise exhibits a similar, positively-accelerating function to RPE when plotted against time (Mihevic, 1981; Carton and Rhodes, 1985). Below an exercise intensity of 65% of VO_2 max however, lactate does not increase appreciably for normal subjects. Trained individuals have an elevated anaerobic threshold, and therefore it can be postulated that lactate may influence perception of effort at high exercise intensities, but its contribution at lower intensities would be minimal (Mihevic, 1981).

Pandolf *et al.* (1972) found that at high work loads, respiratory responses plateaued while RPE accelerated rapidly. As trained individuals can work at up to 65% of their maximal aerobic power without significant elevations in blood lactate concentrations (Astrand and Rodahl, 1977), the authors concluded that due to a large oxygen deficit and a more pronounced anaerobic energy yield, RPE may have been partially monitoring anaerobic metabolites during this high intensity work. No measurement of variables associated with anaerobic metabolism was however attempted. The authors have also noted that during prolonged work the ratings of perceived exertion initially indicate the adaptation to the work task, but later denote the perception of fatigue and not exertion. Carton and Rhodes (1985) report a study wherein following training, at any given submaximal workload, post-training RPE values were lower than those obtained prior to training. This was only true for trained limbs as opposed to untrained ones, and is consistent with the expected lactate response to training, where lower blood lactate concentrations have been found with trained but not untrained limbs (Carton and Rhodes, 1985). Noble *et al.* (1983) found that ratings from Borg's new category-ratio scale corresponded very well with glycogenolytic metabolism leading to lactate accumulation during exercise. In particular, blood lactate and RPE followed a quadratic curve, whilst the muscle lactate increases tended to approximate a cubic function. While this study does not demonstrate any independence between differentiated ratings of perceived exertion as affected by lactate concentrations, it does suggest that perceptions of exertion may be related more closely to blood lactate than muscle lactate. Skrinar *et al.* (1983) however found that blood lactate values were more closely associated with changes in the local ratings of perceived exertion than with central ratings, supporting the conclusion that lactate concentrations act as a potent local sensory cue.

Other reports have yielded some inconclusive results concerning the ralationship between RPE and lactate concentrations. In one investigation, researchers found that the correspondence of perceived exertion and lactate responses under hyperoxic conditions was somewhat inconsistent (Mihevic, 1981; Carton and Rhodes, 1985). Similar research by Allen and Pandolf (1977) however implies a possible relationship between rated perceived exertion and blood lactate. Again examining hyperoxic conditions, these investigators reported a correlation coefficient of $r = 0.64$ between rated perceived exertion and blood lactate at the end of exercise. Experimental manipulations of lactate concentration have therefore yielded rather equivocal results concerning the impact of this parameter for perception of effort. The above studies are however consistent in demonstrating a decrement in lactate concentration at relatively low exercise intensities for both cycle ergometer and treadmill work, thereby providing some support for a link between the two variables (Mihevic, 1981).

Some research has cast doubt on the relationship between blood lactate and perceived exertion. Stamford and Noble (1974) were unable to find differences in arterial lactate concentrations at different work intensities, but RPE were significantly lower at less intense work bouts. This led the authors to conclude that local muscle strain was not reflected by blood lactate as a perceptual cue, and casts some doubt on the importance of blood lactate as a major cue for rated perceived exertion. A closer examination of the study however reveals that data was collected from an extremely fit ($61.4 ml.kg^{-1}.min^{-1} \dot{V}O_2$ max) group of subjects, and as work was performed at or less than 65% of $\dot{V}O_2$ max, exercise intensities may have been insufficient to stimulate a lactate response. This is supported by the observation that negligible increases in blood lactate were observed during the work bouts in the study. Furthermore, rather than employing the RPE scale or standard ratio-scaling procedures, the investigators asked subjects to rate their perception of effort on a 1-9 scale. This limits the meaningful integration of these results with other research in this field. Nevertheless, the above information does suggest that blood lactate levels possibly only affect the perception of effort once a critical exercise intensity threshold has been reached. Other researchers have also presented data which somewhat refute the importance of lactate as a perceptual cue. Kay and Shephard (1969) did not find a relationship between "arterial lactate" and rated perceived exertion. These authors did however speculate that "if lactate could be measured in the vicinity of the muscle pain receptors, there might be a significant relationship". In other words they suggest that the time-lag between the production of lactate by the muscle and its appearance in the blood and the inability to assess lactate concentration at the level of the free nerve endings in the muscle may be responsible for the lack of relationship with perceived exertion. This however is an erroneous conclusion, as Mihevic (1981) points out that blood lactate is generally regarded as an accurate index of muscle lactate concentration, provided it is measured at peak concentrations. This is supported by Davis (1985a), who notes that the pattern of change is the same for blood and muscle lactate. Mihevic (1981) also suggests that the lack of correlation between the two variables in the above study may merely have reflected the restricted perceptual values which were obtained, since the relationship between RPE and lactate was analysed only at a single exercise intensity.

Although some studies provide evidence which supports the role of lactate concentration as a potent stimulus for the perception of effort, the mechanism(s) by which this influence might be mediated is uncertain (Mihevic, 1981). Several researchers have suggested that pain and discomfort in the working muscles may be related to the stimulation of free nerve endings, due to the metabolic acidosis which is induced by elevations in muscle lactate concentrations (Stamford and Noble, 1974; Pandolf, 1978; Carton and Rhodes, 1985). Poulos *et al.* (1974) however contended that blood pH is not an underlying factor in the subjective feelings of fatigue. They concluded that if blood lactate influences RPE, it is probably mediated through a pathway other than blood acidemia.

Kostka and Cafarelli (1982) found that neither induced acidosis nor alkalosis had any effect on effort sensations during heavy exercise (80% $\dot{V}O_2$ max) however, acidosis resulted in 20% increases in sensory intensity. This lends support to the conclusion that blood lactate levels may only affect RPE once a critical exercise intensity threshold has been reached.

From the above, it appears that the evidence implicating blood lactate as a perceptual cue is equivocal. Although there have been conflicting findings, it seems as though blood lactate concentrations may influence perception of exertion by means of some presently unidentified pathway, rather than through a reduction in pH (Mihevic, 1981; Carton and Rhodes, 1985). The review of studies presenting correlational evidence to support the influence of lactate concentration as a perceptual cue shows generally consistent results, indicating that the relationship of lactate concentration with perceived exertion is quite robust. Even though lactate concentration for most individuals does not increase until 50 - 65% of $\dot{V}O_2$ max has been achieved, there is some evidence that lactate concentrations may provide some input for perceived exertion at relatively low exercise intensities. Also, although the mechanism of lactate's perceptual impact is as yet unidentified, the muscular discomfort which typically accompanies lactate accumulation provides a source of sensory information which is readily available to conscious awareness (Mihevic, 1981).

RATINGS OF PERCEIVED EXERTION AT THE ANAEROBIC THRESHOLD

Before examining RPE at the Anaerobic Threshold (AT), it should be noted that there is some controversy over the validity and applications of the concept of AT. A detailed examination of the concept is beyond the scope of this review, but short arguments and conclusions in the debate are presented as an introduction to the problem.

Davis (1985a & b) is a staunch proponent of the utility of the concept and presents it as follows. At low exercise intensities, the level of blood lactate concentration is the same as it is at rest. However, at some particular exercise intensity, which varies among subjects, aerobic metabolism is insufficient to supply O_2 to the working muscles and anaerobic glycolysis contributes to the energy requirements and lactic acid is formed. This is buffered in the blood by sodium bicarbonate, and the carbon-dioxide released in this buffering is exhaled into the atmosphere as the venous blood enters the lungs (Mc Ardle *et al.*, 1981). The onset of metabolic acidosis can be detected in various ways. Initially it was suggested that departures in the linearity of ventilation ($\dot{V}E$) and CO_2 output ($\dot{V}CO_2$), plus an abrupt increase in the gas exchange ratio (R) could be used to mark the AT. While these are valid indices, they are not optimal, as it is often difficult to judge the degree of change (Davis, 1985a). Other methods include the point at which $\dot{V}E/\dot{V}O_2$ and $PETO_2$ (end-tidal PO_2) start to systematically increase (Skinner and

Mclellan, 1980; Davis, 1985a), and of course the invasive method of determining an increase in blood lactic acid (Mc Ardle *et al.*, 1981). Davis (1985a & b) reports studies finding close agreement between noninvasive and invasive methods of determining AT, but Brooks (1985a & b) holds that such correlations are coincidental, and he challenges the theory that pulmonary ventilation tracks blood lactate level. Brooks (1985b) also refutes the notion of AT by pointing out that lactate is produced by muscle under fully aerobic conditions, and that lactate production does not necessarily imply anaerobiosis, i.e. oxygen-limited ATP production.

Despite these reservations, AT remains an attractive concept with great utility. The ability to sustain long-term work is critically dependent on the AT. Davis (1985a) reports that of the various indices purported to predict endurance performance (running economy, relative body fat, $\dot{V}O_2$ max, percentage of slow twitch muscle fibres and the AT), the AT yields the highest correlation with marathon running, to the extent that marathon runners run at a pace that is within 5% of their AT. Similar results are reported for 10km racers. The onset of anaerobiosis normally occurs between 55% and 65% of the $\dot{V}O_2$ max in healthy untrained subjects (McArdle *et al.*, 1981), but the AT is higher in the endurance trained athlete, occuring at 70 - 80% of $\dot{V}O_2$ max (Davis, 1985a). The possible utility of the concept is perhaps best illustrated by the following statement:

> "Many investigators attempt to equate exercise intensity by using the same fraction of $\dot{V}O_2$ max for each subject. But if, say 60% of $\dot{V}O_2$ max is above the anaerobic threshold for one subject and below the AT for another, then the physiological response to exercise is likely to be different" (Davis, 1985a, p.14).

A search of the literature has revealed very little work that has specific applicability to RPE at the AT. Pandolf *et al.* (1972) have suggested that during heavy work involving a large O_2 deficit and a more pronounced anaerobic energy yield, the RPE may be partially monitoring anaerobic metabolites. More specifically, two more recent studies have examined RPE at the AT. Purvis and Cureton (1981), using noninvasive methods of determing AT during exercise, found that for men and women RPE at the AT ranged from 11 - 16 (mean 13.6). This corresponds to a perception of work as "somewhat hard" according to the Borg scale. This is reasonable, since the physiological alterations that occur at exercise intensities above the AT include lactic acid accumulation in the blood, a decrease in blood pH and a disproportionate increase in ventilation in relation to the work rate. The consequences of metabolic acidosis have effects that are both local and central, confirming the multi-faceted construct of RPE. The finding that individuals perceive the point of AT the same makes it possible to prescribe an exercise intensity equal to the AT by using RPE (Purvis and Cureton, 1981).

In a similar study, Demello *et al.* (1987) attempted to determine whether RPE during moderate to heavy submaximal exercise is more closely associated with AT or $\dot{V}O_2$ max. As with the previous study, RPE at the AT corresponded to a Borg scale rating of 13 ("somewhat hard"). In addition, they found that RPE at the AT were not affected by fitness levels, i.e. both trained and untrained subjects perceived the exercise intensity at the AT as "somewhat hard". In agreement with Purvis and Cureton (1981), the authors concluded that the AT is an important anchor point for perception of effort during exercise, as well known metabolic gas exchange alterations are initiated at the AT and become accentuated at higher exercise intensities, contributing to both local and central signals of effort perception.

As seen earlier, Robertson (1982) has hypothesized that RPE is determined by local factors and two central factors, namely % $\dot{V}O_2$ max and ventilatory function. Below the AT, $\dot{V}E$ plays a minor role in RPE, but above this point, it plays an increasingly important role relative to the other factors. The results of the study by Demello *et al.* (1987) support this model by implying that the AT is a pivotal point above and below which the determinants of perceived exertion probably differ. Furthermore, they refine Robertson's (1982) model by demonstrating that the AT is an anchor point at which perception of effort is relatively constant in individuals differing widely in work capacity and state of training.

In conclusion, although controversy exists over the validity of the concept of the AT, it has great utility for exercise prescription according to RPE. Researchers have found that the AT corresponds to a Borg Scale rating of "somewhat hard", and that the AT is a pivotal point above and below which the determinants of perceived exertion probably differ.

OTHER FACTORS AFFECTING RPE

RPE and State of Training

Several studies have demonstrated that fit and unfit subjects rate the effort required to perform standard workloads equally (Carton and Rhodes, 1985). Mihevic (1983), for example, found that individuals differing in cardiovascular fitness rated their perceived exertion at absolute workloads similarly, even though the less fit subjects exhibited significantly greater physiological strain. This is incongruent with theoretical expectations, and suggests that the RPE scale may not be particularly valuable for inter-individual comparisons. From a psychophysical standpoint, Mihevic (1983) feels that the scale may not be sensitive enough to permit fine distinctions between levels of exercise stress or physiological strain which may be mediated by aerobic fitness. It has been suggested that in certain individuals, differences in RPE as a consequence of training are only manifested during intense activity (Carton and Rhodes, 1985). As most of the research in this area has been conducted at moderate exercise intensities, it may well be that any dissimilarities between the perceptual responses of various groups appear only in higher ranges of exercise intensity. This is supported by Mihevic (1983), who states that at higher exercise intensities, RPE differences are expected to reflect physiological differences. Clearly further research into training-related changes in RPE is required (Carton and Rhodes, 1985), perhaps with the emphasis on potential differences during high intensity work.

Perception and Cognition

Multiple physiological indices have, at best, accounted for approximately 65% of the variance in RPE (Morgan, 1973); estimates which may be inflated since investigation has generally been restricted to laboratory settings where the social context of behaviour has been controlled. The dynamics of perceived exertion during exercise thus remain equivocal (Rejeski and Ribisl, 1980). Therefore, while research has been primarily directed at the biological foundations of RPE, many investigators now agree that subjective variables, notably psychological dispositions, can substantially affect effort sense (Rejeski, 1981).

Researchers have suggested that the perception of exertion is influenced by cognition to a large degree. Morgan (1981) suggests that RPE are governed not only by the physiological cost of work, but also by the exercising subject's cognitive appraisal. He contends that effort sense seems to involve a cognitive-perceptual process rather than perception alone. In other words, the effort sense is based upon the physiological cost, cognition and perception. This fits in with the theory that perception of effort is a complex psychophysiologic process. Furthermore, in a more recent paper, Morgan (1985) states that cognitive (thoughts), affective (feelings) and perceptual (sensations) factors can independently, or in concert, influence metabolism. Other researchers also cite evidence supporting a complex interrelationship between cognitive, perceptual and physiological factors in the subjective estimates of work cost (Rejeski and Ribisl, 1980; Hardy *et al.*, 1986).

Several studies have attempted to elucidate the above relationship. Morgan (1981) reports a series of studies in which hypnotic suggestions of uphill work yielded higher RPE than for level grade suggestions. From these results he concluded that perception of effort is governed by one's cognition to a large degree. In other words, thinking that work intensity is greater than it really is can result in elevated RPE . Cognition then can influence RPE, but it is important to note that one's cognition at a given point in time is mediated to a large degree by personality structure (Morgan, 1981).

Morgan (1973) has also suggested that 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. Taking this a step further, Rejeski and Ribisl (1980) suggested that one mechanism through which the cognitive determinants of RPE may become salient during physical tasks is an expectancy concerning task duration. For example, individuals may delay the unpleasant consequences of fatigue by supressing subjective estimates of tiredness until the task is virtually complete. The results of their study support the supposition that the anticipation of continued performance mediates ratings of effort expenditure.

Further support for the role of cognition in RPE comes from work reported by Morgan (1981; 1985), relating to cognitive strategies employed by marathon runners. Decisions (cognition) relating to pace (e.g. increase, discontinue etc.) are thought to be based largely on the runner's perceived exertion (Morgan, 1981). Elite runners were found to use a strategy known as "association" paying attention to body signals), while those less capable used a strategy known as "dissociation" (distracting attention from body signals). To emphasise the role of cognition in RPE, Morgan (1985) suggests that the cognitive strategy associated with the perception of effort may in part contribute to the physical performance. The above findings suggest a complex relationship among cognitive processes, physiological indicants and the perception of exertion. Taken together they suggest that the perception of internal states during physical work can be influenced by cognitive processes (Hardy *et al.*, 1986).

From a conceptual viewpoint, Rejeski (1981) has proposed that cognitive variables should be expected to influence RPE most when the physical task in question is performed at, or has the physiological demands of a submaximal work intensity. In other words, when work has physiological demands at or near maximal capacity, physiological inputs serve as salient sources of information for RPE. However, when work is performed at submaximal levels, there is an increased probability that psychological factors can serve as cues in the subjective perception of exertion. Following on from this, Rejeski (1985) has proposed an active rather than passive conceptual approach to the field of perceived exertion, and in so doing has elaborated on the potential role that informational and affective schema can play in the perception of exertion. According to a parallel-processing model of pain, perception is depicted as an active process and considerable weight is given to preconscious elaboration of sensations. The approach also distinguishes between perception and focal awareness. Relating this to the dissociative strategies described earlier, they provide a relief from fatigue by occupying limited channel capacity that is critical to bring a percept into focal awareness. this has important implications with regard to the working environment and ratings of perceived exertion.

Environment and RPE

In accordance with the above parallel-processing perspective, Pennebaker and Lightner (1980) demonstrated that during exercise, external cues (e.g. terrain) do compete with internal cues (e.g. ventilation). Specifically, despite no differences in fatigue ratings, subjects were found to run faster on a cross-country course than on a track. As fatigue reports were comparable for the two courses, it was hypothesized that shifting attention to external cues led to diminshed responsivity to internal states (Rejeski, 1981). Put another way, as subjects were focussing on external cues to a higher degree on the cross-country course, their processing of internal sensations was restricted (Hardy *et al.*, 1986). Further support for Rejeski's (1985) limited capacity position is provided in an investigation by Stones (1980). The author states that physiological control systems undoubtedly contribute to judgement of pace and fatigue, and it would be surprising if the visual system did not contribute also, at least to pace judgement. Consequently, his research was designed to increase the demand on a runner's visual system by restricting field of vision through the use of specialized goggles. Attentuated visual input resulted in: a) enhancement of perceived pace relative to actual pace, b) lessening of fatigue relative to actual pace, and c) slowing of actual pace, These findings make it apparent that the visual system, in addition to other physiological control systems, contributes to various aspects of the running experience. This raises an interesting question with regard to running environment and fatigue perception; namely, might parallel observations be obtained under conditions where visual input was not attenuated artificially? In other words, would runners on a treadmill report different perceptions of fatigue than when running outdoors at a similar pace? It is worth noting that under conditions of unrestricted vision, the visual field is filled both with near and far objects. For a person in motion, the corresponding retinal projections will therefore be associated with varying degrees of change (Stones, 1980). This may not be the case for treadmill running. Stones (1980) thus found that visual impairment and the subsequent vigilance required for movement resulted in reduced awareness of fatigue-relevant physiological information. Thus, according to this particular investigation, it would appear that what is available in perception can be blocked from consciousness by flooding the lines of communication with distracting stimuli.

Birk and Birk (1987) contend that using RPE, estimated during exercise testing, to control intensity during training by reproduction of similar efforts may be inappropriate. They feel that environmental influences would render direct perceptual translations from the laboratory to the field invalid. Jackson *et al.* (1981) have demonstrated that the physiological and psychological correlates of exercise performance are different in a field setting than in the laboratory. On the other hand, ratings of perceived exertion were not affected by auditory input such as music and mechanical noise, e.g. treadmill operation) (Carton and Rhodes, 1985). Before unequivocally accepting the results of the studies above, it is worth noting that studies of this nature are difficult to control, and may not validly discriminate between the effects of physiological and psychological stress indicators, as has been inferred (Carton and Rhodes, 1985). Nevertheless, in the field, where a myriad of social physiological forces impinge on the performer, the role of physiological feedback to RPE may well be reduced. The potential role that motivational and informational factors may play in the subjective assessment of physical work is thus increased (Rejeski, 1981).

Treadmill versus overground running

The motordriven treadmill is frequently used in biomechanical and exercise physiology studies of locomotion, as well as for training and rehabilitation purposes. The treadmill offers many advantages to studies in human locomotion, mainly because of the control and convenience it offers. Using the treadmill, a familiar human movement can be varied in intensity while the subject performs in close proximity to metabolic and cardiorespiratory recording instruments (Nelson *et al.*, 1972; Wall and Charteris, 1981;

Frishberg, 1983). As a result, the treadmill has played a very important role in the study of human movement.

The treadmill is often used to simulate overground walking and running, but the literature indicates a wide difference of opinion about the validity of the extrapolation of treadmill information to the overground environment or vice-versa (Van Ingen Schenau, 1980). Wall and Charteris (1981) state that even though differences between the two conditions may exist, these are probably outweighed by the convenience offered by the treadmill. If however significant differences do exist between the two modes of locomotion, the extrapolation of information from one environment to the other could involve inherent inaccuracies. Therefore, it is important to examine the results of specific studies before the results of treadmill studies can be generalized to the field.

Several investigators have found differences in the kinematics between treadmill and overground locomotion (Nelson *et al.*, 1972; Elliott and Blanksby, 1976; Frishberg, 1983). Nelson *et al.* (1972) hypothesized that meaningful differences would be observed between the two conditions, indicating that different mechanics are utilized when running on the treadmill than when running overground. Following analysis of their results, these researchers concluded that there were significant biomechanical differences between overground and treadmill running, but that this was particularly so in the case of temporal variables. It should be noted that these differences were only apparent at higher velocities. Elliot and Blanksby (1976) found kinematic differences between the two conditions, but also only at higher velocities (4.82 - 6.2 $m.s^{-1}$). Although the results of these two studies were contradictory in that at a common velocity athletes modified their running style in different ways, both investigators indicate that at approximately 5 $m.s^{-1}$ or faster on the treadmill, modifications in locomotion are likely to occur. Frishberg (1983) examined selected kinematic variables during overground and treadmill sprinting to determine possible physiological differences, as well as differences in running technique due to altered kinematic variables. He found that O_2 debt for the overground condition was 36% greater for the treadmill running condition. Pugh (1971) has proposed that at running velocities above 6 $m.s^{-1}$, air resistance might be responsible for differences between the condition. The reported 36% however, far exceeds other reports of the percentage cost of air resistance to energy expenditure, and as such the large difference cannot be accounted for purely by the air resistance factor (Frishberg, 1983). Frishberg's (1983) kinematic analysis revealed a possible standardization of running form during treadmill locomotion. He hypothesised that the moving treadmill belt brought the supporting foot back under the trunk rather than have the trunk move over the supporting foot. This would have the effect of reducing the energy requirements for the treadmill running condition. Methodological problems with speed-matching between the two sprinting conditions however indicate that Frishberg's (1983) results should be interpreted with caution. The validity of using O_2 debt to measure total energy expenditure is also questionable. Furthermore, the dramatic velocity differences between his and other studies makes comparison difficult.

McMiken and Daniels (1976) measured $\dot{V}O_2$ in a discrete series of three speeds and at maximal effort during treadmill and track running. The aerobic requirement differences were evaluated, and none of the differences were found to be significant. The authors concluded that if real aerobic differences do exist between the two conditions, then they are probably very small. Basset *et al.* (1985) agree that the oxygen demand of level running is similar for both the treadmill and overground situations at speeds under 4.5 $m.s^{-1}$. As stated earlier, Pugh (1971) reported a greater energy cost for track running, but this was attributed to the effects of air resistance rather than to fundamental differences in the mechanics of overground and treadmill locomotion. The question of whether real aerobic differences do exist between the conditions remains unanswered, but at present the treadmill appears to be a valid instrument for the estimation of oxygen uptake when the data are to be applied to track running in calm air at running speeds below 4.5 $m.s^{-1}$.

Most of the above studies were, however, conducted on level surfaces, and the issue of grade locomotion is an ergonomic problem that is far from resolved (Charteris, 1986a). According to the ACSM (1980) prediction formulae, the energy cost for overground running is greater than for running on the treadmill. At a speed of 3.3 $m.s^{-1}$ and at 7.5% grade, the difference would amount to 10.25 $ml.kg^{-1}.min^{-1}$. Conversely, Van Ingen Schenan (1980) used a theoretical physics approach and concluded that there should be no differences between the metabolic energy requirements of inclined treadmill running and overground hill running. If differences do exist, Van Ingen Schenan (1980) feels that they can be attributed to visual, and to a lesser extent, auditory factors. Visual information may be important in maintaining equibilibrium and stability, while the ambience of the treadmill and laboratory could prove to be an extremely stressful environment for a subject. These factors together with wind resistance could cause differences between the two situations, but it appears that measurements of $\dot{V}O_2$ obtained during level and inclined treadmill are valid when applied to the overground situation (Basset *et al.*, 1985).

In conclusion, several studies indicate that at speeds below 5 $m.s^{-1}$, there are no kinematic differences between overground and treadmill running. Furthermore, there are no differences in oxygen demand for the two conditions at speeds below 4.5 $m.s^{-1}$. If differences do occur, they can be attributed to perceptual influences or wind resistance.

Social Influences in the Perception of Exertion

From social-psychological theory it is evident that RPE is influenced by external cues and that they are relevant to the domain of interpersonal as well as self-perception (Rejeski, 1981). Hardy *et al.* (1986) examined the effects of social influence (alteration of one's behaviour, feelings or attitudes by what others say or do) on the self-perception of exertion. In other words, can ratings of perceived exertion be mediated by social influences? They found that subjects performing in the presence of another exercising subject (coactor) appeared to suppress their subjective ratings of exertion, particularly at light to moderate exercise intensities. This was attributed to the adoption of self-presentational tactics (i.e. the subject concerned himself with how he looked relative to the coactor).

The results from the above study suggest that the effects of social influence may be limited to light and moderate exercise intensities. This lends support to Rejeski's (1981) conceptual model in that physiological information appears to be less salient at these intensities than at heavy intensities. This relationship between the cognitive and physiological components of RPE can perhaps best be explained by the saliency of information hypothesis. While exercising, subjects are exposed to both internal sensory information and external environmental information, and when explicit subjective judgements about inner states are required, the two sources of information are differentially weighted. Thus, when internal cues are weak or ambiguous, external sources of information are given more weight. However, when internal cues are strong, their salience determines one's judgement (Hardy *et al.*, 1986).

By examining the effects of social influence, the above results support the premise that psychological variables and variables of a cognitive social-psychological nature play a significant role in the perception of exertion. Whereas physiological variables obviously account for a significant portion of the response variance in RPE, researchers would be remiss in ignoring the role that psychological factors can play in the subjective assessment of physical work (Hardy *et al.*, 1986).

Motivation and Emotional Factors Affecting RPE

Alderman (1974) views the study of motivation as the study of human action and its determinants. He holds that it is concerned with the analysis of those factors which initiate individual action and then direct it towards a particular end or goal. When a person is forced to participate in a physical activity without adequate information, he will usually experience a feeling of disinclination to continue with the activity (Karpovich and Sinning, 1977). Motivation, therefore, accounts for the initiation, direction and persistence of behaviour (Braun *et al.*, 1979), and as such can probably affect subjective ratings of exertion during an exercise task. Activation or arousal refers to the physiological and psychological processes that permit the individual to perform a task with varying degrees of intensity. An optimum level is needed to perform any given task, as both under- and over-arousal can impair performance (Cratty, 1973). In other words, motivation determines the level of operation on any specific task, and explains the intensity with which individuals engage in activity and the level of effort sustained in the activity.

Existing data support the supposition, expressed above, that the RPE responses are mediated by motivation factors. Attribution research in sport has reported that effort ratings are higher after conditions of success than failure (Rejeski, 1981). The dynamic operating in such circumstances is assumed to be one of individuals protecting their self-concepts, i.e. a rationalisation of performance according to perception of effort. As we have seen, social influences may affect self-presentational strategies and thereby affect RPE (Hardy *et al.*, 1986), but although this may be the case, specific predictions are unwarranted based on existing data. Furthermore, while ego-involvement may be constant, the mediation of exertion by motivational input may not be consistent for all tasks. The issues involved in the subjective self-report may also become clouded by motivational input if any confusion exists between the perception of exertion and other similar, though not analogous constructs, such as pain, toughmindedness etc. Hence, researchers need to be aware of the epistemological status of exertion (Rejeski, 1981).

In summary, motives are factors which impinge on the human as he moves, and they influence the intensity of his activity and determine how long he will persist in difficult tasks (Cratty, 1968). The self-report of exertion may have motivational and emotional antecedents, and existing data support the notion that RPE are mediated by motivational factors. Finally, the potential role of motivation and emotions in RPE is worth pursuing, and casts further doubt on the generalisability of controlled laboratory study to the field (Rejeski, 1981).

Personality Variables Affecting RPE

It has previously been noted that multiple physiological indices account for approximately 65% of the variance in RPE (Rejeski and Ribisl, 1980; Rejeski, 1981; Carton and Rhodes, 1985). Morgan (1973) has suggested that at least a portion of the remaining unexplained variance might be dependent upon factors of a psychometric nature.

In an investigation designed to examine RPE in relation to the interaction of psychometric variables with the standard bio-psycho-physical factors, Morgan (1973) demonstrated that neurotics and depressives may lack the ability to accurately rate perceived exertion. He also concluded that perceived exertion ratings are probably dependent in part upon the subject's level of state anxiety, as well as depression. Hence a portion of the unexplained variance in perceived exertion work could reflect the differential responses of subjects exhibiting divergent behavioural characteristics (Morgan, 1973).

Extroverts are known to have higher pain thresholds than introverts ((Rejeski, 1981), and in another experiment, Morgan (1973) supported this and found significant differences in RPE for the two groups. Extroversion, for example, was inversely correlated with RPE. In other words, extroverted subjects perceived the same exercise intensity to be less effortful than did introverted subjects. Furthermore, stated work preference was found to correlate with extroversion, the extroverted subjects selecting higher levels at which to work than did the introverted subjects.

Therefore, on the basis of the studies reviewed, it seems reasonable to propose that one's perceived exertion for standard work is dependent in part upon several psychological factors. Specifically, it would seem that somatic perception, anxiety, neuroticism and extroversion are probably interactive variables in the perceptual processing of information (Morgan, 1973). Thus it appears that perception of effort is correlated with the selected psychological states and traits mentioned above in a rather complex manner, and this emphasises that individual differences in personality structure may play a role in the mediation of effort sense (Morgan, 1981).

ATTITUDES AND PHYSICAL ACTIVITY

Kenyon (1968, p.2) defines an attitude as

> "...a latent or nonobservable, complex, but relatively stable disposition reflecting both direction and intensity of feeling towards a particular concrete or abstract object".

An attitude can be considered the cause of a person's behaviour, and the concept of an attitude includes the idea of unconscious determinants of behaviour and the dynamic interplay of conflicting motives. Attitudes translated into motivational force determine the selection of activity, the amount of persistence at the activity, and the intensity and vigour of performance (Singer, 1977). Furthermore, an attitude helps to explain the consistency of a person's behaviour, since a single attitude may underlie many different actions. An attitude has also been defined as:

> "...a mental or neural state of readiness, organized through experience, exerting a directive or dynamic influence upon the individual's response to all objects and situations with which it is related" (Oskamp, 1977, p.9).

Attitudes, then are predispositions to respond, but are distinguished from other such states of readiness in that they predispose towards an evaluative response. Thus attitudes are referred to as "tendencies of approach and avoidance". As such, they are amongst the most important determinants of human behaviour (Osgood *et al.*, 1957). From the above it is apparent that the central feature of attitude is the idea of "readiness for response", i.e. the preparation for behaviour. Attitudes can be a motivating force in that they impel behaviour and guide its form and manner. An attitude then, is generally seen as a disposition to respond in a favourable or unfavourable (evaluative) manner to given objects or concepts (Oskamp, 1977).

Many factors influence attitude development and change. Firmly held attitudes are often formed early in life and are often very resistant to change. Reinforcement theories contend that attitudes are formed because of the rewards or punishments associated with them, e.g. classical and operant conditioning. In classical conditioning, a positive or negative emotional reaction becomes associated with some object without a corresponding set of cognitive beliefs. In operant conditioning, people tend to repeat behaviours that result in something desirable and fail to repeat those that result in something undesirable (Braun *et al.*, 1979).

Although attitudes have been identified as constituting a readiness for response, they are not behaviour *per se*. It therefore follows that they cannot be directly observed. Attitudes are studied through a process of inference based on the study of responses which are observable (Oskamp, 1977). An attitude scale is a self-report measure and therefore suffers from the weaknesses typical of this type of instrument in that it reflects only what the individuals know and are willing to relate (Baumgartner and Jackson, 1982). Problems which affect the validity of attitude scales include the following response sets: 1) carelessness on the part of the subject. This can be minimised by building rapport and stressing the importance of the task. 2) Social desirability, i.e. to give the most socially "acceptable" answer. It is difficult to combat this response set. 3) Extremity of response or mid-set response occurs where there are more than two answers. There has been little study on this response set. 4) Acquiescence (yea-saying) is an agreement response set. The use of a balanced response scale such as the Semantic Differential eliminates this (Oskamp, 1977).

The Semantic Differential (SD) is an instrument which allows for measurement of concept meanings in terms of semantic scales of known factor composition (Maul and Pargman, 1978). The Osgood *et al.* (1957) scale thus attempts to measure the connotative meaning of a concept or object, and the scale is of such a general sort that it can be applied to any concept. The subject does not make opinion statements but responds to bipolar adjectives in an attempt to communicate his feelings. By submitting the ratings to factor analysis, three basic dimensions on which people make semantic judgements were identified, namely 1) evaluation (E), 2) potency (P), and 3) activity (A). Osgood *et al.* (1957) state that the evaluative factor is pervasive in human judgement. It involves adjectives such as pleasant - unpleasant, good - bad. The potency factor is concerned with power and the things associated with it; size, weight, toughness and the like. The third dimension is the activity factor - concerned with quickness, excitement, warmth, agitation and so on. The evaluative factor is dominant as an expression of attitude, while the potency factor is about equal and slightly greater in magnitude than the activity factor. The evaluation dimension virtually serves as a definition of attitude (Oskamp, 1977), and so responses to this factor's adjective pairs are excellent measures of verbalized attitudes. Clearly this dimension is affective in nature. The potency and activity factors are more cognitive in nature, and as such they reveal the respondents interpretation of the concept's physical characteristics (Osgood *et al.*, 1957; Oskamp, 1977). With regard to the selection of concepts and adjective pairs (scales), several factors must be borne in mind. Firstly, there are no standard concepts and no standard scales; rather the concepts and scales used in a particular study depend on the purposes of the research. The nature of the problem chiefly defines the class and form of the concept in particular (Osgood *et al.*, 1957). The factorial composition of scales is one criterion for their selection, as is their semantic stability. Of more importance however is their relevance to the concepts being judged, and often scales of unknown factorial composition are highly relevant to a particular problem (Osgood *et al.*, 1957).

In conclusion, an attitude can be considered the cause of a person's behaviour, and translated into motivational force, can determine the selection of activity and the intensity with which the activity is pursued. Furthermore, an attitude can be seen as an evaluative readiness for response to a situation. Although it is clear that there are inherent risks in the use of rating scales, valuable evidence has been offered on the validity, reliability and sensitivity of the Semantic Differential (Osgood *et al.*, 1957), and research has established the SD as an appropriate instrument for the measurement of attitudes, both in general application and as to situations involving the study of man-in-motion (Maul and Pargman, 1978).

CHAPTER THREE

EXPERIMENTAL METHODS AND PROCEDURES

INTRODUCTION

Eleven extremely well-conditioned (mean $\dot{V}O_2$ max 66.8 $ml.kg^{-1}. min^{-1}$) male Caucasian subjects (mean age 26.6 years) volunteered to participate in the study. All subjects were active members of running clubs in the Grahamstown area, and were recruited on the basis of their high level of involvement in competitive running. The subject sample can therefore be considered a homogenous group, and any conclusions drawn from the data must bear this in mind.

Each subject read and signed a written informed consent form (Appendix 2) prior to participation in the study, and biographical and anthropometric data were recorded prior to testing. Subjects were also required to complete an attitudinal questionnaire (Appendix 3) before both the overground and treadmill testing sessions. Subjects were required to participate in the following five test sessions:

1) Biographical data, anthropometric measures and treadmill habituation:
2) a $\dot{V}O_2$ max test;

3) a speed-matching session at 70% of $\dot{V}O_2$ max to determine overground running speed at 3.8% and 7.5% grade;
4) a 4km run on a road of known gradient, at the speeds determined by the speed-matching session;
5) a run on the treadmill, replicating the gradient, speed and time measures of the overground situation.

The following data were collected for analysis:

1) skinfold fat data;
2) attitudinal responses to a Semantic Differential scale,
3) differentiated ratings of perceived exertion, i.e. local, central and overall ratings;
4) heart rate;
5) oxygen consumption ($\dot{V}O_2$);
6) minute ventilation ($\dot{V}E$);
7) volume of expired carbon dioxide ($\dot{V}CO_2$); and
8) respiratory exchange ratio (R).

ENVIRONMENTAL VARIATION

All testing was done in two locations: namely the Work Physiology Laboratory in the Department of Human Movement Studies at Rhodes University: and on Trunk Road 2/15 Komgha river - Grahamstown, kilometres 34.2 - 38.2 (Appendix 4). With the exception of wind speed, every attempt was made to conduct the laboratory testing under similar environmental conditions to those which occurred in the overground condition. When possible, the time of day at which testing was conducted was standardised in order to minimise diurnal variations in physiological and psychophysical repsonses.

INDIVIDUAL DIFFERENCES

In addition to attempts to standardise the time of day at which testing occurred, each subject wore similar clothing and the same running shoes for each test. This was considered necessary in order to minimise energy cost variations due to the wearing of different shoes (Frederick, 1985).

Subjects were also requested to refrain from vigorous exercise and excessive food intake for up to 3 hours before testing.

PILOT TESTING

Pilot tests were conducted to evaluate primarily the reliability of testing procedures and equipment. Concurrent validity of the "on-line" system of gas analysis was assumed by reference to Goslin *et al.* (1985). The Borg scale for differentiated ratings of perceived exertion is frequently used (Gamberale, 1985), and the Semantic Differential Attitude Scale is a commonly used and accepted measure of attitude (Osgood *et al.*, 1957; Oskamp, 1977; Baumgartner and Jackson, 1982). The assessment of validity and reliability of heart rate collection procedures is described in the following pages.

Validity and reliability of heart rate collection procedures

Pre-pilot testing was conducted to evaluate the heart rate monitoring equipment to be used in this study. Six subjects (three male, three female, mean age 25 years) pedalled on a Monark cycle ergometer at 60 revolutions per minute, with an initial load of 1 kg (≈60 Watts). Pedal frequency was maintained with the aid of a Franz electric metronome. A load of one kilogram was added every two minutes. Subjects exercised for a total of seven minutes. Heart rate measures were taken every 60 s by three separate assistants and conveyed independently to a recorder. Cardionics cardiometern analogue readings and Tunturi Pulsemeter digital readings were taken every 60 s, while the period of radial palpation comprised 20 s of every minute (10 s before and after the other two readings).

A two-way Anova with repeated measures was applied to the data to ascertain whether or not there were any significant differences. In addition, the maximum heart rate of each subject was calculated, as was the percentage of maximum actually achieved by each subject.

There was a significant difference ($p < 0.05$) between the means of measurements with respect to time (Appendix 8). This reflects the normal response to work, particularly work of an incremental nature. No significant differences ($p < 0.05$) were observed between the three types of measurement, and there was no significant interaction.

These results then indicate that the measures used were reliable.

Assuming that radial palpation is a valid method of obtaining exercising heart rate, the Cardionics Cardiometern and the Tunturi Pulsemeter were found to be valid and reliable for measuring exercising heart rates from rest to 80% of maximum heart rate. Figure 1 illustrates the linearity of responses, but also indicates that the Cardionics Cardiometern may be more reliable than the Tunturi Pulsemeter at higher exercising heart rates. Consequently the Cardionics Cardiometern was used to measure heart rate for this research.

Three subjects volunteered to participate in pilot testing (mean age 24.3 years, mean $\dot{V}O_2$ max 72.9 $ml.kg^{-1}.min^{-1}$, mean body mass 70.1 kg and mean relative body fat 9.7%). Each subject signed an informed consent form prior to testing. The subjects reported for the five test sessions mentioned earlier on a test - retest basis, i.e. each subject reported for testing on ten separate occasions. The protocol adopted for each session followed the research protocols described below.

THE RESEARCH PROTOCOLS

Anthropometric Data

The following anthropometric measurements were obtained from each subject prior to the first session of treadmill habituation: body mass and four skinfold measures (triceps, biceps, subscapular and supra-iliac).

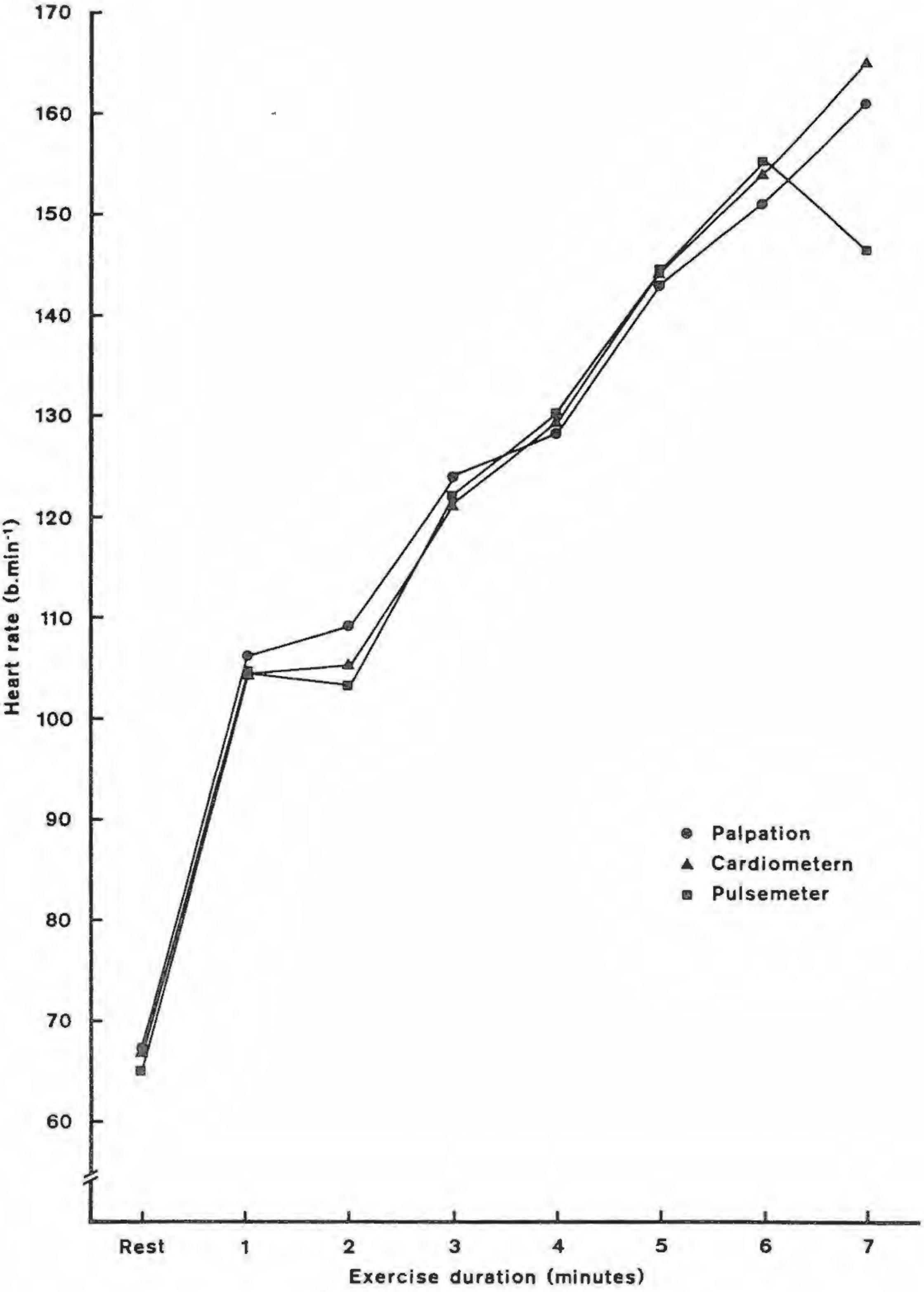

Figure 1: Heart rates measured by palpation, cardiometern, and pulsemeter during a 7 min with an incremental load on a cycle ergometer.

Body mass - A previously calibrated (Goslin, 1985) Seca beam balance scale was used to measure body mass to the nearest 0.1 kg. Clothed only in his running shorts, each subject stood on the scale while the investigator moved the sliding counter-weights and recorded the body mass.

Skinfold fat measurements - These were obtained using a Harpenden caliper, with a jaw pressure of 10 $g.mm^{-3}$, at four sites, namely triceps, biceps, subscapular and supra-iliac. Durnin and Womersley (1974) found that this procedure enabled the tester to assess total body fat with relative ease and reasonable accuracy. Measurement at all four sites involved the following steps. The skinfold was grasped between the thumb and index finger, 1 cm above the prescribed site, and pressure applied. The skinfold was raised and maintained, with the crest of the fold following the specified alignment (Copley, 1980). The caliper jaws were then placed 1 cm from the fingers at a depth approximately equal to the thickness of the fold, at right angles to the prescribed site. The spring handles were released and the skinfold was held throughout the operation. The measurement was taken after the full pressure of the caliper jaws had been applied and the drift of the needle had stopped. Each measurement was taken twice, and was recorded to the nearest 0.1 mm. If the difference between two measures was greater than 1 mm, a third reading was obtained and the mean of the closest pair was recorded.

Triceps skinfold - This was measured on the posterior surface of the unclothed pendant right arm at a level midway between the acromion and the olecranon. The midpoint was established with the elbow fixed at 90 degrees. The skinfold was lifted parallel to the long axis of the arm, afterwhich the subject lowered the forearm and the caliper jaws were applied.

Biceps skinfold - This was measured on the anterior surface of the pendant right upper arm, at the same level as the triceps skinfold. The skinfold was lifted parallel to the long axis of the upper arm.

Subscapular skinfold - This was measured 1 cm below the inferior angle of the scapula with the subject standing erect and the upper limbs pendant. The fold was measured in an oblique plane ascending medially at an angle of approximately 45 degrees to the horizontal. (Figure 2).

Supra-iliac skinfold - This was measured 3 cm above the anterior superior iliac crest. The fold was taken in an oblique plane parallel to the crest.

The above procedures are in accordance with those outlined by Durnin and Womersley (1974). Relative body fat, absolute body fat and lean body mass were calculated according to formulae presented by Copley (1980). The specific equations used in these calculations appear in Appendix 5.

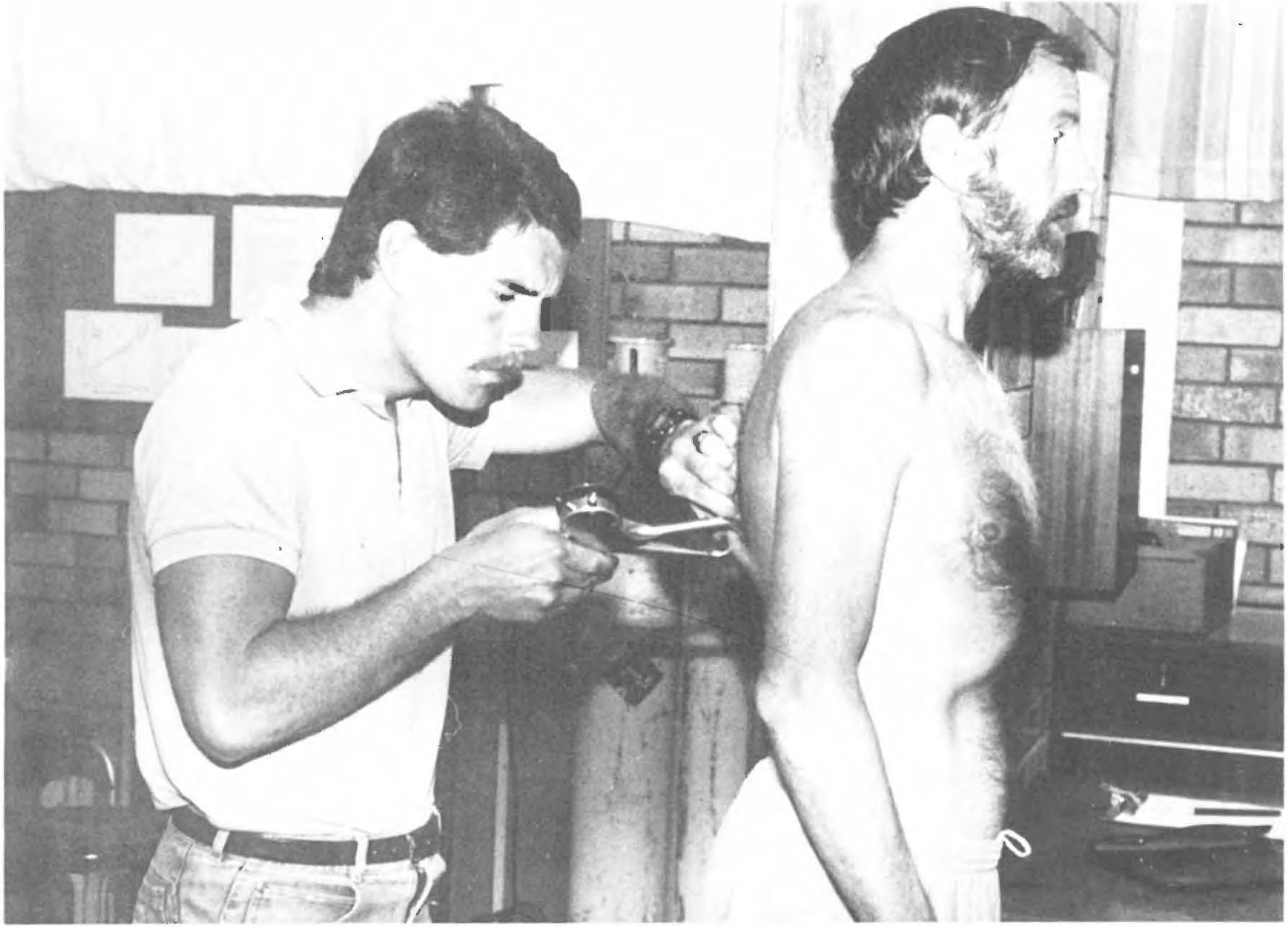

Figure 2: Obtaining the subscapular skinfold measurement.

Treadmill Habituation

Wall and Charteris (1980) have demonstrated that the kinematics of treadmill locomotion alter as the novice learns how to walk on the moving belt surface. Although accomodation to the surface may initially be rapid, kinematic changes continue towards a stable gait pattern with distributed practice over a period of one hour (Wall and Charteris, 1981). These authors have also suggested that there may be metabolic correlates of these progressive changes, and that changes in skill level may result in a lowering of the energy cost of gait as the novice becomes an accomplished treadmill walker. Furthermore, they recommend that when studies to investigate the subtle differences between overground and treadmill locomotion are contemplated, it would be inappropriate to employ subjects habituated for anything less than one hour, in several distributed practice sessions, and that measurements should not be taken during the first two minutes of performance.

Schieb (1986) states that the actual time required before the individual feels comfortable with the treadmill seems to depend on factors such as length of time into the treadmill run and overground running experience, while Van Ingen Schenau (1980) feels that psychological factors such as apprehension may retard accomodation. Therefore when, as in the case of this study, the treadmill is used to derive cardiovascular measures in order to assign a subject's workload to the overground situation, it is important to expose the subject to an adequate amount of treadmill locomotion (Schieb, 1986).

Investigating the problem of treadmill accomodation, Schieb (1986) concluded that minimal amounts of treadmill training are necessary for a subject to fully accomodate to the treadmill. Personal communication with Charteris (1987) led to the conclusion that for the purposes of this research a habituation period of 10 min would be sufficient, as fine measures of gait would not be collected. This habituation period would also introduce subjects to the particular ambience of the laboratory.

Accordingly, after practising getting on and off the treadmill safely, each subject was habituated with 10 min of randomly distributed walking and running, with speed ranging from 4 km to 17 km per hour, and gradient ranging from 0% - 5%. In addition, the $\dot{V}O_2$ max test and speed-matching session served as further periods of habituation prior to the simulation of the overground run. It is also worthy of mention that prior to participation in this study, 9 of the 11 subjects were experienced treadmill runners.

Measurement of Maximal Oxygen Consumption

Subjects were asked to refrain from any heavy exercise prior to the $\dot{V}O_2$ max test. The test protocol comprised a continuous run on a Quniton model 643 motor-driven treadmill at progressively increasing work intensities. The following procedures were followed during the test of maximal oxygen consumption:

1) The subjects body mass was measured.

2) Laboratory barometric pressure, temperature and relative humidity were measured.
3) The on-line system programme (Goslin *et al.*, 1985) was loaded and initialised. This allowed assessment of oxygen consumption for 25 s out of every 30 s.
4) The treadmill was set to 8 $km.h^{-1}$ at 0% grade.
5) The subject started running on the treadmill with the mouthpiece and noseclip in place.
6) After a period of 1 min, which allowed adequate expired air mixing, the computer and external timer were started.
7) After each minute, the speed was increased by $1km.h^{-1}$.
8) If the subject had not achieved his $\dot{V}O_2$ max by the time a speed of 17 $km.h^{-1}$ was reached, the grade was raised 1% at the end of each minute until the test was terminated.

Astrand and Rodahl (1977) and McArdle *et al.*, (1981) have identified several specific criteria as being indicative of maximal oxygen consumption. Where any three of the criteria below were met simultaneously, the subject was deemed to have achieved his maximal oxygen consumption.

1) Delta oxygen consumption from the last 30 s of each minute to the next less than 100 $ml.min^{-1}$ or 1.5 $ml.kg^{-1}.min^{-1}$.
2) The attainment of age-predicted maximum heart rate.
3) Respiratory exchange ratio greater than 1.00.
4) Subjective exhaustion, or a rating of perceived exertion above 17.

Katch *et al.* (1982) have suggested that the peak oxygen consumption value on a continuous treadmill test is of sufficient magnitude to warrant calling it the maximal value. Consequently, in cases where the abovementioned criteria were not met, the peak oxygen consumption value alone was used.

Following termination of the test, the subject came off the mouthpiece but continued to run as treadmill speed was reduced to a walking level. After coming off the treadmill, the subject continued walking for 3 min in order to "cool off".

The $\dot{V}O_2$ max test was included for the following reasons:

1) To determine the aerobic fitness levels for all subjects.
2) To enable the tester to determine 70% of maximal oxygen intake. This was the projected relativised intensity at which subjects would be working for the overground and treadmill conditions.

Gradient

To enable comparisons between the overground and treadmill conditions, the gradient occurring in the overground condition needed to be replicated on the treadmill. Consequently, all overground sessions took place on the same 4km stretch of road which had a known gradient. This testing took place on Trunk Road 2/15 Komgha river - Grahamstown, Department of Roads, Cape Provincial Administration, from kilometre 34.2 - 38.2 (Appendix 4). As two means from four data collections were to be analysed, gradient for the 4 km distance was calculated along two 2 km stretches, ensuring greater accuracy of treadmill simulation of the overground gradient than if merely the mean of the entire distance was simulated. The mean gradient for km 0-2 was calculated as 3.88%, and the mean gradient for km 2-4 as 7.56%. This was accomplished in the following manner:

$$\text{Tan } \theta = \frac{\text{opp}}{\text{adj}}$$

For km 0 - 2:

$$\frac{77.58\text{m}}{2000\text{m}}$$
$$= 0.03879 \tan^{-1}$$
$$= 2.2213896°$$

Now for % gradient from known (angular) slope,
take Tan of θ X 100 = %
$\therefore$ Tan of θ = 0.03879 X 100
= 3.88%

For km 2 - 4:

$$\frac{151.29}{2000}$$
$$= 0.075645 \tan^{-1}$$
$$= 4.3259006°$$

Now for % gradient from known (angular) slope,
take Tan of θ X 100 = %
$\therefore$ Tan of θ = 0.075645 X 100
= 7.56%

Having a known overground gradient, it was still necessary to check the percentage grade readouts on the Quinton model 643 motor-driven treadmill. Gradient calibration was done in the following manner:

1) Gradient was raised to 3.8% according to the analogue display.
2) The gradient was then calculated trigonometrically to determine percentage grade (Tan $\theta = \frac{\text{opp}}{\text{adj}}$; Tan θ X 100 = % grade).
3) The treadmill was returned to 0% grade, and the above procedures

(measurements and calculations) were repeated five times to ensure accuracy.

4) The indication point for 3.8% was clearly marked on the analogue display unit.
5) The above procedure was repeated for 7.5% gradient.

Relativising the Intensity of Work

To enable comparisons between subjects, work intensity was relativised so that each subject would be working at approximately 70% of his maximal $\dot{V}O_2$. $\dot{V}O_2$ max differences between individuals would result in different speeds when relative work intensity was held constant. This test session was therefore designed to determine the speed at which each subject would be running while working at 70% of his $\dot{V}O_2$ max at positive gradients of 3.8% and 7.5%.

Justification for the Relative Intensity Selected

A minimum intensity of 70% of max $\dot{V}O_2$ was selected for several reasons. Firstly, the researcher wished to examine ratings of perceived exertion whilst working near the aerobic threshold. The onset of anaerobiosis normally occurs between 55% and 65% of the maximal oxygen uptake in healthy untrained subjects (McArdle *et al.*, 1981), and self regulation of work intensity to 62% of maximal oxygen uptake was found to be perceptually comfortable, while 79% was found to be hard (Carton and Rhodes, 1985). Since the research objectives of this study were to examine physiological and perceptual responses to work at higher intensities than comfortable, the 70% level was adopted. The relative contribution of local and central factors to overall perceived exertion at higher work intensities was also to be evaluated, again necessitating a minimum intensity of 70% of maximal oxygen uptake.

Determining Overground Running Speed

To prescribe an intensity of 70% for the overground run, it was necessary to determine running speed at 70% of $\dot{V}O_2$ max for the two gradients of 3.8% and 7.5%. For this purpose, an accurate and timeous display of relative $\dot{V}O_2$ max whilst running on the treadmill was necessary, in order for the researcher to regulate exercise intensity at the particular grades to the required intensity. The computer-aided, on-line gas-analysis system developed and validated by Goslin *et al.* (1985) provided ongoing feedback as to the relative $\dot{V}O_2$ at which the subject was working.

Prior to this test, the desired work intensity of 70% of $\dot{V}O_2$ max was calculated, and the treadmill was set to 3.8% grade. Running speed achieved at approximately 70% of $\dot{V}O_2$ max during the test of maximal oxygen uptake was determined by consulting the computer printout, and 3 $km.h^{-1}$ was subtracted from this value to determine initial treadmill speed for this test. (Pilot testing had previously revealed that subtracting 3 $km.h^{-1}$ from level running speed at 3.8% grade, and a further 2.5 $km.h^{-1}$ at 7.5% grade, compensated for the increased grade by maintaining a relatively stable exercise intensity.)

With the subject running at 3.8% grade, fine adjustments (if necessary) were made to treadmill speed in order to maintain an exercise intensity of 70% of maximal oxygen uptake. A minimum of ten relative $\dot{V}O_2$ values and corresponding speeds were obtained before adjusting treadmill grade to 7.5% and reducing speed initially by a further 2.5 $km.h^{-1}$. Constant adjustments of treadmill speed were avoided if possible in order to enable the $\dot{V}O_2$ to stabilise.

From the computer printout, running speeds for the overground condition were determined in the following way:

1) For 3.8% grade, the mean of the 5 closest approximations to 70% of the subjects $\dot{V}O_2$ max was determined.
2) The mean of the 5 speeds corresponding to the above $\dot{V}O_2$ values was then calculated.
3) This value was divided by 60 to convert to a running speed in $min.km^{-1}$.
4) The decimal was converted to seconds by multiplying it by 60, giving a running speed in minutes and seconds per kilometre for 3.8% grade.
5) The above procedure was repeated for 7.5% grade.

This enabled the researcher to set each individuals' speed, and thus relative intensity, for kilometres 0-2 (3.8% grade) and 2-4 (7.5% grade) for the overground condition.

The On-line System of Gas-Analysis

Before proceeding with a description of testing in the overground condition, a description of on-line system developed and validated by Goslin *et al.* (1985) is necessary, as the use of this system was vital to this research, particularly in terms of the convenience of setting relative work intensity to determine overground running speed. The following is an extract (with modifications where applicable) from the paper by Goslin *et al.* (1985), pp 54 - 57 .

> The hardware configuration 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 0.3-0.5 cm w.p., depending on the air flow. Expired air was directed, through 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 $\mathrm{ml.min^{-1}}$ for analysis. Upon exit from the flow-through mixing chamber, the air passed through a 1 meter 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 way wide fluctuations in the gas fractions were avoided while ensuring reasonably sensitive responses to real changes in the 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 PC1 medical Ametek Applied Electrochemistry N-22 oxygen sensor and S-3A1 oxygen analyser, and a Gould Godart Capnograph Mark III carbon-dioxide analyser. Analogue signals from the temperature sensor and the two gas analysers were fed into a multiplexor and then into a 12 bit, 8 part 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 (32k core memory). Ongoing visual feedback of oxygen consumption, of $\dot{V}O_2$ max rate of change of oxygen consumption, respiratory exchange ratio, treadmill speed and elapsed time were provided on the computers 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 were printed after each sample: experiment elapsed time, sample duration, $\dot{V}O_2$ max (%), $\dot{V}CO_2$ ($l.min^{-1}$), respiratory exchange ratio, minute volume inspired ($l.min^{-1}$), ventilatory equivalent for oxygen and carbon-dioxide and ventilatory frequency. In addition, the gas fractions of O_2 and appropriate STPD factors were recorded for each sample, as well as 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 0-38 degrees Celsius. Ventilation rates were compared with those obtained by observation techniques.

The system software, written in BASIC, enabled either continuous sampling (Cont 30) or manual (MANUAL) sequence sampling. It not only performed data collection and averaging functions, but also computed many derived variables and output these to both a video terminal and a hard copy printer. The "Cont 30" programme was used for the test of maximal oxygen uptake and the test to determine overground running speed, while the "Manual" programme was used for the treadmill simulation of the overground condition. Examples of printouts produced by the "Cont 30" and "Manual" programmes are presented in Appendix 6.

The Attitude Scale

On arrival at the Work Physiology laboratory, the subjects body mass was measured on a Seca beam balance scale. Following this the subject was asked to complete a "Semantic Differential Attitude

Scale (Osgood *et al*. 1957) (Appendix 3) pertaining to running on the treadmill. (An identical questionnaire, pertaining to running outdoors was completed by the subject prior to testing in the overground condition.)

With the experiment designed to evaluate attitudinal differences to running overground and running in the laboratory, it was important to use the same tool for both concepts. The Semantic Differential was chosen as it is flexible in use, i.e. many different concepts can be measured by it without revising the scale. The scale is also easily administered, and, depending on the adjectives used should be easily understood. Because feelings about any concept are expressed in adjectives, the scale uses responses to bipolar adjectives to measure attitude (Oskamp, 1977).

The subject was presented with an Attitudinal Questionnaire and a pencil. Instructions were given to the subject verbally. Following this, the subject was given the opportunity to read the instructions which appeared on the Questionnaire. The subject was then encouraged to ask questions should anything be unclear, after which he was asked to complete the Questionnaire in his own time.

Ratings of Perceived Exertion

Borg's (1970) category rating scale (Appendix 1) was applied to enable comparison with other studies, and to examine the relationship between RPE and various physiological measures. Recognising that the perception of exertion is affected by a complex interaction of many factors, subjects were asked to differentiate between local, central and overall perceptions of exertion (Pandolf 1978; 1982).

The subjects were given detailed written instructions (Appendix 14) and were asked to read them carefully.

Differential ratings of perceived exertion were obtained at 4 points during the overground run; namely at kilometres 35.2, 36.2, 37.2, and 38.2, i.e. at one kilometre intervals. The ratings were obtained in the following manner: the data-collection vehicle drove on the right hand side of the subject, maintaining a speed consistent with that of the running speed of the subject (the subjects had been instructed to make every attempt to run at his prescribed speed, and not to regulate his speed with that of the vehicle). A collection-assistant then held a large copy of the rating scale out of the window of the vehicle and asked for a local rating of perceived exertion (Figure 3). The subjects' verbal response was confirmed and recorded. This procedure was then repeated for the central and overall ratings of perceived exertion.

Figure 3: Obtaining a Rating of Perceived Exertion during the overground condition.

Equipment for the Overground Condition

The following equipment was transported to the test site in the Datsun E20 minibus which was used for testing: Meterological bags for gas collection X 4, Rubber stoppers with clamps for the above, Two-way valve, Assembled Hans-Rudolph 2700 pulmonary valve, Rubber stopper for the above, Head support for the Hans-Rudolph valve, Collins ridged tubing, Noseclip, Cardionics Cardiometern and conductive strips soaked in 0.09% NaCl solution, Stopwatches X 2, Ratings of perceived exertion instructions and chart, Anemometer, Data sheet and pencil.

The Test Site

The location for overground testing was from kilometres 34.2 to 38.2 on Trunk road 2/15 Komgha river to Grahamstown, Department of roads, Cape Provincial Administration (Appendix 4). The measurements presented in this appendix were checked with a Trumeter measuring device on two separate occasions and were found to be accurate (Figure 4). Actual data collection took place four times during each session, i.e. the 4 km stretch was divided into one kilometre sections for collection purposes. In order to facilitate data collection and speed adjustments, marking points were painted on the road surface at kilometres 34.2, 35, 35.2, 36, 36.2, 37, 37.2, 38 and 38.2. Data collection took place at the following points: 1) 35-35.2 km 2) 36-36.2 km 3) 37-37.2 km 4) 38-38.2km. As stated earlier, the mean gradient for kilometre 0-2 was calculated as 3.8% and for km 2-4 as 7.5%. Thus, although there were four collection

Figure 4: Determining distances for purposes of data collection.

periods to enhance accuracy and reduce error of measurement, the run was to be analysed in two sections as determined by the differences in grade. For purposes of analysis therefore, the data from collection points 1 and 2 were meaned, as were the data from collection points 3 and 4, yielding derived parameters for km 0-2 and km 2-4 respectively.

The Overground Condition

On arrival at the test site, the subject was given a period of five minutes within which to warm up and stretch. It was left to each individual to decide on his warming up procedure. While the subject warmed up, the tester measured wind speed ($m.s^{-1}$) and direction with a hand anemometer. The mean of readings at 15 s, 30 s and 60 s was recorded as the wind speed. Following the warm-up, elasticised conductive strips were attached to the Cardionics Cardiometern lead and placed around the chest at the level of the xiphoid process, and pre-test heart rate was obtained. The subject was then instructed as to what his predetermined pace (as determined by speed matching) should be for both the first two kilometres and the second two kilometres. After trying on (and adjusting if necessary) the Head support with the attached Hans-Rudolph 2700 pulmonary valve and mouthpiece, a stationary drill of collection procedures was conducted, and the subject was given the opportunity to ask any questions. On a signal from the tester, the stopwatches were started and the subject began running. The vehicle then moved off to the first collection point.

The vehicle was parked exactly 300 m before each kilometre point, and as the runner approached, the driver attempted to match the speed of the vehicle with that of the runner. The runner then passed the Cardiometern lead (which had been carried in his right hand) to an assistant sitting in the front of the vehicle, who immediately plugged the lead into the Cardiometern (Figure 5). The tester in the back section of the bus then passed the headgear back to the runner, who donned the headgear, inserted the mouthpiece and applied a noseclip handed to him by the tester. At a marked point 200 m before the kilometre mark, the tester opened the two-way tap attached to the Hans-Rudolph valve (Figure 6) in order to allow the subject's expired air to flow through the length of Collins ridged tubing and into the meterological bag inside the bus (Figures 7 and 8). Expired air was collected for 60 s. Once the tester had inserted a plug into the numbered meterological bag to prevent leakage, the subject removed his noseclip and handed the headgear to the tester. Heart rate was recorded halfway during the period of gas collection, i.e. after 30 s. Once the Cardiometern lead had been returned to the subject, he was asked to rate local, central and overall perception of exertion. (see earlier). Following this the subject was informed as to how his pace corresponded to the predetermined pace, and whether he should speed up or slow down. In order to prevent large fluctuations in physiological functions, it was considered unwise to make drastic adjustments to the subjects running speed. The above procedure was repeated at each of the four collection points, after which the vehicle returned to the laboratory so that the expired air could be analysed.

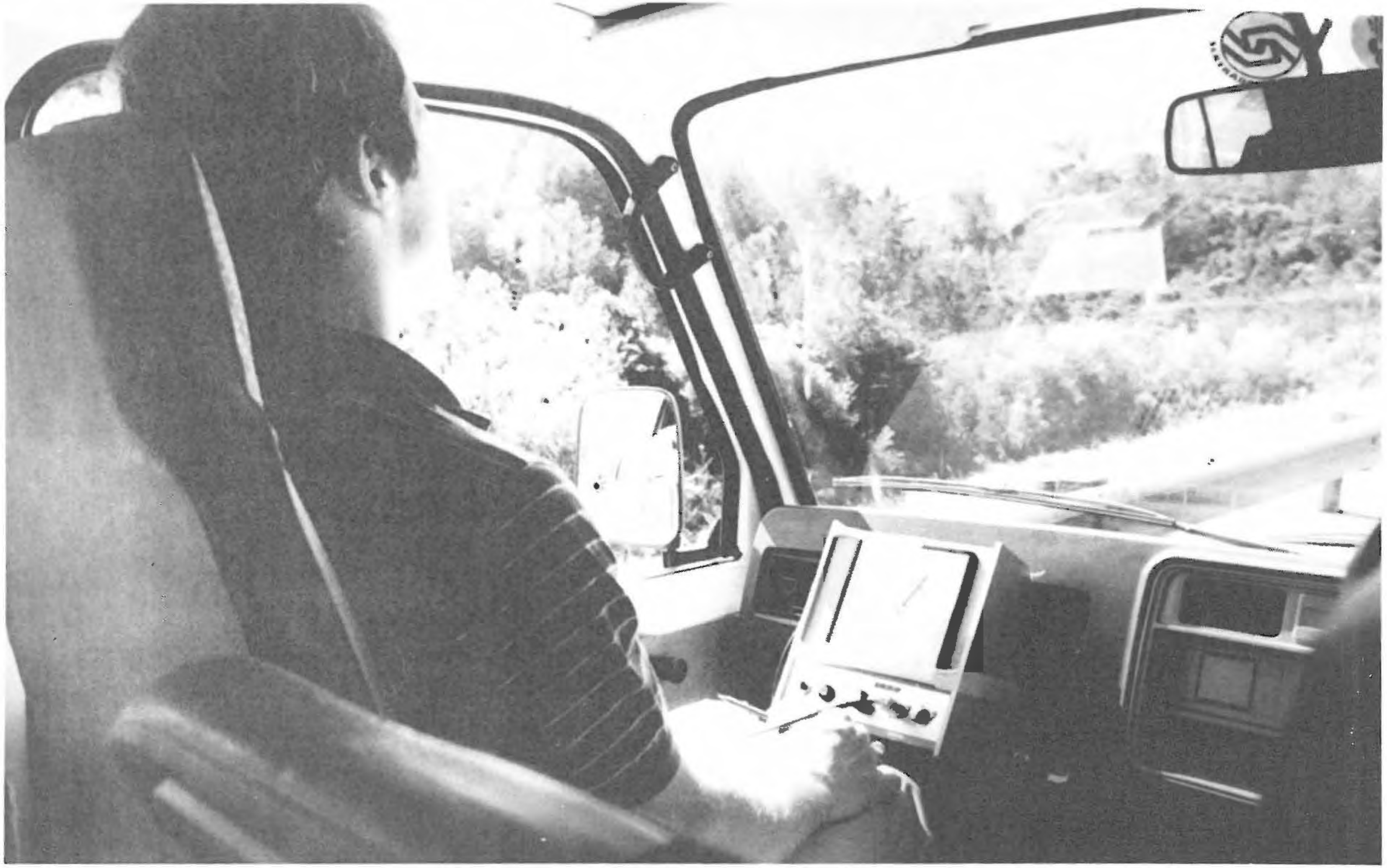

Figure 5: Obtaining a measure of heart rate during the overground condition.

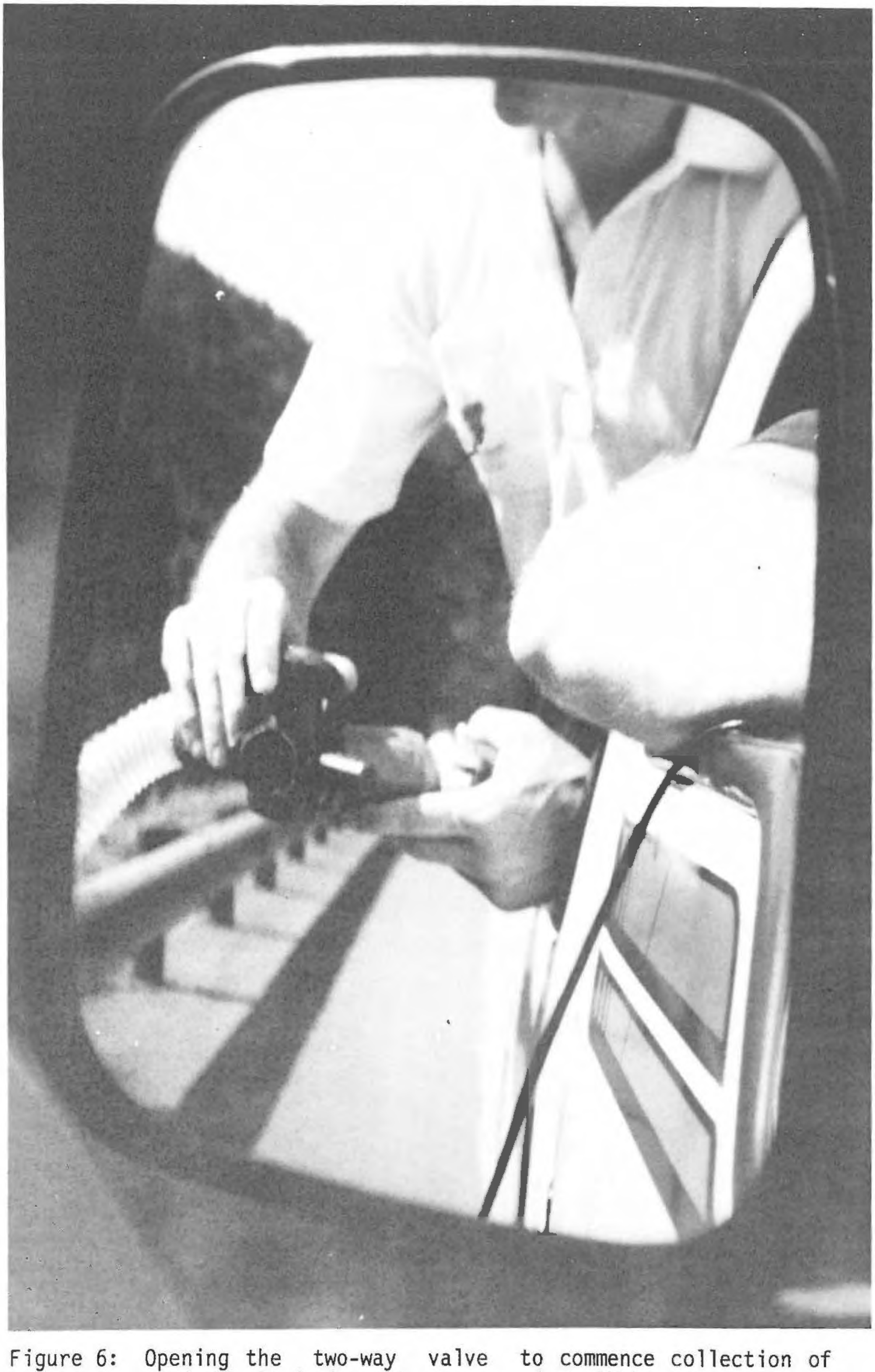

Figure 6: Opening the two-way valve to commence collection of expired air during the overground condition.

Figure 7: Collection of expired air for gas-analysis during the overground condition.

Figure 8: Collection of expired air for gas analysis during the overground condition.

Upon arrival in the laboratory, analysis was performed as soon as possible to obviate diffusion of the gas. Fractions of expired oxygen and carbon dioxide were obtained using the analysers of the "on-line" system described earlier and the volume of each meterological bag was measured using a Singer gasmeter. The following derived data were then calculated: Relative $\dot{V}O_2$ (ml.kg^{-1}.min^{-1}), $\dot{V}CO_2$ (l.min^{-1}), $\dot{V}E$ (l.min^{-1}) and the respiratory quotient (for calculations, see Appendix 7). The subject's running speed (km.h^{-1}) for each 2 km section was also calculated.

The Treadmill Condition

Each subject reported to the laboratory where body mass was measured on a Seca beam balance scale. Following this, the subject completed the attitudinal questionnaire pertaining to running on the treadmill (Appendix 3). Barometric pressure (mmHg), ambient temperature (°C) and relative humidity were then recorded. Following this, the on-line system was activated according to the methods prescribed by Williams (1986). The system software used was the "MANUAL" programme.

Subjects were enjoined to attempt to replicate their overground warm-up routine, after which they were given the opportunity to re-read the ratings of perceived exertion instructions and to ask questions. The Cardiometern lead and conductive strips were then placed on the subject in the same manner as for the overground run. The treadmill speed was set to the exact running speed of the subject's first 2 km of the overground run, and the grade was initially set to 3.8%.

When the run commenced, the stopwatch was started. Gas collection times had been determined by using elapsed time at each kilometre point of the overground run. Time of collection was thus consistent for both conditions. One minute prior to gas collection, the subject inserted the mouthpiece and applied a noseclip (this served to expel ambient air from the "on-line" system). At collection time, the MANUAL programme was activated and gas analysis proceeded (Figures 9 and 10) as described by Goslin *et al.* (1985). Halfway through this analysis, heart rate (as measured by the Cardionics Cardiometern) was recorded. On completion of the 60 s period of gas-analysis the subject came off the mouthpiece and removed the noseclip, and local, central and overall ratings of perceived exertion were obtained (Figure 11) in exactly the same manner as in the overground condition. The procedure outlined above was repeated four times, each at the same elapsed time at which overground collection procedures were performed for that particular subject.

At the elapsed time corresponding to the subject's overground 2 km point, the treadmill grade was increased to 7.5% and speed adjusted to correspond to the subject's overground speed for kilometres 36.2 - 38.2. On completion of the fourth collection period, the test was terminated and the computer print-out was retrieved (Appendix 6).

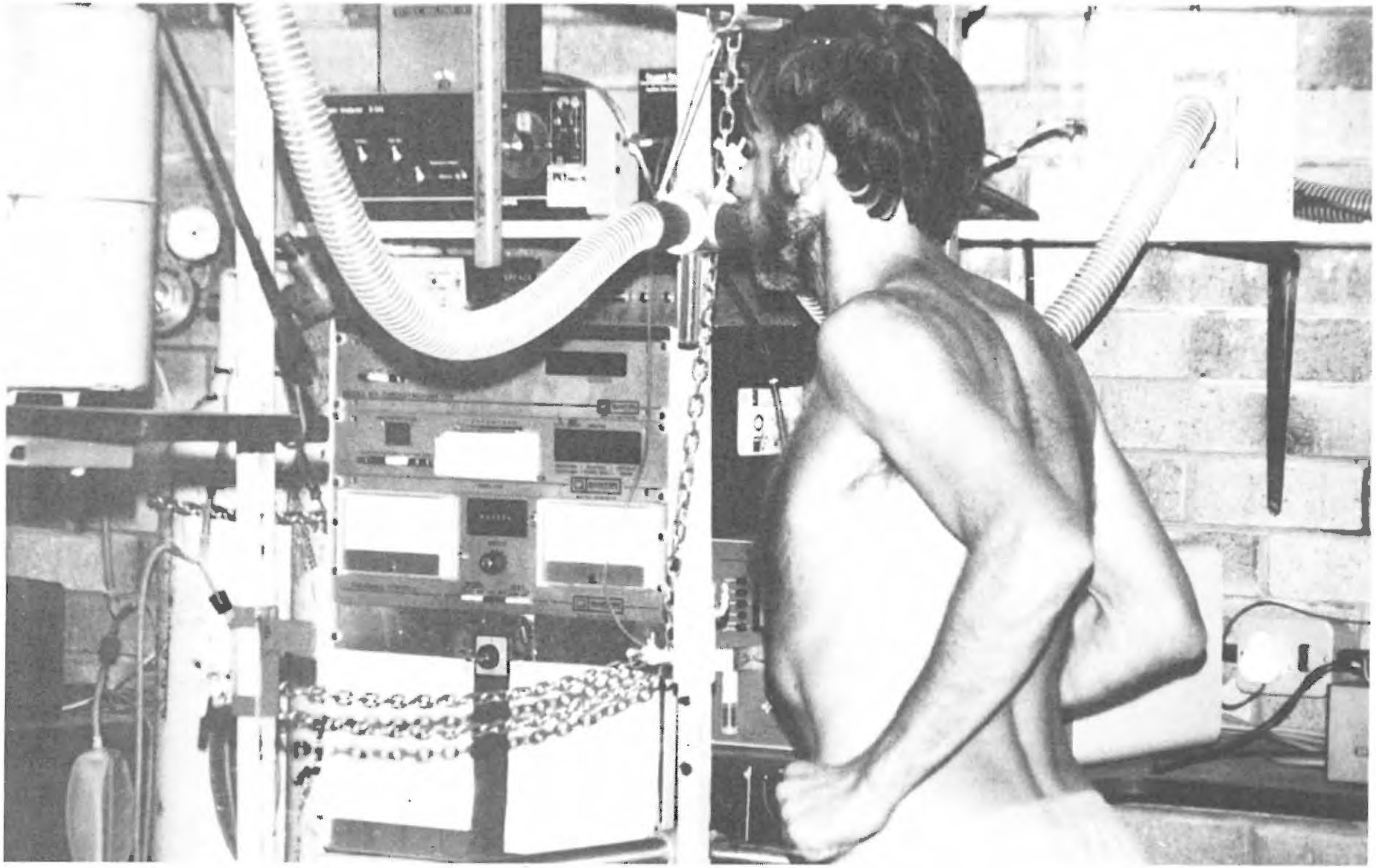

Figure 9: Gas-analysis via the "on-line" system during the treadmill condition.

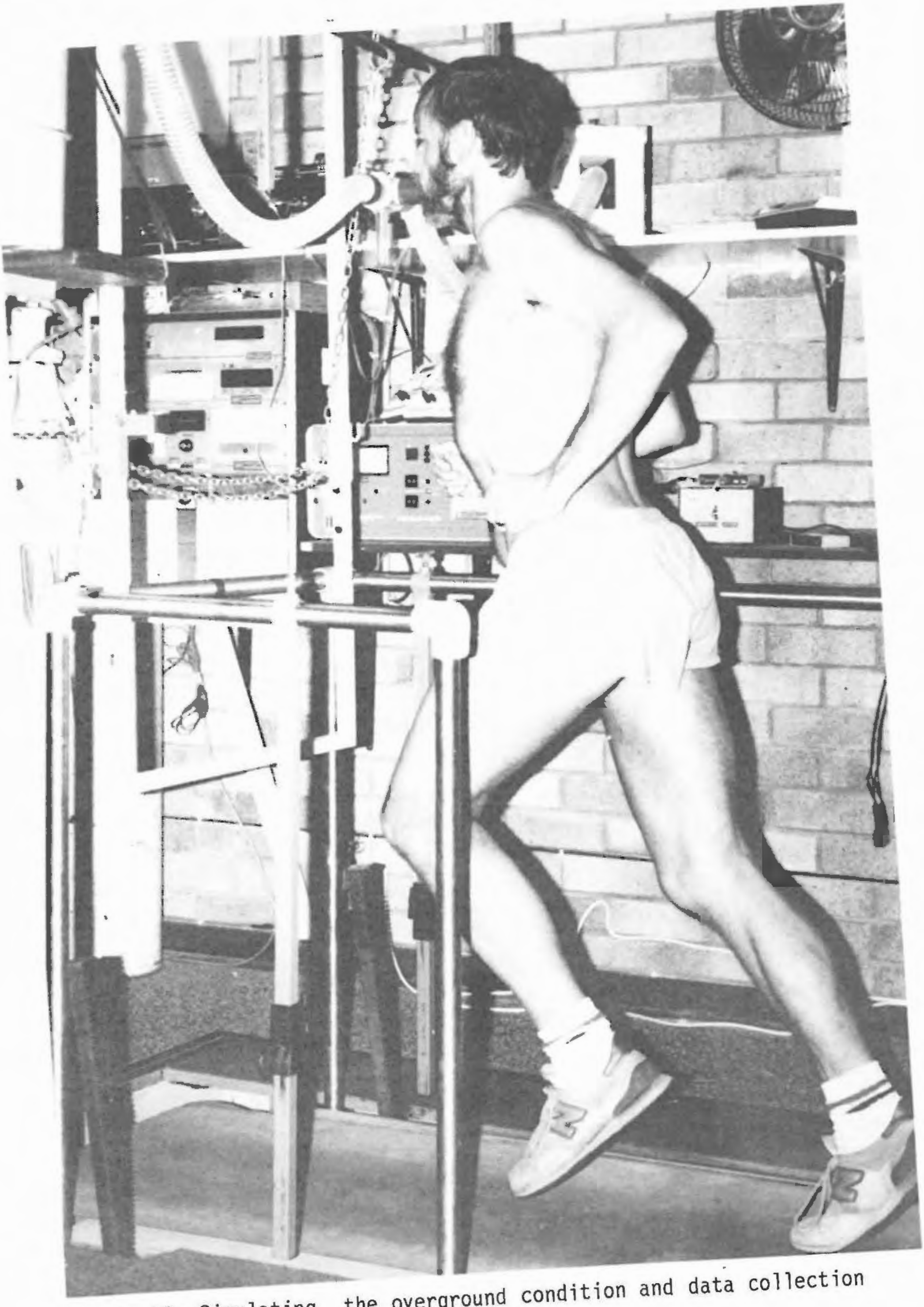

Figure 10: Simulating the overground condition and data collection procedures.

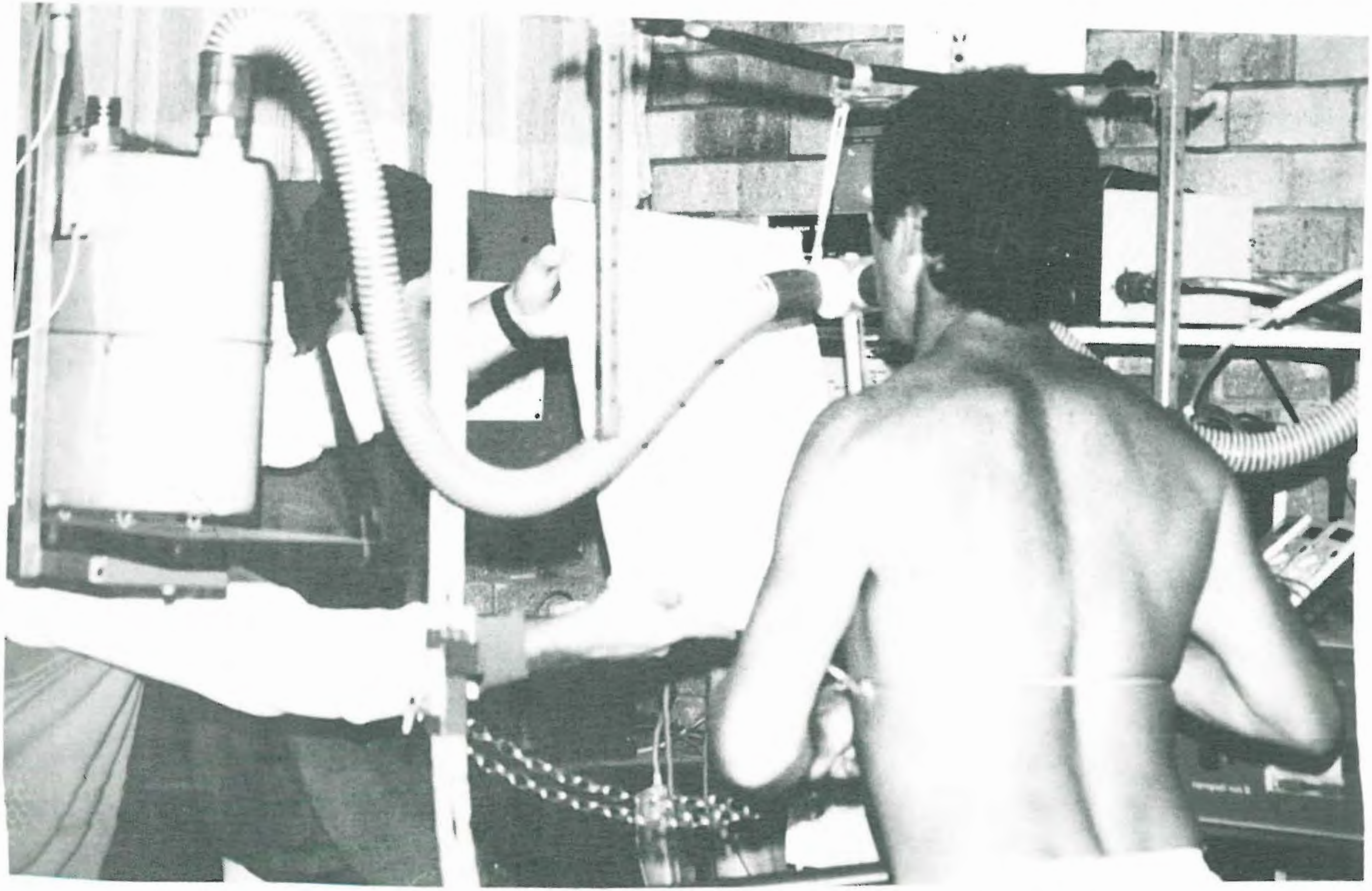

Figure 11: Obtaining a Rating of Perceived Exertion during the treadmill condition.

STATISTICAL ANALYSIS

Confidence Level

Franks and Huck (1986) state that while there will be valid differences of opinion concerning the appropriate significance level for any one study, the often unthinking, automatic selection and acceptance of the 0.05 level cannot be justified. They suggest that significance level should be decided based on the sample size, variability of variables, desired effect size and the relative importance of Type I and Type II errors.

Bearing the above in mind, the 0.05 level of probability was employed throughout the statistical treatments in this study to test the significance of differences and interactions. Therefore there were still 5 chances out of a 100 that a Type I error could have been committed (rejecting a true hypothesis). The chances of committing a Type II error (failing to reject a false hypothesis) are dependent on subject numbers. While the probability of committing a Type II error is lower at the 0.05 level than at a higher level of probability, the reasonably small number of observations in this study leaves this probability at a moderately high level. Time demands placed on subjects however kept subject numbers low. Thus, considering the limitations related to subject availability, and in order to optimise the balance between the possibility of committing Type I and Type II errors, the 0.05 level of probality was used.

Two-factor analyses of variance with repeated measurements on both factors (Ferguson, 1981) were computed to determine whether there were differences and interactions between overground and laboratory values for the following parameters: Differentiated ratings of perceived exertion, Heart rate, $\dot{V}O_2$, $\dot{V}E$, R and $\dot{V}CO_2$.

Related "Student's" t-tests (Ferguson, 1981) were computed to determine whether there were attitudinal differences towards the overground and laboratory conditions, and to determine whether environmental conditions differed significantly between the two situations.

Single variable statistics (mean, median, and standard deviation) were computed for each of the 12 overground condition attitude scales, and for each of the 12 laboratory condition attitude scales.

One-independent variable regression analyses were then computed to examine possible correlations between:

a) Differentiated ratings of perceived exertion and physiological measures in the overground condition.
b) Differentiated ratings of perceived exertion and physiological measures in the laboratory condition.
c) Overground and laboratory measures of perceived exertion, and physiological functions for these conditions.

CHAPTER FOUR

RESULTS AND DISCUSSION

PILOT TEST RESULTS

The pilot tests were conducted to evaluate primarily the reliability of the test protocols employed in this study. Procedures adopted have been described in detail in Chapter Three.

Related "Student's" t-tests (Ferguson, 1981) were computed to determine whether significant differences ($p < 0.05$) existed between measures *within* the overground and laboratory conditions on a test - retest basis. There were no differences for predicted speed, actual speed, physiological measures, anthropometric measures, ratings of perceived exertion, attitude scores and environmental conditions, with the following exceptions: between heart rates for the two overground conditions; and between local RPE's, $\dot{V}E$ values and R values for the two laboratory conditions (Appendix 8). Although the heart rate difference within the overground conditions was significant, it was only about 7 $b.min^{-1}$. The differences in local RPE and $\dot{V}E$ within the laboratory conditions may have been related, and could also have been the result of the ambience of the laboratory situation. These suppositions will be discussed in detail later in this chapter.

Two-factor analyses of variance (Ferguson, 1981) were then computed to evaluate performance and physiological differences ($p < 0.05$) between the overground and laboratory conditions. It was determined (Appendix 8) that there were no differences and no interactions between any of the performance and physiological variables for the two conditions. Further related t-tests then indicated that there were no differences between overground and laboratory environmental conditions, and that attitude scores were reliable for each condition on test - retest basis. These pilot results were of critical importance to the study, for if differences between conditions had been found, the validity of the research results would be open to question.

SUBJECT CHARACTERISTICS

Table I illustrates that the young male subjects (mean age 26.55 years) were in extremely good physical condition (mean $\dot{V}O_2$ max - 66.6ml.kg^{-1}.min^{-1}; mean relative body fat - 12.48%). The physical working capacities of the subject group were higher than those reported by most other studies in this area of research, and consequently the present investigation was able to offer insights into RPE for a specific population group, namely that of highly trained individuals. In view of this, and the intensity at which subjects worked, the present study examined RPE in areas that have,

Table I: Performance and anthropometric characteristics of the eleven male subjects.

Parameter	Mean	Standard deviation
Age (years)	26.55	6.47
$\dot{V}O_2$ max ($ml.kg^{-1}.min^{-1}$)	66.60	6.79
70% of $\dot{V}O_2$ max ($ml.kg^{-1}.min^{-1}$)	46.62	4.75
Triceps skinfold (mm)	7.46	1.68
Biceps skinfold (mm)	3.79	0.76
Subscapular skinfold (mm)	9.58	1.90
Sum of 4 skinfolds (mm)	6.28	1.58
Relative Body Fat (%)	12.48	2.14
Absolute Body Fat (kg)	9.18	1.92
Lean Body Mass (kg)	64.2	6.19
Body Mass (kg)	73.37	7.13

to date, been relatively neglected by researchers.

DIFFERENCES BETWEEN THE OVERGROUND AND TREADMILL CONDITIONS

Environmental Conditions

Table II shows that there were no temperature, barometric pressure or relative humidity differences between the overground and treadmill conditions. A mean wind speed of 3.26 $m.s^{-1}$ was however observed in the field, but, as a result of the geological formation surrounding the test site, the wind direction was seldom constant. Thus, with the exception of wind speed (the effects of which were probably minimal and were difficult to quantify), the environmental conditions were similar for both tests. Physiological, perceptual and attitudinal differences can therefore not be accounted for by environmental factors.

Table II: Environmental conditions for the field and laboratory work tasks (* represents a significant difference).

Variable	Field	Lab	Significance ($p < 0.05$)
Temperature (°C)	17.18	16.91	
Barometric Pressure (mmHg)	717.22	720.18	
Relative Humidity (%)	75.64	75.18	
Wind Speed ($m.s^{-1}$)	3.26	---	

Working Conditions

Chapter Three described how the grade of the laboratory run was set to replicate that of the overground condition. The elapsed time (and consequently running speed) of the laboratory session was precisely matched to that of the overground condition. The performance variables for the two conditions were thus equated, and differences between physiological, perceptual and attitudinal measures for the two conditions were unlikely to have been due to performance differences.

Heart Rate

Several studies have suggested a strong link between heart rate and perceived exertion (Pandolf, 1978; Carton and Rhodes, 1985) under certain conditions. The present study found low-moderate correlations ($r = 0.5$ to 0.65) between differentiated RPE and heart rate for the field condition (Table III). In the laboratory however, the correlations were effectively non-existent ($r = -0.14$ to 0.49) (Table III). This indicates that pertubation of either heart rate or effort sense occurred in the laboratory situation. It is however difficult to speculate on the interactive effects of the two measures, as correlations do not imply causality. It is prudent to note that while heart rate and RPE are probably indirectly related through their common dependence on physical strain (Carton and Rhodes, 1985), the relationship cannot yet be satisfactorily explained in cause and effect terms. This is evident from the fact that for both conditions, correlations between local RPE and heart rate were substantially higher than for central RPE and heart

Table III: Correlation coefficients *within* the field and laboratory conditions, between RPE measures, between physiological variables and between differentiated RPE measures and physiological variables.

Variables	Field r	Lab r
Local/Central	0.78	0.55
Local/Overall	0.96	0.94
Local/Heart Rate	0.65	0.49
Local/$\dot{V}O_2$	0.83	0.61
Local/$\dot{V}E$	0.70	0.62
Central/Overall	0.90	0.76
Central/Heart Rate	0.50	-0.14
Central/$\dot{V}O_2$	0.55	0.23
Central/$\dot{V}E$	0.45	0.32
Overall/Heart Rate	0.59	0.29
Overall/$\dot{V}O_2$	0.74	0.49
Overall/$\dot{V}E$	0.66	0.54
Heart Rate/$\dot{V}O_2$	0.72	0.65
Heart Rate/$\dot{V}E$	0.68	0.62
$\dot{V}O_2$/$\dot{V}E$	0.76	0.82

rate. This is contrary to theoretical expectations, and serves to further refute the notion of causality between the two variables.

The high correlation between heart rate and RPE reported by Borg (1970) involved a work task where intensity increased progressively. The moderate correlations found in the present research (Table III) are similar to those reported by Mihevic (1981), who states that the relationship between the two variables is much less substantial for a single exercise intensity. This is supported by the results of the present research, where a relatively constant intensity was maintained. The results of the present research thus support the results of similar studies reviewed.

That the attempt to replicate field exercise intensity in the laboratory in terms of heart rate was successful is evident in Figure 12. As expected, Table IV also shows a very high correlation ($r = 0.93$) between heart rates for the two conditions. It is therefore unlikely that any perceptual differences were due to heart rates.

Borg (1970) maintained that exercise intensity expressed by means of heart rate could be predicted by utilising the formula HR = RPE X 10. Table V and Figure 13 illustrate that this formula connot reliably be applied to the results of the present research, for neither the field or laboratory conditions, nor the overall RPE or differentiated ratings. The failure of the formula in respect of the present research further refutes the notion of causality between the two variables and indicates that RPE is probably not primarily mediated by heart rate. Several researchers have previously reached similar conclusions, and it has been noted that factors such as type of work (Pandolf, 1978), motivation, disease, drugs and heat (Rejeski, 1981) can affect the linearity of the relationship. The above results then support the conclusion that heart rate, *per se*, exerts little influence on RPE and is not a primary factor fundamental to effort sensation. Some factor(s) other than heart rate (such as metabolic demand and strain on the local musculature) must then be operating as a basis for perceptual differences (Noble *et al.*, 1973b). Other researchers (Mihevic, 1981; Robertson, 1982) agree that heart rate, *per se*, is not a dominant factor in an individual's subjective rating of exercise stress, and it has been suggested that other haemodynamic mechanisms may provide more potent signals of exertion (Robertson, 1982).

This study then found that while modest correlations did exist between heart rate and RPE at 70% of $\dot{V}O_2$ max exercise intensity, the correlations were higher in the field condition. The lower correlations obtained in the laboratory were possibly the result of perturbation due to the less familiar indoor environment. The results also provide support for the notion that the heart rate - RPE relationship cannot be explained in terms of cause and effect. Finally, as there were no significant differences between heart rates in the field and in the laboratory, (Table VI)it is unlikely that any observed differences were mediated by heart rate. Clearly therefore, heart rate is not a major factor influencing the subjective report of exertion.

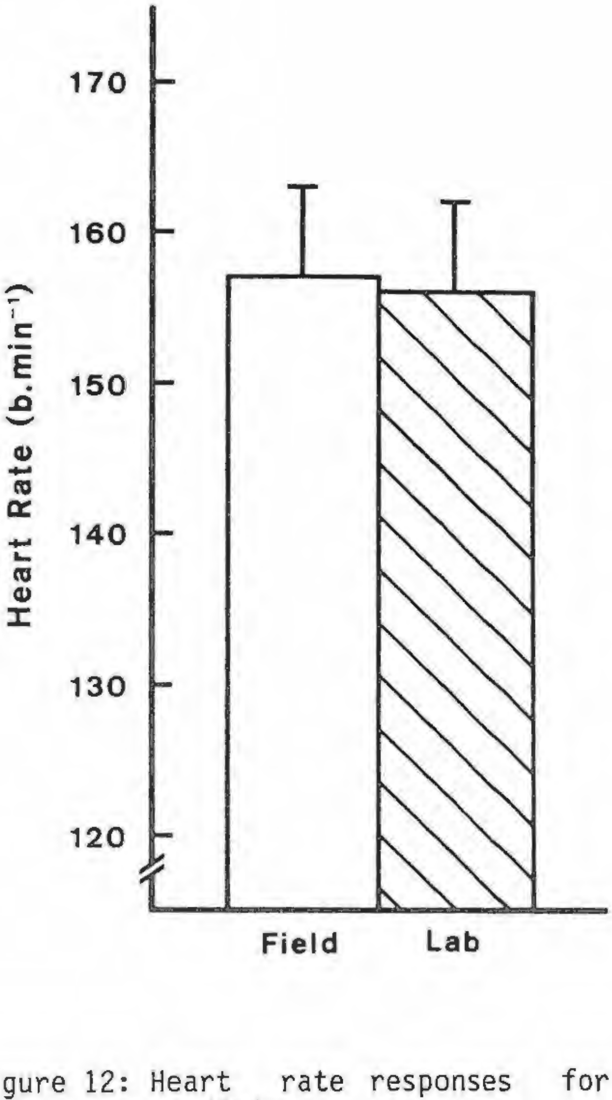

Figure 12: Heart rate responses for the field and laboratory conditions.

Table IV: Correlation coefficients *between* the field and laboratory conditions, between differentiated RPE measures and between physiological variables.

Variable	
Local RPE	0.75
Central RPE	0.63
Overall RPE	0.70
Heart Rate	0.93
$\dot{V}O_2$	0.91
$\dot{V}E$	0.96
R	0.31
$\dot{V}CO_2$	0.93

Table V: Predicted heart rates and actual heart rates (   ) for the field and laboratory conditions, obtained using the Borg (1970) formula.

Variable	Field HR ($b.min^{-1}$)	Laboratory HR ($b.min^{-1}$)
Local RPE	110.7 (157)	119.6 (156.43)
Central RPE	108.6 (157)	113.6 (156.43)
Overall RPE	108.9 (157)	118.2 (156.43)

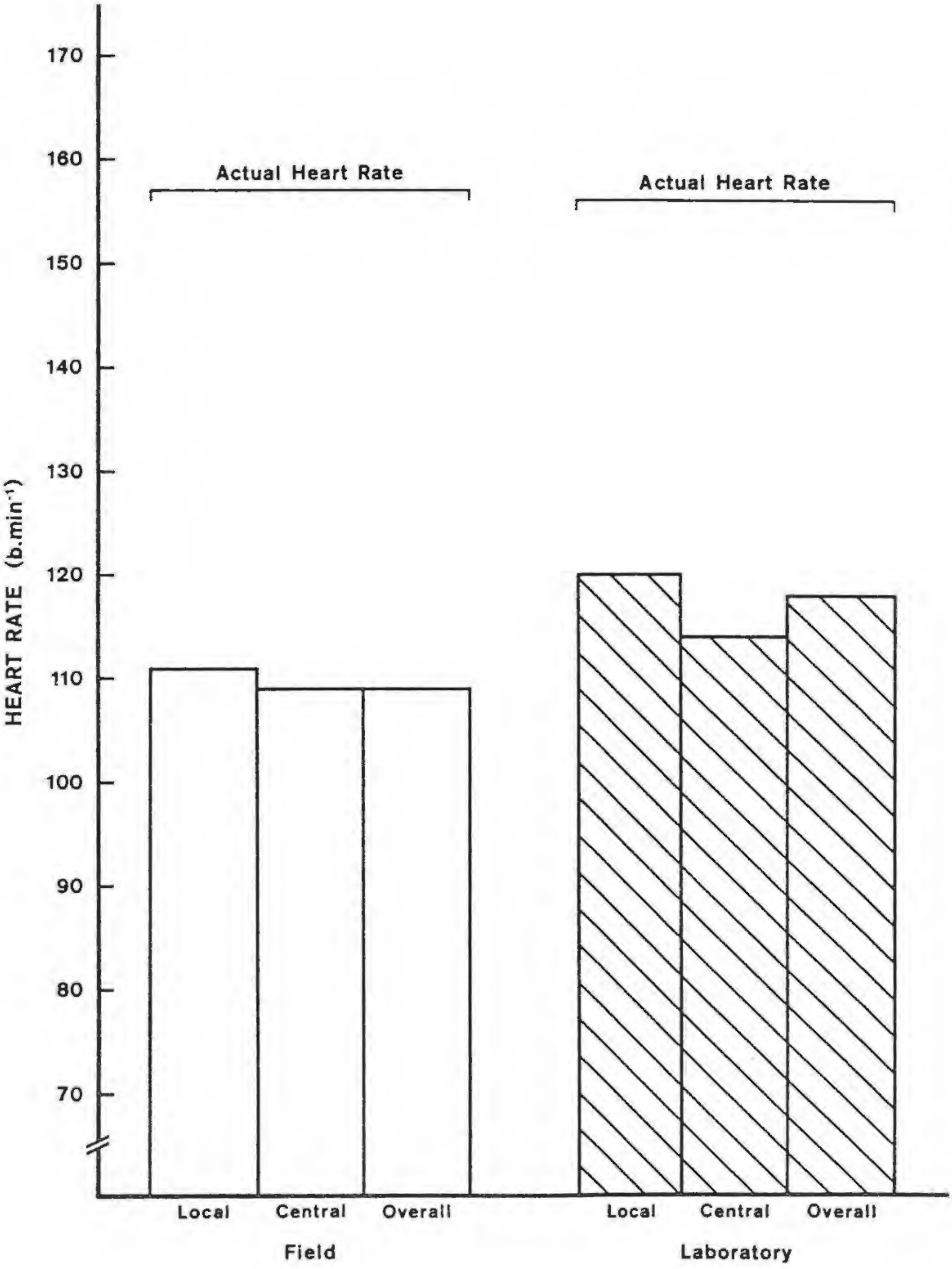

Figure 13: Heart rate predictions from differentiated RPE for the field and laboratory conditions, as compared to actual heart rates achieved.

Table VI : Perceptual, physiological and attitudinal responses to the field and laboratory work tasks (* represents a significant difference).

Variable	Field Response	Labarotory Response	Significance ($p < 0.05$)
Local RPE	11.07	11.96	*
Central RPE	10.86	11.36	
Overall RPE	10.89	11.82	*
Heart Rate ($b.min^{-1}$)	157.00	156.43	
$\dot{V}O_2$ ($ml.kg.min^{-1}$)	47.59	48.45	
$\dot{V}E$ ($l.min^{-1}$)	69.05	75.13	*
R	0.91	0.93	
$\dot{V}CO_2$ ($l.min^{-1}$)	3.81	3.35	*
Factor E	26.55	16.73	*
Factor P	16.64	13.91	
Factor A	18.27	16.18	*
Total SD Score	61.46	46.82	*

Metabolic Demand

As was the case for heart rate, there was no difference between oxygen consumption in the field and in the laboratory (Table VI, Figure 14). The metabolic demands of the exercise tasks were thus equivalent, and Figure 15 shows that in the field subjects worked at 71.46% if their maximal oxygen uptake, while in the laboratory they worked at 72.75% of their maximal capacity. As expected, there was an extremely high correlation ($r = 0.97$) between $\dot{V}O_2$'s for the two conditions (Table IV).

$\dot{V}O_2$ has long been associated with providing central signals of exertion during dynamic exercise, and correlation coefficients of between 0.76 and 0.97 have been reported for the $\dot{V}O_2$/RPE relationship (Pandolf, 1978). Table III reveals that while correlation coefficients between the two variables were relatively high ($r = 0.55$ to 0.83) for the field condition, this was not the case in the laboratory ($r = 0.23$ to 0.61). Contrary to expectations, in both cases central RPE and $\dot{V}O_2$ had the lowest correlation, whilst local RPE and $\dot{V}O_2$ showed the highest correlation. Clearly some factor(s) pertaining only to the laboratory situation resulted in the lower correlation between the variables in that condition. As there is no evidence that $\dot{V}O_2$ is consciously monitored by the individual during exercise (Mihevic, 1981), it is difficult to speculate about the mechanisms that regulate the transmission and intensity of this sensory signal.

In order to examine the origins of $\dot{V}O_2$ as a sensory signal, a number

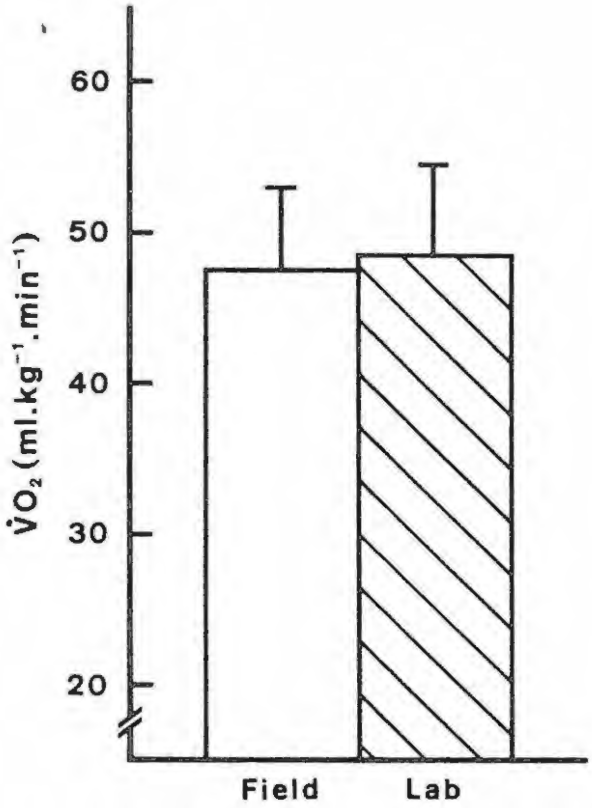

Figure 14: $\dot{V}O_2$ responses for the field and laboratory conditions.

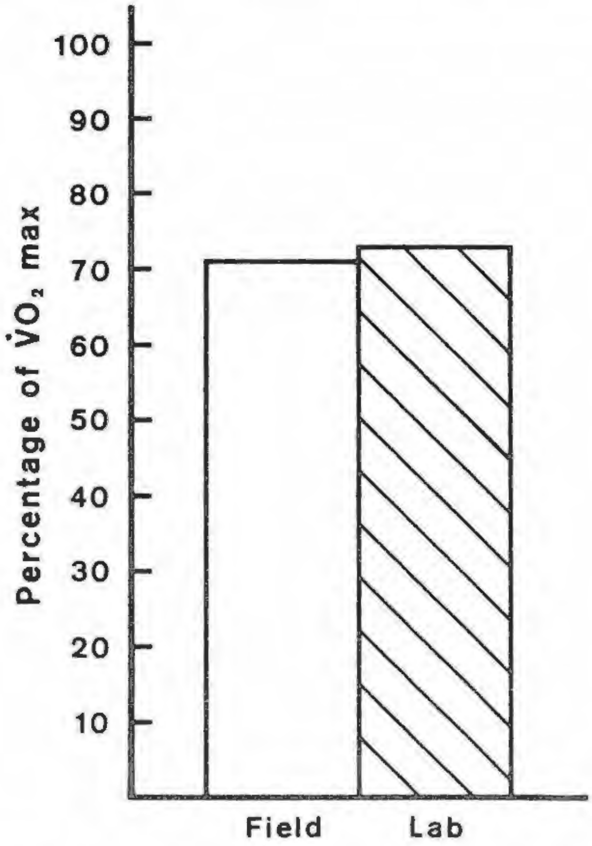

Figure 15: $\dot{V}O_2$ responses for the field and laboratory conditions, expressed as a percentage of $\dot{V}O_2$ max.

of studies have examined perceptual differences in terms of absolute and relative oxygen requirements. The results of several investigations have indicated that perceptual differences are frequently eliminated when relative exercise intensities (% $\dot{V}O_2$ max) are employed (Skinner *et al.*, 1973; Mihevic, 1981; Robertson, 1982). Other reports have however indicated that the relationship between RPE and $\dot{V}O_2$ may be spurious, and that the functional relationship between RPE and relative exercise intensity may be subject to distortion (Rejeski, 1981; Carton and Rhodes, 1985). Despite this, Skinner *et al.* (1973) concluded that RPE is most closely related to the proportion of maximal capacity required for a given task. Therefore, although $\dot{V}O_2$ may not be directly related to perception of effort, perceptual differences are small when work is relativised.

Bearing the above in mind, the work tasks performed by the subjects in the present research were relativised in order to minimise perceptual differences. In this way it was hoped that consistent and meaningful subjective sensations of effort would be obtained. The experimental procedures adopted were aimed at eliciting a metabolic demand of 70% for both conditions in order to evaluate perceptual responses to work in the field and the laboratory. Figure 15 indicates that the procedures were successful. It has already been noted that there were no differences in metabolic demand between the two conditions. As with heart rate, and particularly in this case as intensities were relativised, the sensory signal associated with oxygen consumption was unlikely to have been the main driving factor responsible for perceptual differences between the overground and treadmill conditions.

The results of the present investigation thus support the contention that oxygen uptake, *per se*, is not the major factor in the signalling of effort during physical work. It must be noted that while it is reasonable that perception of effort may be comparable across conditions at similar metabolic demands, relative exercise intensities based on $\dot{V}O_2$ max do not necessarily equate other physiological responses such as lactate production and ventilatory hyperpnea, which are modified by fitness and may also have an impact on perceived exertion at moderate to high exercise intensities. The results of the present research support the notion that the impact of relative aerobic power is mediated by other, more readily monitored responses. As factors such as $\dot{V}E$ and blood lactate are linked to relative metabolic demand, it is likely that $\dot{V}O_2$ is indirectly, rather than directly, related to effort perception.

Ventilatory Responses

Morgan (1981) has suggested that ventilation covaries in a direct manner with RPE, and he proposed that as ventilatory distress is readily perceived, it is quite likely that it serves as a primary cue in the perception of work cost. Several other studies (Robertson, 1982; Carton and Rhodes, 1985; Messier *et al.*, 1986) support the role of minute ventilation as a sensory cue which has an impact on effort perception.

Figure 16 and Table VI indicate that there was a significant

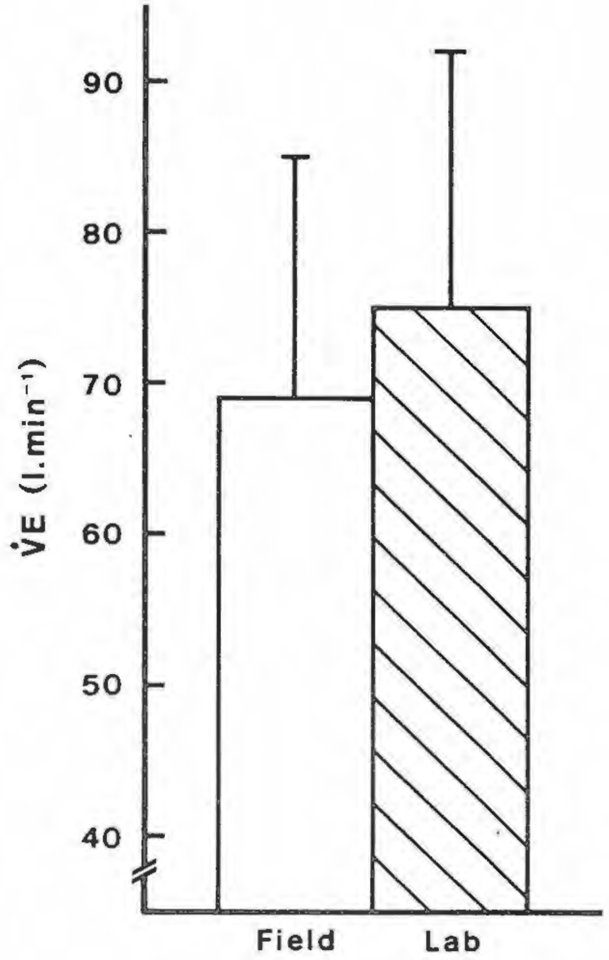

Figure 16: V̇E responses for the field and laboratory conditions.

difference between field and laboratory VE. This was contrary to protocol expectations, as the intention was to equate all physiological measures between the two conditions. It has already been noted that work intensity, expressed in terms of heart rate and oxygen consumption, was the same for the overground and treadmill situations. The fact that $\dot{V}E$ values were significantly different does not however mean that the experimental methods were unsuccessful. On the contrary, the results reinforce previously suggested links between minute ventilation, cognition and perception.

Firstly, ventilatory responses could have been associated with cognitive processes. Morgan *et al.* (1976) showed that thinking that work is more difficult than it actually is can result in elevated ratings of perceived exertion, and the authors associated the alterations in subjective reactions with alterations in ventilatory responses. Thus cognitive factors linked with ventilatory alterations can influence ratings of perceived exertion. Although the role of cognition will be discussed later, it is important to note here that the above statement has important implications for the present research. If the subjects' cognitive appraisal of the exercise situation led them to believe that a work task was more difficult than it actually was, both RPE and VE could be elevated. It has already been noted that $\dot{V}E$ was significantly elevated (+ 6.08 l.min^{-1}) for the laboratory condition. Can this elevation be attributed to cognition? In reply to the question "Which of the two exercise tasks was the more stressful?", each of the eleven subjects reported that they thought the laboratory condition to be the more stressful. It would be presumptuous to assume that the simple question posed comprehensively assessed the subjects cognitive appraisal of the situations, but the results suggest that there may have been some link, however tenuous, between cognition and elevated minute ventilation.

Secondly, it is important to note that along with elevated $\dot{V}E$ for the laboratory work task, there were concomitant RPE increases for this condition. Of these increases, only those for local and overall RPE were significant. Thus, although $\dot{V}E$ is classed as a central signal contributing to effort perception, in this case there was a stronger link between $\dot{V}E$ and local and overall RPE. This is borne out by the correlation coefficients presented in Table III which indicate that local RPE is most closely associated with $\dot{V}E$, followed in turn by overall and central RPE. A possible explanation for this is that local RPE dominated the sensation of effort to such a degree that the existence of $\dot{V}E$ as a central signal was obscured. It must also be remembered that correlation does not necessarily imply causation, and therefore the importance of $\dot{V}E$ as a central signal of exertion is not compromised. It is also worth noting that the $\dot{V}E$/RPE correlations were higher for the field condition than for the laboratory condition (Table III). Some factor(s) in the laboratory situation must then have contributed to the perturbation of the $\dot{V}E$/RPE relationship.

Rejeski (1981) reported that to significantly affect RPE, ventilatory volume had to change at least 30 l.min^{-1}. This has been supported by other researchers such as Mihevic (1981), who suggested that the role of ventilation as a perceptual cue is minimised at low-moderate exercise intensities. Robertson (1982) has also stated that conscious monitoring of ventilatory discomfort may only become significant during higher respiratory rates. Furthermore, in attempting to identify the relative intensity at which $\dot{V}E$ contributes significantly to effort perception, he found that the point of onset of the central ventilatory signal falls between 45 - 70% of $\dot{V}O_2$ max.

Assuming that the elevated RPE values for the laboratory condition were due at least in part to elevated $\dot{V}E$ measures, the results of the present study suggest that $\dot{V}E$ may have an even greater impact on RPE than as proposed by the above investigations. With only a 6.08 $l.min^{-1}$ increase in $\dot{V}E$, significant RPE elevations were observed (Table VI, Figure 17). Furthermore, as work intensity for both tasks exceeded 70% of $\dot{V}O_2$ max, it can readily be assumed that afferent impulses from the respiratory apparatus were consciously monitored by the exercising subject. Caution must however be exercised before concluding that $\dot{V}E$ was the major factor contributing to increased perceptions of effort. $\dot{V}E$ is generally regarded as a central signal for perceived exertion, but the results of the present study indicate that local RPE may have influenced the sensations of effort to the extent that they dominated the input of central signals towards the overall RPE.

The present study then noted increased $\dot{V}E$ for the laboratory conditions with concomitant increases in RPE, the increases in local and overall RPE being significant. It is possible that the increases in ventilation could have been due to cognitive appraisal of the ambience of the laboratory. Furthermore, the work tasks were of a sufficient intensity to enable subjects to consciously monitor ventilatory stress. Finally, accepting that minute ventilation has an impact on the perception of effort, and notwithstanding the influence of local RPE on the overall RPE, it is likely that $\dot{V}E$ contributed to the observed elevations in RPE.

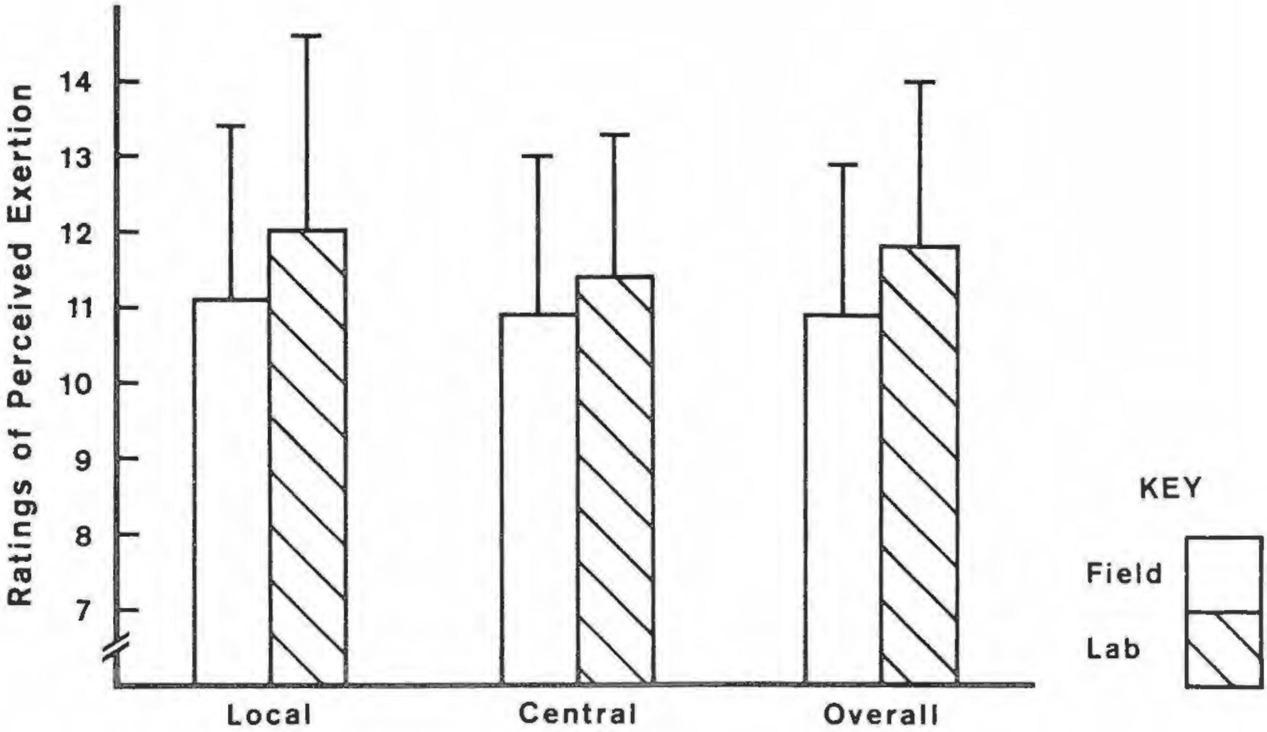

Figure 17: Differentiated RPE responses for the field and laboratory conditions.

Ratings of Perceived Exertion

The main objective of the present study was to identify several physiological cues which could have affected the perception of exertion. However, the conceptual approach adopted by the present research demands that, bearing in mind the well-documented interrelationships among physiological responses during exercise and the integrated nature of perceived exertion, the perceptual response to exercise must be evaluated in terms of various modifying variables. In addition to this, the relative contribution of central and local factors to overall effort sensation was assessed. In so doing, the present research assumes implicitly Pandolf's (1978) model which suggests that the interrelationships between subjective perceptual ratings and specific physiological responses to various types of work can be better defined and compared using differentiated ratings. The model makes provision for the division of undifferentiated RPE into local and central factors, thereby encouraging comparisons between these components, with further contrasts to the overall exertion. In addition to this, the model conforms to the conceptual framework guiding the present research in that it treats RPE as a multi-faceted construct.

Classification of a response as a local factor is based on the mediation of feelings of strain in the exercising muscles and joints, and sensory input for this measure may derive from parameters such as lactate concentrations, Golgi tendon organ activity, and general muscle sensations. Table VI and Figure 17 show that local RPE was significantly elevated for the laboratory condition as compared to the field condition. It has already been noted (Figure 15) that there were no work intensity differences between the two conditions. What local factors could then have occasioned the increase in local RPE?

Carton and Rhodes (1985) have reported strong correlations between RPE and blood lactate. Below an exercise intensity of 65% of $\dot{V}O_2$ max however, lactate does not increase appreciably for normal subjects. Bearing in mind that trained individuals have an elevated anaerobic threshold, blood lactate would only influence perception of effort at high exercise intensities. Whilst acknowledging that blood lactate measures did not form part of the experimental protocol, this may have been the case in the present research, as subjects were working at an intensity corresponding to their anaerobic threshold (Table VII, Appendix 9). Pandolf *et al.* (1972) reported plateaus in respiratory responses at high work loads, while RPE continued accelerating. The authors proposed that the effort sensation may have been due to the monitoring of anaerobic metabolites. In support of the effect of blood lactate on local RPE, Skrinar *et al.* (1983) found that blood lactate values were more closely associated with changes in the local ratings of perceived exertion than with central ratings, supporting the conclusion that lactate concentrations act as a potent local sensory cue. On the surface then, it seems that possible differences in blood lactate concentrations could have been responsible for the elevated local RPE. Closer examination of the results however indicates that this would be an erroneous conclusion. Unlike the results of Pandolf's (1972) study, respiratory responses did not plateau. It cannot

Table VII: Estimations of the Anaerobic Threshold ($\dot{V}O_2$ ml.kg^{-1}.min^{-1}) and the Anaerobic Threshold as a percentage of the subjects' $\dot{V}O_2$ max.

Subject	$\dot{V}O_2$ at AT (ml.kg^{-1}.min^{-1})	% $\dot{V}O_2$ max at AT
1	46.47	69.15
2	56.69	70.95
3	51.93	69.80
4	50.05	76.56
5	43.70	69.59
6	46.38	73.28
7	45.53	77.57
8	50.07	74.28
9	48.72	72.85
10	41.66	73.99
11	57.03	79.54
Mean	48.93	73.41
SD	4.92	3.43

therefore be concluded that increases in local RPE can be accounted for solely by possible increases in blood lactate. Furthermore, and bearing in mind that no measures of blood lactate were taken, it cannot be assumed that there were any differences in blood lactate concentrations between the two conditions, as there was no significant difference in work intensity between the two conditions. Thus, while accepting that blood lactate levels can affect particularly local RPE once a critical exercise intensity threshold has been reached, the present study cannot offer any evidence that blood lactate levels were responsible for elevated local RPE in the field condition. It can be assumed that the muscular discomfort which typically accompanies lactate accumulation provides a source of sensory information which is readily available to conscious awareness, but the equivalent exercise intensities, and the fact that there was no respiratory quotient difference between the two conditions, indicates that similar levels of sensory awareness from this source were potentiating on perception of effort during the field and laboratory exercise tasks.

It has already been noted (Noble *et al.*, 1973a) that perceived exertion is a function of both metabolic equivalence and of the stress placed on local musculature in the accomplishment of a given work task. Figure 17 indicates that local, central and overall measures of RPE increased in the laboratory as opposed to the field condition. Table VI however shows that only the increases for local and overall RPE were significant. For both the field and laboratory conditions, correlation coefficients between local/overall RPE (r = 0.96 and 0.94 respectively) were higher than for correlations between central/overall RPE (r = 0.9 and 0.76) respectively. These results indicate that in the present study, local RPE were more closely related to overall RPE than central RPE were.

Robertson (1982) has supported the importance of local factors by stating that they are assumed to provide the primary sensory signals, while central factors act as an amplifier or gain modifier that potentiate the local signals in proportion to the aerobic metabolic demand. Other researchers have supported this conclusion. Pandolf (1978) has proposed that the dominance of either local or central factors in the subjective estimate of exertion is in part related to the amount of active muscle mass employed by the particular type of work. Ekblom and Goldbarg (1971) originally suggested that local factors would dominate effort perception only during work involving small muscle groups, but recent research (Pandolf, 1982; Noble and Allen, 1984) indicates that local components provide the most intense sensory stimulus, irrespective of the amount of active muscle mass involved. There is thus increasing evidence that central factors do not play as important a role in the perception of exertion as was originally thought. The results of the present study support the above conclusion, in that in an activity employing large muscle mass and placing relatively intense demands on the cardiorespiratory system, local factors dominated the overall effort sensation. Pandolf (1978) has proposed that when a particular factor or psychological cue becomes accentuated by either elevated rate, concentration or value, it can dominate the overall rated perceived exertion. Consistent with current theory, this was evidently the case for local factors in the present research. Before unreservedly accepting the dominance of local over central RPE signals, it should be noted that the nature of the present research may have contributed towards this dominance. The work task was uphill running (mean grade 7.5%), and it is well documented that slopes present additional difficulty when compared with level surfaces (Charteris, 1986a). At a grade comparable to that of the exercise task in the present study, energy requirements were found to increase 40% over those utilised for horizontal running (Gregor and Costill, 1971). Charteris (1986a) also found that the angular excursions of limbs changed even at 5% grade. Concomitant soft-tissue and muscular responses lead to the assumption that grade locomotion could result in elevated local RPE. Therefore it can be argued that grade running places more stress on the active musculature than level running does at similar levels of metabolic intensity. Thus, while the present research provides support for the dominance of local over central cues for effort perception, this dominance may have been mediated by the specific nature of the exercise task.

In conclusion, local and overall RPE's were significantly higher for the laboratory condition than for the field condition. While blood lactate can be a potent source of local sensory input, it is unlikely that this parameter could have been responsible for the differences. The results also indicate that while local factors provided a more potent sensory input into the overall perception of exertion than did central factors, this may in part have been due to the nature of the exercise task. Nevertheless the results support the conclusion that central factors may not play as important a role in the perception of exertion as was previously thought.

Ratings of Perceived Exertion and the Anaerobic Threshold

The anaerobic threshold (AT) of each subject was determined from the $\dot{V}O_2$ max test data by noting the point of departure from linearity of $\dot{V}E/\dot{V}O_2$. Davis (1985a & b) has reported studies supporting the validity of this method, but Brooks (1985a & b) holds that correlations between noninvasive and invasive methods are coincidental. Convenience determined that the noninvasive methods be employed in this study. Despite Davis' (1985a) correlational evidence, it should be noted that the noninvasive methods employed in the present research did present some problems, in that it was often difficult to judge the $\dot{V}O_2$ value at which $\dot{V}E/\dot{V}O_2$ began to increase more steeply. Where there was some doubt, e.g. if there were two or three points denoting departures from linearity, the mean $\dot{V}O_2$ and % of $\dot{V}O_2$ max of these points was taken to represent the AT. It is acknowledged that this may have suppressed the sensitivity of the measure by compromising accuracy, but due to the difficulty of determining AT in this manner, it must also be noted that at the same time this method reduced the chances of error. As the determination of AT was peripheral to the aims of the present research, it was deemed preferable to reduce sensitivity, thereby reducing the chance of error.

Appendix 9 contains the figures illustrating the determination of AT for the eleven subjects. Table VII indicates that the mean AT was located as being at 73.41% of the mean $\dot{V}O_2$ max. In untrained subjects, the onset of anaerobiosis normally occurs between approximately 50 - 60% of $\dot{V}O_2$ max, while the AT is higher in endurance trained athletes, occuring between approximately 70 - 80% of $\dot{V}O_2$ max. Earlier, (Table I) subjects were described as being extremely well-conditioned on the basis of their $\dot{V}O_2$ max. The mean AT of 73.44% serves to support this earlier classification.

Figure 15 shows that subjects were working at 71.46% and 72.75% of their $\dot{V}O_2$ max for the field and laboratory conditions respectively. Thus in both cases, subjects were working at an intensity just below, and very close to, their anaerobic threshold. Previous studies (Purvis and Cureton, 1981; Demello *et al.* (1987) have found that subjects exercising at the AT reported RPE of 13.6 and 13.0 respectively. This corresponds to a Borg scale rating of "somewhat hard". The subjects in the present study reported overall RPE of 10.89 and 11.82 for the field and laboratory conditions, values which are lower than those reported by the above authors. This could possibly be explained by the fact that the subjects in the present research were working at an intensity slightly below their anaerobic threshold. When working at or above the AT, it is reasonable to expect a rating of "somewhat hard", as the physiological alterations that occur at these intensities include lactic acid accumulation in the blood, a decrease in blood pH and a disproportionate increase in ventilation in relation to the work rate. Accepting this, could the observed increases in local RPE have been due to these physiological alterations? Whilst bearing in mind the difficulties associated with noninvasive determination of AT, this is unlikely, as subjects were working at an intensity slightly below the point of onset of anaerobiosis. With regard to the conceptual base espoused by this study, it is noteworthy that the consequences of metabolic acidosis have effects that are both local and central, confirming the multi-faceted construct of RPE.

In conclusion, research has shown that the AT is an important anchor point for perception of effort during exercise, as well known metabolic gas exchange alterations are initiated at the AT and become accentuated at higher exercise intensities, contributing to both local and central signals of effort perception. Using a noninvasive method of determining AT, this study found that subjects were working at a level of intensity slightly below their AT, and that this intensity corresponded to overall RPE of 10.89 and 11.82 for the field and laboratory conditions respectively. It is unlikely that factors such as blood pH or lactic acid accumulation were responsible for this difference, as the work intensity was below the AT. It is likely that an increase in work intensity, corresponding to exercising at the AT, would have resulted in RPE approximating those reported by previous studies in this area of research.

Other Factors Affecting RPE

State of Training

Some concern has been expressed (Mihevic, 1983) that the RPE scale may not be sensitive enough to permit fine distinctions between the levels of exercise stress or physiological strain which may be mediated by aerobic fitness. Several studies have shown that fit and unfit subjects rate the effort required to perform standard workloads equally (Carton and Rhodes, 1985), and this suggests that the RPE scale is sensitive enough for the AT to be regarded as an anchor point for RPE for subjects regardless of level of fitness.

The present research found the RPE scale to be sensitive enough to monitor perceptual differences between a homogenous group of subjects working at the *same* level of intensity for two conditions. Clearly then, the RPE scale as used in this study permitted fine perceptual distinctions between similar work tasks. State of training obviously did not impinge on effort sensation, as the comparisons were between the same subjects for two conditions of similar intensity. It has been suggested that in certain individuals, differences in RPE as a consequence of training are only manifested during intense activity (Carton and Rhodes, 1985). Mihevic (1983) supports this by stating that at higher exercise intensities RPE differences are expected to reflect physiological differences. Thus it may well be that any dissimilarities between perceptual responses appear only in higher ranges of exercise intensity. Bearing in mind that the subjects worked at an intensity slightly above 70% of $\dot{V}O_2$ max, it is possible that perceptual differences could be due to the fact that in some individuals differences in effort sensation occur only during intense work. It must be remembered however that while 70% of maximal capacity is a relatively high work intensity, the subjects in the present research were elite marathoners and were in fact working below their anaerobic threshold. Therefore it is more likely that factors other than differences in state of training between subjects, or work intensity, were responsible for elevations in RPE during the laboratory condition.

In short, while the RPE scale may not be sensitive enough to permit fine perceptual distinctions at low levels of exercise intensity, such distinctions could become apparent at higher levels of intensity. This may have been the case in the present research, where RPE differences were found for the same group of individuals between two exercise conditions, both involving a relatively high level of work intensity. State of training could clearly not have affected RPE, as the differences found were between the same subjects for two similar work tasks.

Perception and Cognition

It has been suggested (Morgan, 1981) that the perception of exertion is influenced by cognition to a large degree. He has also stated that RPE are governed not only by the physiological cost of work, but also by the exercising subject's cognitive appraisal of the demands imposed by the work task. The proposal that effort sense seems to involve a cognitive-perceptual process rather than perception alone has important implications for the present research. By accepting that cognitive, perceptual and physiological factors can influence ratings of perceived exertion, the present research conforms to the conceptual paradigm outlined in Chapter Two. Although cognition was not accessed, the perceptual differences between the field and laboratory conditions will be examined in respect of possible cognitive influences on RPE.

Morgan (1981) has reported studies in which hypnotic suggestions of uphill work yielded higher RPE's than for level grade suggestions. Thus, thinking that work intensity is greater for one condition than for the other can result in elevated RPE. Leading on from this, if subjects in the present study thought that treadmill work was going to be "harder" than the overground run, or perhaps if they simply preferred working in the field environment, their perceptual responses would reflect this. The results (Figure 17) suggest that this may indeed have been the case, as both local and overall RPE were elevated for the treadmill condition. It must however be remembered that there is no evidence of the degree of cognitive appraisal prior to the work tasks. It has already been noted that in a simple measure of cognitive appraisal presented after the laboratory (simulated field) session, subjects indicated that they thought the treadmill condition to be the more stressful, despite the similarities in heart rate and metabolic demand. This appraisal was consistent with the increases in local and overall RPE and provides support for the proposal that there is a complex interrelationship between the cognitive, perceptual and physiological factors in the subjective estimates of work cost.

Assessing the relative contributions of local and central factors to overall perceived exertion with respect to cognitive influences lends support to their importance to the perceptual process. It has already been established that local factors dominated the differentiated rated perceived exertion, and reasons for this have been advanced. From a cognitive perspective, the subject's expectance of the task may have contributed to this dominance. Being experienced road runners, the subjects intuitive expectations of uphill running were possibly that the rather severe mean grade would result in local muscular discomfort, particularly in the quadriceps. This expectation would certainly be reasonable, for as has already been noted (Charteris, 1986a), local factors are likely to increase as soft-tissue and muscle activity follow changes of the angular excursions of limbs in grade walking. Therefore, the reasonable cognitive expectations of experienced runners could have contributed to the dominance of local over central factors of perceived exertion, for both the field and laboratory conditions. Indirect support for this theory of expectancy is provided by Rejeski and Ribisl (1980), who have suggested that one mechanism through which the cognitive determinants of RPE may become salient during physical tasks is an expectancy concerning task duration. Whilst not directly applicable to the present research, their findings do indicate that cognitive expectations can affect the perception of effort.

Rejeski (1981) has proposed that cognitive variables should be expected to affect RPE most when the physical task in question is performed at, or has the physiological demands of, a submaximal work intensity. The perceptual differences noted in the present research could thus partly have been the result of cognitive factors, as the work intensity for both conditions was below the subjects' anaerobic threshold. In other words, the work intensity may not have been sufficient for physiological inputs to have been salient sources of information for RPE. Thus, it is probable that cognition served, at least in part, as a cue in the subjective perception of the work task.

Rejeski (1985) has proposed an active conceptual approach to the study of perceived exertion, and in so doing has elaborated on the potential role that informational and affective schema can play in the perception of exertion. He stresses the importance of preconscious elaboration of sensations, and distinguishes between perception and focal awareness. Relief from fatigue can thus be achieved by dissociative strategies occupying limited channel capacity that is critical to bringing a percept into focal awareness. This has important implications with regard to RPE and the working environment. For example, it could be postulated that in the field, sensory stimuli may occupy the attentional channels. In so doing, they provide relief from exertion, and prevent perception being attended to by focal awareness. The result of this would be suppressed ratings of perceived exertion. Conversely, in the laboratory, sources of sensory stimuli are limited, forcing subjects to bring percepts into focal awareness and consequently resulting in elevated sensations of effort. The results of the present study are consistent with this theory, in that local and overall ratings of perceived exertion were elevated for the laboratory condition.

In conclusion, the perception of exertion is influenced by cognition to a large degree. Cognitive appraisal of the work tasks in the present study may have contributed to elevated local and overall RPE for the laboratory condition. Furthermore, cognitive expectance as to the nature of the work task may have contributed to the dominance of local over central factors of perceived exertion. In addition, the intensity at which subjects worked may have reduced the impact of physiological cues for RPE over cognitive ones. Finally, sensory stimuli in the overground environment may have prevented percepts being brought into focal awareness, with the result that RPE were suppressed in this condition. These conclusions support the assumption that sensory cues for perceived exertion interact with psychological factors prior to perception, and that the conscious recognition of exertional cues is similarly amenable to mediation by cognition.

Environment and RPE

The treadmill is often used to simulate overground locomotion, and it is frequently used in studies examining biomechanical and physiological aspects of walking or running. There have however been some differences of opinion about the validity of the extrapolation of treadmill information to the overground environment or *vice versa*. It is crucial to the present research that some clarity is obtained as to possible differences between the two conditions.

Wall and Charteris (1981) have stated that even if differences between the two conditions do exist, then these are probably outweighed by the convenience offered by the treadmill. For the purposes of validating comparisons made in the present research, it is however imperative that any potential differences be accounted for. Several researcher (Nelson *et al.*, 1972; Elliott and Blanksby, 1976) have found biomechanical differences between the treadmill and overground conditions, but both of these studies concluded that any biomechanical differences on the treadmill are only likely to occur at speeds exceeding 5 $m.s^{-1}$. It can be seen from Table VIII that the mean speed for both work tasks in the present research was well below this threshold for alterations. Other researchers (Bassett *et al.*, 1985) have stated that the treadmill appears to be a valid instrument for the estimation of oxygen uptake when the data are to be applied to overground running at speeds below 4.5 $m.s^{-1}$. Once again Table VIII illustrates that the running speed achieved in this

Table VIII: Total running time and running speed for both the overground and treadmill conditions.

Subject	Total Running Time (s)	Running Speed ($m.s^{-1}$)
1	1215	3.29
2	1331	3.01
3	1125	3.56
4	1231	3.25
5	1482	2.70
6	1418	2.82
7	1580	2.53
8	1343	2.98
9	1491	2.68
10	1513	2.64
11	1374	2.91
X	1373	2.94
SD	141.27	0.32

study was below that required for metabolic differences to occur between the two conditions. From the above it can therefore be concluded that valid metabolic comparisons can be made between the overground and treadmill conditions, and that theoretically, neither biomechanical factors or oxygen consumption should differ between conditions to the extent that perceptual differences would arise.

Most of the studies cited above were however conducted on level surfaces, and Charteris (1986a) has stated that the issue of grade locomotion is an ergonomic problem that is far from resolved. It is hoped that the results of the present study will contribute, at least at a metabolic level, to some clarity with regard to this matter. Bassett *et al*. (1985) report that the ACSM (1980) prediction formulae hold that, at a speed of 3.3 $m.s^{-1}$ and at a 7.5% grade, the metabolic demand of treadmill running would exceed that of overground running by 10.25 $ml.kg^{-1}.min^{-1}$. As the mean grade of the work task in the present research was also 7.5%, and the running speed 2.94 $m.s^{-1}$, this prediction can be examined practically. Assuming parity in running speed and grade, Figure 18 illustrates that, according to the results of the present research, the ACSM (1980) guide may not be valid with regard to possible metabolic differences between overground and treadmill grade running. Applied to Figure 18, the 10.25 $ml.kg^{-1}.min^{-1}$ difference appears to be marked, particularly in view of the fact that there was no actual difference between the overground and treadmill conditions. It must be remembered however, that Figure 18 only assumes parity between

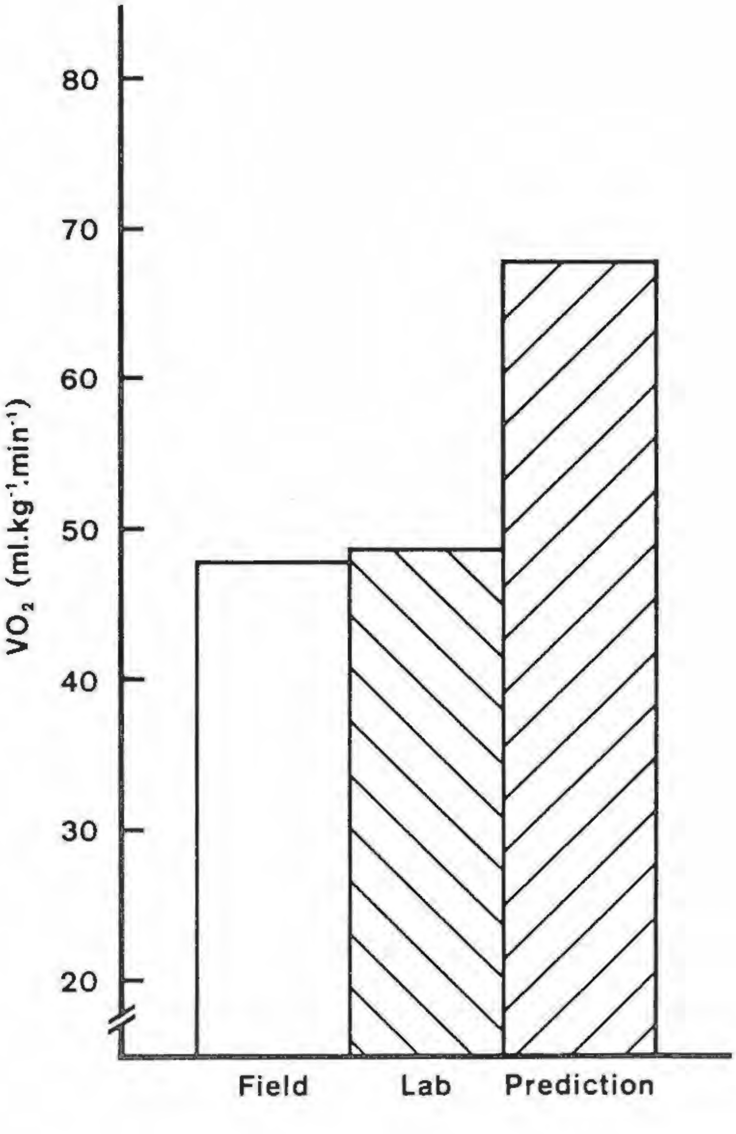

Figure 18: Actual VO_2 values for the field and laboratory conditions, and the ACSM (1980) predicted VO_2 for the laboratory, with all work tasks being performed at 7.5% grade.

actual and predicted speeds, and the difference between speeds could have resulted in a less pronounced difference between actual $\dot{V}O_2$ and predicted $\dot{V}O_2$. Nevertheless, the ACSM (1986) prediction formulae for overground and treadmill energy requirements also indicate that for 5% grade running at 3.1 $m.s^{-1}$, overground running will be 8.4 $ml.kg^{-1}.min^{-1}$ more energetically expensive than treadmill running. Once again, the results of the present research contradict this and indicate that there were no differences between the metabolic energy requirements of inclined treadmill and overground hill running. This is consistent with Van Ingen Schenau's (1980) theoretical physics approach to the problem, and he states that if metabolic differences are found, it is unlikely that they will be the result of mechanical factors. Rather, they could perhaps be attributed to visual factors, as visual information may be important in maintaining equilibrium and stability. Furthermore, the ambience of the treadmill and laboratory could prove to be an extremely stressful environment for a subject.

Therefore, in relation to previous research in this area, the results of the present study show that any perceptual differences found between the overground and treadmill conditions were unlikely to be the result of biomechanical or oxygen demand differences caused by mechanical factors inherent in the two situations. Furthermore, it was demonstrated that, despite theoretical expectations to the contrary, there were no differences in metabolic demand at a 7.5% grade for both conditions. Finally, if differences do occur, they can probably be attributed to visual and environmental factors, rather than to factors of a mechanical nature.

In accordance with Rejeski's (1985) parallel processing model, Hardy *et al.* (1986) have suggested that, during exercise, external cues (e.g. the terrain) do compete with internal cues (e.g. ventilation). In other words, it is possible that shifting attention to external cues leads to diminished responsivity to internal states. Thus, by focussing on the external cues (the environment) during the field condition, subjects could have restricted the processing of internal sensations such as perceived exertion. That this probably occurred to some degree is borne out by the elevated ratings of perceived exertion reported for the laboratory condition. In this condition, external cues (distractions) were limited by the clinical setting, and the resultant ambience probably contributed to increased attention to internal sensations, resulting in the elevated ratings of perceived exertion. Bearing in mind that external cues compete with internal cues, it is also possible that the environment affected minute ventilation, resulting in elevations for the laboratory condition, which further contributed to increased RPE. That this may have occurred is borne out by the fact that, unlike heart rate and $\dot{V}O_2$, $\dot{V}E$ is consciously monitored via afferent pathways. Therefore, diminished responsivity to internal cues such as minute ventilation, due to increased focussing on external cues in the environment, probably contributed to the suppressed RPE reported for the field condition.

Additional support for the above interpretation of results is provided by Stones (1980), who found that attenuated visual input resulted in a lessening of fatigue relative to running pace. In other words, the perception of fatigue was suppressed by increasing the demand on a runner's visual system. This finding leads to a question crucial to the present research, namely: would runners on a treadmill report different perceptions of exertion than when running outdoors at a similar pace, bearing in mind that in this case visual input would not be attenuated artifically but would be determined by the peculiarities of the particular environment? It is worth noting that in the outdoor setting, the visual field is filled with both near and far objects. For a person in motion, the corresponding retinal projections will therefore be associated with varying degrees of change, while this may not be the case for treadmill running. These varying degrees of change can be seen as distracting stimuli which flood the lines of communication, thereby blocking what is available to perception of effort. This provides further support for the conclusion that the environmental cues available for perceptual processing can result in significant perceptual differences between environments. Birk and Birk (1987) also contend that environmental influences render direct perceptual translations from the laboratory to the field invalid, and Jackson *et al.* (1981) have demonstrated that the physiological and psychological correlates of exercise performance are different in a field setting than in a laboratory. The results of the present research support the contention that environmental cues may influence perceptual responses in that particular environment.

In conclusion, external cues inherent in an environment may suppress internal sensations. With regard to the present research, it is possible that the environmental ambience of the laboratory resulted in increased attention to internal cues such as minute ventilation, and this in turn contributed towards elevated ratings of perceived exertion for the laboratory condition. Furthermore, by decreasing the demands placed on the visual system for the laboratory conditions, subjects were probably forced to increasingly attend to perceptual cues. Therefore, in the field, where a myriad of social-psychological forces impinge on the performer, the role of physiological feedback to RPE may well be reduced, and the potential role that environmental informational factors may play in the subjective assessment of the physical work is thus increased. Finally, the results of the present research provide support for the contention that environmental cues may exert a substantial influence on ratings of perceived exertion.

Social and Psychological Factors

It has been found (Hardy *et al.*, 1986) that social factors such as the adoption of self-presentational tactics can affect the subjective ratings of exertion, particularly at light - moderate exercise intensities. Specifically, subjects performing in the presence of another exercising subject (coactor) suppressed their RPE. As there were no coactors involved in the present research, the supressed RPE for the field condition can obviously not be attributed to how the subject concerned himself with how he looked relative to anyone else. It is however worth noting that in the field condition, there were never less than three researchers assisting in the collection of data, while for the laboratory conditions there was only one. Thus, although no firm conclusions can be drawn, it is possible that some form of self-presentational tactic may have been operating to mediate the subjective assessment of physical work. With this in mind, RPE researchers would be remiss in ignoring the role that social influences can play in the rating of perceived exertion, particularly at light - moderate exercise intensities, where physiological information appears to be less salient than at high intensities.

Motivation accounts for the initiation, direction and persistence of behaviour, and as such can probably affect subjective ratings of exertion during an exercise task. Thus, motivation determines the level of operation on any specific task, and explains the intensity with which individuals engage in activity and the level of effort sustained in the activity. Accepting the above, it is difficult to attribute differences in RPE found in the present research to motivational factors, as the level of operation (intensity) and other performance variables of the laboratory task was matched to that of the field task. Thus, even if an exercising subject experienced a feeling of disinclination to continue in either condition, the initiation, direction and persistence of the work task was predetermined. This, and the fact that levels of arousal were not accessed for either task, precludes any firm conclusions with regard to the possible effects of motivation on RPE in the present research. It must however be remembered that the self-report of exertion may have motivational and emotional antecedents, and that RPE may be mediated by motivational factors. For future research, the potential role of motivation and emotions in RPE is worth pursuing. The fact that these factors can impinge on RPE casts further doubt on the generalisability of controlled laboratory study to the field.

It has been noted that multiple physiological indices account for approximately 65% of the variance in RPE, and Morgan (1973) has suggested that at least a portion of the remaining unexplained variance might be dependent upon factors of a psychometric nature. Thus, the portion of the unexplained variance could reflect the differential responses of subjects exhibiting divergent behavioural characteristics. The perception of effort has been found to be correlated with several psychological traits in a complex manner, and this emphasises that individual differences in personality structure may play a role in the mediation of effort sense. Psychological states and traits such as somatic perception, anxiety, neuroticism and extroversion were however not accessed in the present research, so the interactive effects of these variables cannot be used to explain the RPE differences that were found. That psychological factors can significanly impinge on effort perception should however not be forgotten, and future research in this field should attempt to account for the unexplained variance by evaluating the effects on RPE of factors such as social influence as well as psychological factors such as motivation, anxiety, neuroticism, extroversion and attitudes.

Attitudes

In order to access some tangible psychological trait which may have influenced the RPE, attitudes were accessed prior to each work task. The results of the present research indicate that there were attitudinal differences in the subjects' approach to the two different work tasks. Figures 19 and 20 show that attitudes, as measured by the Semantic Differential Attitude Scale, were generally more favourable towards running outdoors than towards running on the treadmill. Table VI confirms that there were significant differences in attitudes towards the two conditions, with the evaluation, activity and overall scores being significantly more favourable for the overground condition.

An attitude has been described as reflecting both the direction and intensity of feeling towards a particular concrete or abstract object, and as such can be considered the cause of a person's behaviour. Thus the concept of an attitude includes the idea of unconscious determinants of behaviour and the dynamic interplay of conflicting motives. Furthermore, an attitude helps to explain the consistency of a person's behaviour. This has important implications for the present study, in that there was not a consistent behavioural response, as accessed through self-report of attitudes, between the two conditions. In conjunction with this, there were perceptual differences between the two conditions, leading to the conclusion that there may be some as yet unidentified link between attitudes towards a work task and the perception of exertion during a work task. In other words, a negative attitude towards a particular task may result in elevated ratings of perceived exertion during that task. Figures 17, 19 and 20 provide support for this contention in that negative attitudes towards the laboratory

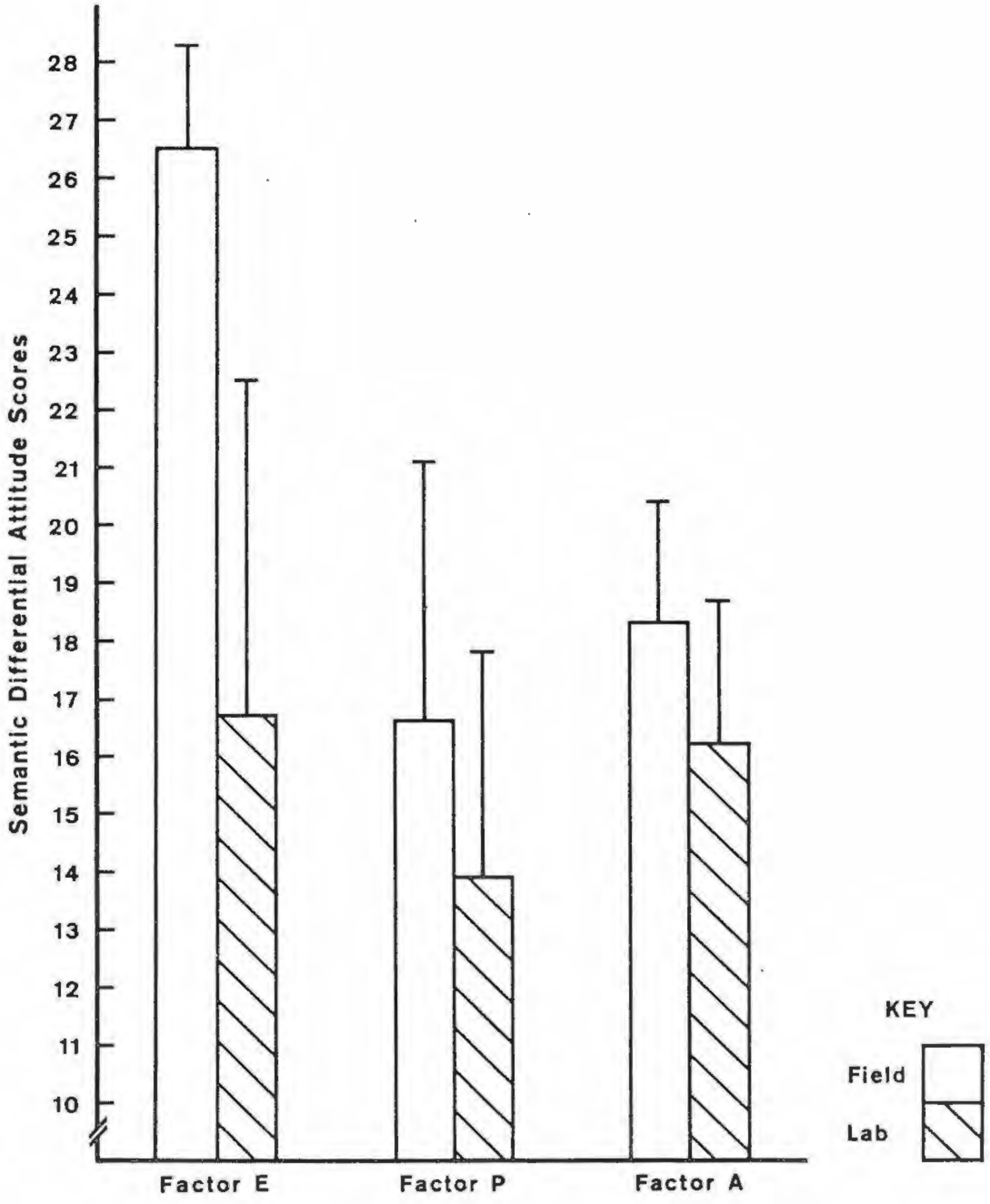

Figure 19: Attitudinal responses for factors E, P and A of the Semantic Differential Scale, towards both the field and laboratory conditions.

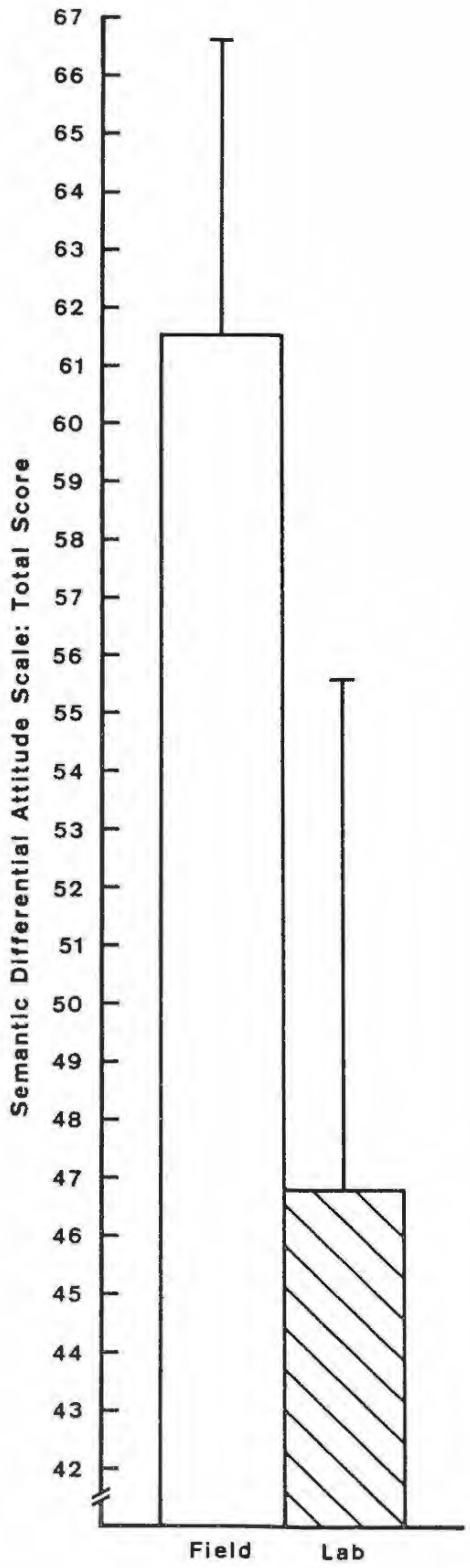

Figure 20: Total attitude score responses (Semantic Differential Scale) towards the field and laboratory conditions.

situation (as compared to the field situation) were concomitant with elevated local and overall RPE for the treadmill condition. Identifying the pathway or link between the two variables is beyond the scope of this research, but in view of the suggested relationship, would be an important avenue for further research.

Attitudes predispose towards an evaluative response and exert a directive, dynamic influence upon responses to all objects with which they are related. Of the three factors identified by Osgood *et al.* (1957), the evaluative factor (E) is dominant as an expression of attitude, while the potency factor (P) is about equal and slightly greater in magnitude than the activity factor (A). Factor E then virtually serves as a definition of attitude and is clearly affective in nature, while the other factors are cognitive, and as such reveal the respondents' interpretation of the concepts physical characteristics.

Figure 19 and Table VI show that there were significant differences between factor E responses for the two conditions, with the evaluative dimension being more favourable for the field than for the laboratory conditon. As this factor is pervasive in judgement, and as attitudes are referred to as "tendencies of approach and avoidance", it is an important determinant of human behavioural responses. The evaluative dimension of a verbalised attitude could thus, in some presently unidentified manner, mediate a behavioural response such as the subjective reports of exertion. Similarly, there were differences between the two conditions for factor A which also parallelled the differences in RPE. Concerned with characteristics such as quickness, excitement, agitation etc., factor A could also possibly influence perceptions of exertion. For example, if in a subjects attitudinal judgement he perceived that characteristics such as those above were more pronounced in a particular work situation, his ratings of perceived exertion could be expected to rise for that particular task. That this may indeed have been the case in the present research is evidenced by the results illustrated in Figures 17 and 19 and Table VI. It is also worth noting that, through the medium of factors E and A, both affective and cognitive reactions to the situation influenced the differences in attitude. Thus, tentatively accepting some link between attitudes and perception, this confirms the multidemensional nature of the construct of RPE, and the contention that several factors interact to contribute towards the Gestalt of perceived exertion. This research has proposed a link between attitudes towards a work task and ratings of perceived exertion during that work task. Future research should attempt to elucidate this relationship, not merely in correlational terms, but also in terms of cause and effect.

Differences in attitudes towards the field and laboratory situations have been reported. Bearing in mind that attitudes help to explain consistency of behavioural responses, possible reasons for the differences need to be examined. In other words, what factor(s) resulted in more favourable attitudes towards the field setting? It is only possible to speculate on these reasons, but it is likely that the relatively unfamiliar ambience of the laboratory, with the attendant auditory and visual perturbation, resulted in the more favourable attitudinal responses towards the overground situation. The reasonable assumption can be made that subjects felt more "comfortable" in the overground condition as they were all experienced marathoners. Whilst not being novices at treadmill running, the difference in their experience in the two situations was vast. Thus, while there may have been no metabolic or biomechanical differences between the two conditions, the more "stressful" environment posed by the ambience of the laboratory may have resulted in unfavourable attitudes towards that condition, which may in turn have affected RPE.

In conclusion, the present research found that attitudes towards overground running were more favourable than attitudes towards treadmill running at the same levels of performance, and bearing in mind that RPE were elevated for the laboratory condition, it is possible that attitudes influence subjective reports of effort through some as yet unidentified pathway. Furthermore, the attitude changes noted in this study were found to have both affective and cognitive components. If a link exists between attitudes and RPE, this serves to confirm the multidimensional nature of the latter construct. Finally, it is likely that the attitudinal differences were, at least in part, due to perception and cognitions towards the particular characteristics inherent in the two environments, and, assuming a link between attitudes and RPE, this helps to explain the perceptual differences between the conditions.

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

AIMS OF THE STUDY

Perceived exertion has been defined as one's subjective rating of the intensity of work being performed (Morgan, 1973), and therefore 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. Overall perceived exertion, with input from local (muscluar) and central (cardiorespiratory) factors, is based upon a psychophysiological process which is technologically inaccessible, but which is readily avaiable in terms of self-awareness, and which can be expressed by means of the RPE category-rating scale.

The relationship between ratings of perceived exertion and various physiological measures has been well established and documented, but most studies have been confined to the somewhat artificial conditions of the laboratory. Very little appears to have been done to examine subjective self-reports of effort in normal field conditions. RPE has great utility, particularly for example in exercise prescription. Extrapolation of RPE responses from the laboratory to the normal working environment may however be invalid, as in the field a myriad of psycho-social forces impinge on the performer. It is generally accepted that 35% of the unexplained variance in RPE may be due to factors of a psychometric nature, and the saliency of these factors to RPE may in fact be mediated by environmental cues. To date, assumptions regarding the extrapolation of RPE data to the field from the laboratory have been accepted without empirical foundation. The present study therefore attempted to examine the applicability of laboratory RPE to field conditions.

Specifically, the present research attempted to examine possible differences between field and laboratory RPE when the overall performance and physiological measures for the two conditions were equated for a task of uphill running. Furthermore, by accessing differentiated RPE, the interactive effects of local, central and overall RPE were examined. Finally, by examining attitudes towards the work task, this study attempted to identify a tangible psychological factor that may be responsible for a portion of the presently unexplained variance in RPE.

METHODS

Eleven well-conditioned (mean VO_2 max 66.6 $ml.kg^{-1}.min^{-1}$, mean relative body fat 12.48%, mean anaerobic threshold 73.41%) male caucasian subjects (mean age 26.6 years) voluntarily participated in the following data collection sessions:

1) biographical data, anthropometric measures and treadmill habituation;
2) $\dot{V}O_2$ max test;
3) speed-matching session at 70% of $\dot{V}O_2$ max to determine overground running speed at 3.8% and 7.5% grade;
4) attitudinal questionnaire, followed by a 4km run on a road with a known gradient, at the speeds determined by the speed matching session;
5) attitudinal questionnaire, followed by a run on the treadmill, replicating the gradient, speed and time measures of the overground condition.

(It is important to note that for the laboratory condition, subjects worked at exactly the same grade and speed as for the field condition, that is, the performance conditions were equated.)

The following data were collected for analysis:

1) skinfold fat data;
2) attitudinal responses to a Semantic Differential scale;
3) differentiated (local, central and overall) ratings of perceived exertion;
4) heart rate;
5) oxygen consumption ($\dot{V}O_2$);
6) minute ventilation ($\dot{V}E$);
7) volume of expired carbon dioxide ($\dot{V}CO_2$);
8) respiratory exchange ratio (R); and
9) the anaerobic threshold (AT) was estimated from the $\dot{V}O_2$ max data.

The results were analysed using single variable statistics, related "Student's" t-tests, two-factor analyses of variance with repeated measurements on both factors, and one-independent variable regression analyses.

RESULTS

With the exception of wind speed (the effects of which were probably minimal and were difficult to quantify), there were no differences between environmental conditions (temperature, relative humidity and barometric pressure) for the overground and treadmill conditions. Any subject response differences between the overground and treadmill situations are not therefore attributable to differences in physical environmental conditions.

The positive treadmill gradient was set to replicate that of the overground condition, and elapsed time (and consequently running speed) on the treadmill was precisely matched to that of the overground condition. The performance variables for the two conditions were thus equated, and physiological, perceptual and attitudinal response differences between the working environments are unlikely to have been due to performance differences.

There was no heart rate difference between work tasks in the field and laboratory conditions. It is therefore unlikely that any perceptual differences were mediated by heart rate. Contrary to theoretical expectations, correlations between local RPE and heart rate were substantially higher than those between central RPE and heart rate. This finding serves to further refute the notion of causality between the two variables. The results also indicate that the formula HR = RPE X 10 may not be valid in all situations, and this lends support to the conclusion that heart rate, *per se*, exerts little influence on RPE and is not a primary factor fundamental to effort sensation. Correlations between heart rate and RPE were higher in the field than in the laboratory, indicating that some perturbation of the relationship occurred in the laboratory environment. Thus, while heart rate and RPE are probably indirectly related through their common dependence on physical strain, the relationship cannot be satisfactorily explained in cause and effect terms. These results then indicate that heart rate was not a major factor influencing the subjective reports of exertion, and that other haemodynamic mechanisms may have provided more potent signals of exertion.

With work intensity relativised at 70% of $\dot{V}O_2$ max, there were no oxygen consumption differences between the overground and treadmill conditions. The sensory signal associated with oxygen consumption was therefore unlikely to have been the main driving factor responsible for any perceptual differences between the two work tasks. Lower correlations between central RPE and metabolic demand were observed in the laboratory than in the field condition. Clearly some factor(s) pertaining only to the laboratory affected the relationship, but as there is no evidence that $\dot{V}O_2$ is consciously monitored, it is difficult to speculate about the mechanisms that regulate the transmission and intensity of this sensory signal. The results then support the notion that the impact of relative aerobic power on RPE may be mediated by other, more readily monitored, responses such as lactate production and ventilatory hyperpnea. $\dot{V}O_2$, *per se*, is therefore probably indirectly, rather than directly, related to effort perception.

Minute ventilation was significantly higher during the laboratory work task than during the field work task. This result was concomitant with significant increases in local and overall RPE, and reinforces previously suggested links between $\dot{V}E$, perception and cognition. All eleven subjects reported that, notwithstanding the actual similar work intensities, they thought the laboratory work task to be the more stressful. Thus the subjects' cognitive appraisal could have led to alterations in ventilatory responses, which could in turn have affected RPE. The above results then suggest that there may have been some link, however tenuous, between cognition and elevated minute ventilation. The results also show that, for the present research, there was a stronger link between $\dot{V}E$ and local RPE than between $\dot{V}E$ and central RPE. This is contrary to expectations, as $\dot{V}E$ is generally classed as a central sensory signal, but the probable explanation for this is that local RPE dominated the sensation of effort to such a degree that the existence of $\dot{V}E$ as a central signal was obscured. It was also noted that the $\dot{V}E$/RPE correlations were higher for the field condition than for the laboratory condition. Once again therefore, some factor(s) in the laboratory environment probably acted to perturb the relationship between physiological and perceptual responses to work. In conclusion, the results of the present research suggest that the elevations in minute ventilation may have been occasioned by the subjects' cognitive appraisal of the work environment. Furthermore, the work was of sufficient intensity to enable subjects to consciously monitor ventilatory stress, and bearing in mind the nature of the work task (i.e. grade running) and the dominance of local RPE, it is likely that $\dot{V}E$ contributed to the observed elevations in RPE.

Through accessing differentiated ratings of perceived exertion, it was found that local and overall RPE were significantly elevated for the laboratory condition as compared to the field condition. As there were no task-characteristic and no performance differences between the conditions, some other factor(s) must have occasioned the observed increases. Although blood lactate levels can affect local RPE, it is unlikely that the differences were due to elevations of this measure, as the exercise intensity was the same for the two conditions. The results also indicate that local RPE were more closely related to overall RPE than were central RPE. This provides support for the contention that central factors do not play as important a role in the perceptions of exertion as was originally thought, and that when a particular factor becomes accentuated by either elevated rate, concentration or value, it can dominate the overall rated perceived exertion. The results of the present research thus provide support for the dominance of local over central cues for effort perception, but it must be remembered that this dominance may have been mediated by the specific nature of the exercise task, in this case uphill running.

Using a noninvasive method of determining the anaerobic threshold (AT), it was found that subjects were working at a level of intensity slightly below their AT, and that this corresponded to overall RPE of 10.89 and 11.82 for the field and laboratory conditions respectively. Although AT is an important anchor point for perception of effort during exercise, it is unlikely that RPE elevations in the laboratory were mediated by this factor, as exercise intensity was equated for the two conditions. Furthermore, it must be remembered that although metabolic gas exchange alterations at or above the AT contribute to effort perception, subjects in the present study were working below their AT.

Although cognition was not accessed, except in a very limited manner, the results of the present research support the premise that the perception of exertion is influenced by cognition to a large degree. Cognitive appraisal of the work tasks may have contributed to elevated local and overall RPE for the laboratory condition, in that if subjects thought that treadmill work was going to be "harder" than the overground run, their perceptual responses would reflect this. The results suggest that this may indeed have been the case. Furthermore, cognitive expectance as to the nature of the work task (uphill) may have contributed to the dominance of local over central factors of perceived exertion. In other words, the subjects' intuitive cognitive expectations (mediated by experience) of uphill running were possibly that grade running would result in local muscular discomfort. In addition, the intensity at which subjects worked may have increased the impact of cognitive cues for RPE at the expense of physiological cues. Finally, sensory stimuli in the overground environment may have prevented percepts being brought into focal awareness, with the resultant suppression of RPE for this condition. The results obtained, coupled with theoretical expectations, lend support to the contention that sensory cues for perceived exertion interact with psychological factors prior to perception, and that conscious recognition of exertional cues is similarly amenable to mediation by cognition.

It has already been noted that local and overall ratings of perceived exertion were elevated for the laboratory condition, and several possible reasons for this have been advanced. Another explanation may be that the elevations could have been due to factor(s) inherent in the working environment. More specifically, by focussing on the external cues (the environment) during the field condition, subjects could have restricted the processing of internal sensations such as perceived exertion, resulting in depressed RPE in the field. Therefore the external cues, or distractions, were limited by the clinical setting. Bearing in mind that external cues compete with internal cues, it is also likely that by diminishing responsivity to internal states, the ambience of the working environment affected minute ventilation, which further contributed to the increased RPE. Visual factors inherent in the working environment also probably contributed to the observed elevations in RPE for the laboratory condition. In the field, the retinal projections of a man in motion will be associated with varying degrees of change, which can be regarded as distracting stimuli which flood the lines of communication, thereby blocking what is available to the perception of effort. Treadmill locomotion has no such rates of change during locomotion, and the consequent lack of distracting stimuli probably contributed to the elevated RPE during this condition. Accepting the above, it seems that environmental influences may render direct perceptual translations from the laboratory to the field invalid. Thus the physiological and psychological correlates of exercise performance may be different in the field setting than in the laboratory. In conclusion, external cues inherent in an environment may suppress internal cues for perceived exertion. Therefore, with regard to the present research, it is probable that the environmental ambience of the laboratory resulted in increased attention to internal cues such as minute ventilation, and that this in turn contributed towards elevated RPE. Furthermore, by decreasing the demands placed on the visual system in the laboratory work task, subjects were forced to increasingly attend to perceptual cues. Therefore, in the field, where a myriad of psycho-social forces impinge on the performer, the role of physiological feedback to RPE was reduced and the role of environmental informational factors was increased. The results of the present research then provide support for the contention that environmental cues can exert a substantial influence on ratings of perceived exertion.

The results indicate that there were attitudinal differences in the subjects' approach to the two work tasks, in that attitudes were more favourable towards running outdoors than towards running on the treadmill. In conjunction with the perceptual differences found, this leads to speculation that there may be some as yet unidentified link between attitudes towards a work task and the perception of exertion expressed during the task. In other words, the results of the present research lead to the conclusion that negative attitudes towards exercising in the laboratory situation (as compared to the field situation) were concomitant with elevated local and overall RPE for the treadmill condition. Thus attitudes could, in some presently unidentified manner, mediate a behavioural response such as the subjective report of exertion. Also, by tentatively accepting some link between attitudes and perception, the present research confirms the multidimensional nature of RPE. The working environment may have contributed to the negative attitudes towards the laboratory work task in that the unfamiliar ambience (with the attendant auditory and visual perturbation) could have influenced attitudes towards exercising in the laboratory. In short, the results indicate that it is possible that attitudes influenced the subjective reports of effort through some as yet unidentified pathway. The attitudinal differences between the two conditions had both affective and cognitive components, and this provides support for the contention that several factors interact to contribute towards the Gestalt of perceived exertion. Finally, it is likely that the attitudinal differences were, at least in part, due to perception and cognition towards the particular characteristics inherent in the two environments, and assuming a link between attitudes and RPE, this helps to explain the perceptual differences between the conditions.

CONCLUSIONS

1) It is unlikely that heart rate, *per se*, is a major factor directly influencing the perception of exertion. While heart rate and RPE are probably indirectly related through their common dependence on physical strain, other haemodynamic mechanisms may provide more potent signals of exertion.

2) The impact of relative aerobic power on RPE is probably mediated by other, more readily monitored, responses to exercise (for example $\dot{V}E$). $\dot{V}O_2$, *per se*, is therefore more likely to be indirectly, rather than directly, related to effort perception.

3) Elevations in minute ventilation may be occasioned by an individual's cognitive appraisal of a particular work environment. Furthermore, if a work task is of sufficient intensity to enable individuals to consciously monitor ventilatory stress, it is likely that $\dot{V}E$ can mediate ratings of perceived exertion.

4) Local factors play a more important role in the perception of exertion than was previously thought. It is likely that when a particular cue becomes accentuated by either elevated rate, concentration or value, it can dominate the overall rated perceived exertion. The nature of the work task may also play a role in mediating the potentiating input of a particular factor.

5) The perception of exertion is influenced by cognition to a large

degree. Cognitive appraisal of a work task can affect the RPE for that work task. Furthermore, cognitive expectancy as to the nature of a task could affect the relative contributions of differentiated ratings to the overall perceived effort. Sensory stimuli in an environment can prevent percepts from being brought into focal awareness, consequently affecting RPE. Sensory cues for perceived exertion thus interact with psychological factors prior to perception, and the conscious recognition of exertional cues is amenable to mediation by cognition.

6) Environmental cues, or the ambience of a particular working environment, can exert a substantial influence on ratings of perceived exertion. By reducing the role of physiological feedback and attention to internal states, working in a field rather than a laboratory situation can result in depressed RPE for the former condition. Environmental influences may therefore render direct perceptual translations from the laboratory to the field invalid.

7) Attitudes towards a work task could, in some presently unidentified manner, mediate the self-reports of exertion for that particular task. Attitudes in turn may be mediated by perceptions and cognitions of a particular working environment.

8) The perception of effort is a multidimensional construct, and numerous physiological, psychological, social and environmental factors interact to contribute towards the overall Gestalt of perceived exertion.

HYPOTHESIS RETENTION/REJECTION

HYPOTHESIS A: The results of the research support a *tentative acceptance of the alternate hypothesis*, namely that: There are differences between local ratings of perceived exertion obtained in the field and local ratings of perceived exertion obtained in the laboratory, when the overall performance and physiological measures are equated, when attitudes towards the conditions are taken into account, and when the field conditions with respect to temperature and gradient are simulated on the treadmill.

HYPOTHESIS B: The results of the research support a *tentative retention of the null hypothesis*, namely that: There are no differences between central ratings of perceived exertion obtained in the field and central ratings of perceived exertion obtained in the laboratory, when the overall performance and physiological measures are equated, when attitudes towards the condition are taken into account, and when the field conditions with respect to temperature and gradient are simulated on the treadmill.

HYPOTHESIS C: The results of the research support a *tentative acceptance of the alternate hypothesis*, namely, that: There are differences between overall ratings of perceived exertion obtained in the field and overall ratings of perceived exertion obtained in the laboratory, when the overall performance and physiological measures are equated, when attitudes towards the condition are taken into account, and when the field conditions with respect to temperature and gradient are simulated on the treadmill.

RECOMMENDATIONS

1) That the conscious monitoring of minute ventilation, and the consequent effect on RPE, be more closely examined so as to further identify the mechanisms that underlie the potentiating impact of this central factor on the ratings of perceived exertion.

2) That the relative contributions of differentiated RPE be further examined by taking into account task specificity or any characteristic features inherent in a particular task. This will elucidate the interaction of variables contributing to RPE and may also clarify a further portion of the unexplained variance in RPE.

3) That RPE be accessed during work rates both at and above the subjects' anaerobic threshold, in order to ascertain whether the AT is an anchor point for the perception of effort, and to examine perceptual responses to work above the AT.

4) That the impact of cognition on RPE be more closely examined by accessing cognitive expectancies towards a work task.

5) That, if a similar study were to be conducted, the work task be performed at or near 0% grade, in order to avoid task expectancy

concerning the nature of the task influencing RPE.

6) That the aims of the present research be applied to an ergonomic problem, namely: for a manual work task, will behavioural responses (such as RPE) be affected by the working environment. In other words, can a more "comfortable" working environment be created, specifically related to the perception of exertion responses.

7) That an attempt be made to further reduce the unexplained variance in RPE by examining the link between attitudes and the perception of effort. Such research should not only attempt to identify the pathway whereby attitudes influence RPE, but also to explain this mediation in cause and effect terms.

8) That future research in this area be conducted on a larger, more heterogenous group, so that findings can have more general applicability.

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APPENDIX 1

The Borg RPE Scale

RATINGS OF PERCEIVED EXERTION

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

APPENDIX 2

Informed Consent Form

Rhodes University

Department of Human Movement Studies

Subject Informed Consent Form

I, ..., having been fully informed of the nature of the research entitled Physiological and psychophysical factors in the Ratings of Perceived Exertion during uphill overground and treadmill running, do hereby give my consent to act as a subject in the above-named research.

Procedures, risks and benefits.

You will be asked to run five times; once on the road and four times on the treadmill. The tests will be as follows:

A. A short session (10 min.) designed to achieve treadmill habituation. (This will not be necessary if you have previous treadmill experience.)

B. A test of maximal work capacity involving a progressively increasing speed run on the treadmill while we continuously measure oxygen consumption via inspired and expired air analysis.

C. A treadmill run at set grades and at a pre-determined percentage of your maximal work capacity, to determine running speed at that grade and percentage.

D. A four kilometre road run at a predetermined speed.

E. A four kilometre run on the treadmill during which an attempt will be made to replicate the conditions that occurred in D, e.g. grade and running speed.

During tests B - E the following data will be collected: Heart Rate, Oxygen consumption, Pulmonary ventilation, Respiration rate, Ratings of Perceived Exertion and muscular discomfort.

Prior to test D we will measure your height, body mass and four skinfolds. Before tests D and E you will also be asked to fill in a pre-test questionaire.

The risks you may encounter during these experiments are similar to those experienced during light to heavy exercise. We will have a safety person on hand at all times to protect your interests.

The benefits you will accrue will include personal information on your maximal exercise capability ($\dot{V}O_2$ max), your Ratings of Perceived Exertion and an estimate of your percent body fat, your lean body mass and ideal body mass. Furthermore, you will be providing a valuable service to the advancement of our knowledge in this area of human performance.

I am fully aware of the procedures involved as well as the potential risks and benefits attendant to my participation as explained to me verbally and in writing. In agreeing to participate in this research, I waive any legal recourse against the researchers or

Rhodes University, from any and all claims resulting from personal injuries sustained. This waiver shall be binding upon my heirs and personal representatives.

I realise that it is necessary for me to promptly report to the researcher any signs or symptoms indicating any abnormality or distress.

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

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

Subject (or legal representative)

_______________ _______________ _____

(Print name) (Signature) (Date)

Person Administering Informed Consent

_______________ _______________ _____

(Print name) (Signature) (Date)

Witness

_______________ _______________ _____

(Print name) (Signature) (Date)

Project Supervisor

_______________ _______________ _____

(Print name) (Signature) (Date)

APPENDIX 3

Attitudinal Questionnaires

Attitudinal Questionnaire

Name:

Date:

Instructions:

You will be asked to give a graded response towards certain adjectives that may reflect your feelings towards running outdoors .Here is how to use these scales: You can place your mark (x) in one of seven places between each adjective pair. The proximity of your mark to either adjective will depend on which end of the scale seems most characteristic of running outdoors .

Example 1: If you feel that running outdoors is extremely pleasant, place your mark as follows:

PLEASANT	X							UNPLEASANT

Example 2: If you feel that running outdoors is very pleasant, place your mark as follows:

PLEASANT		X						UNPLEASANT

Example 3: If you feel that running outdoors is fairly pleasant, place your mark as follows:

PLEASANT			X					UNPLEASANT

Example 4: If you feel that running outdoors is neither pleasant nor unpleasant, place your mark as follows:

PLEASANT				X				UNPLEASANT

Example 5: If you feel that running outdoors is fairly unpleasant, place your mark as follows:

PLEASANT					X			UNPLEASANT

Example 6: If you feel that running outdoors is very unpleasant, place your mark as follows:

PLEASANT						X		UNPLEASANT

Example 7: If you feel that running outdoors is extremely unpleasant, place your mark as follows:

PLEASANT							X	UNPLEASANT

Rate the concepts in order and do not omit any. Please do not look back and forth through the items. Do not try and remember how you marked similar items earlier in the test. Make each item a separate and independent judgement. Work at fairly high speed throughout the test. Do not worry or puzzle over individual items. It is your first impressions, the immediate feelings that we want. On the other hand please do not be careless, as we want your true impressions.

RUNNING OUTDOORS IS ....

INTERESTING								BORING
STRENUOUS								EFFORTLESS
UNENJOYABLE								ENJOYABLE
RELAXED								INTENSE
UNEVENTFUL								EVENTFUL
PLEASANT								UNPLEASANT
SEVERE								UNDEMANDING
SLOW								FAST
LIGHT								HEAVY
WORTHLESS								WORTHWHILE
RUGGED								GENTLE
DYNAMIC								STATIC

Attitudinal Questionnaire

Name:

Date:

Instructions:

You will be asked to give a graded response towards certain adjectives that may reflect your feelings towards running on the treadmill .Here is how to use these scales: You can place your mark (x) in one of seven places between each adjective pair. The proximity of your mark to either adjective will depend on which end of the scale seems most characteristic of running on the treadmill .

Example 1: If you feel that running on the treadmill is extremely pleasant, place your mark as follows:

PLEASANT	X							UNPLEASANT

Example 2: If you feel that running on the treadmill is very pleasant, place your mark as follows:

PLEASANT		X						UNPLEASANT

Example 3: If you feel that running on the treadmill is fairly pleasant, place your mark as follows:

PLEASANT			X					UNPLEASANT

Example 4: If you feel that running on the treadmill is neither pleasant nor unpleasant, place your mark as follows:

PLEASANT				X				UNPLEASANT

Example 5: If you feel that running on the treadmill is fairly unpleasant, place your mark as follows:

PLEASANT					X			UNPLEASANT

Example 6: If you feel that running on the treadmill is very unpleasant, place your mark as follows:

PLEASANT						X		UNPLEASANT

Example 7: If you feel that running on the treadmill is extremely unpleasant, place your mark as follows:

PLEASANT							X	UNPLEASANT

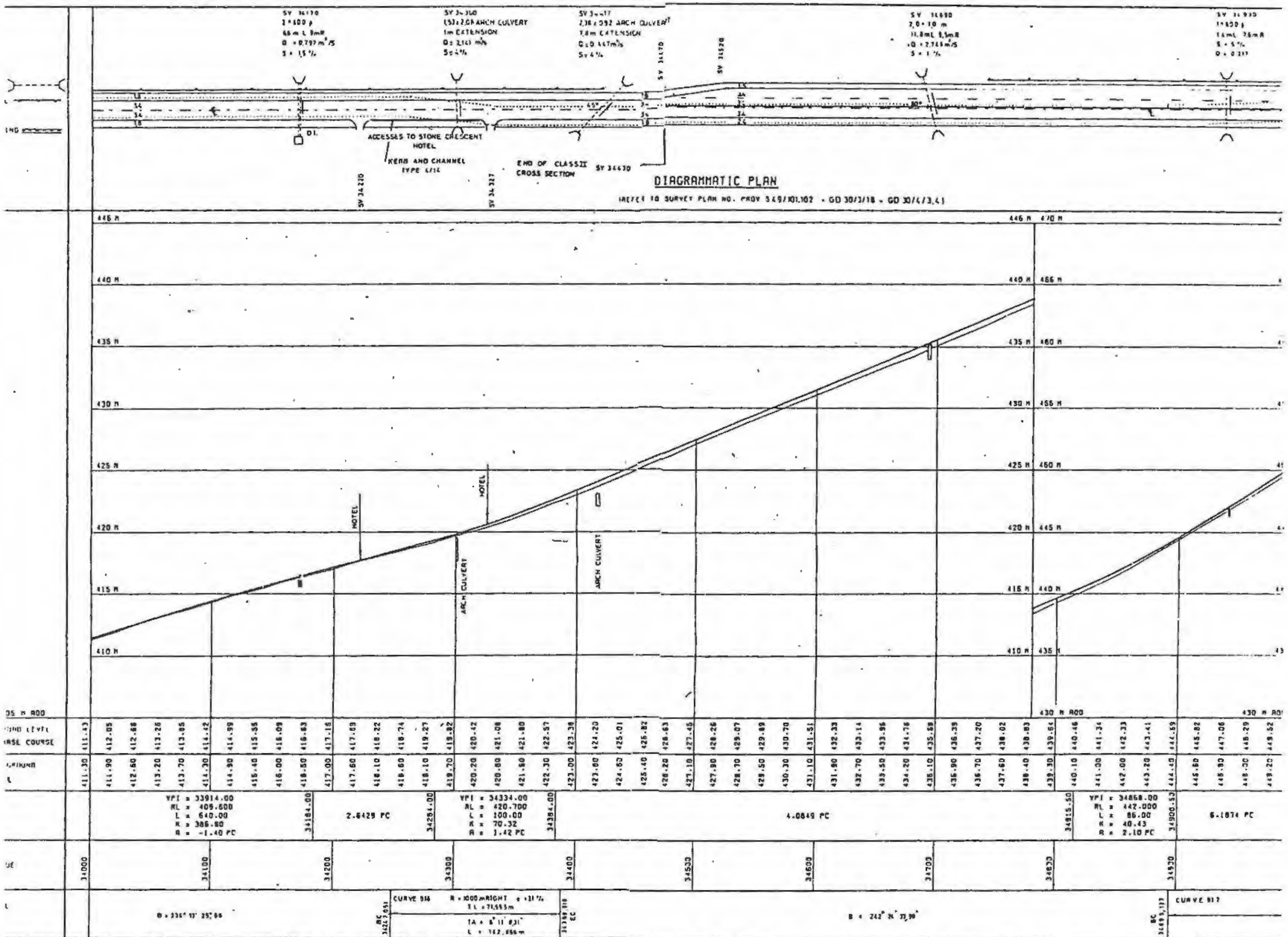
Rate the concepts in order and do not omit any. Please do not look back and forth through the items. Do not try and remember how you marked similar items earlier in the test. Make each item a separate and independent judgement. Work at fairly high speed throughout the test. Do not worry or puzzle over individual items. It is your first impressions, the immediate feelings that we want. On the other hand please do not be careless, as we want your true impressions.

RUNNING ON THE TREADMILL IS ....

INTERESTING								BORING
STRENUOUS								EFFORTLESS
UNENJOYABLE								ENJOYABLE
RELAXED								INTENSE
UNEVENTFUL								EVENTFUL
PLEASANT								UNPLEASANT
SEVERE								UNDEMANDING
SLOW								FAST
LIGHT								HEAVY
WORTHLESS								WORTHWHILE
RUGGED								GENTLE
DYNAMIC								STATIC

APPENDIX 4

Trunk Road 2/15 Komgha River - Grahamstown, Kilometres 34.2 - 38.2.



DESIGNED BY. L E T S

DRAWN BY.

CHECKED BY. L E T S

PROVINCIAL ROADS ENGINEER

DATE 22 ... 83

CAPE PROVINCIAL ADMINISTRATION

DEPARTMENT OF ROADS

TRUNK ROAD 2/15 KOMGHA RIVER - GRAHAMSTOWN

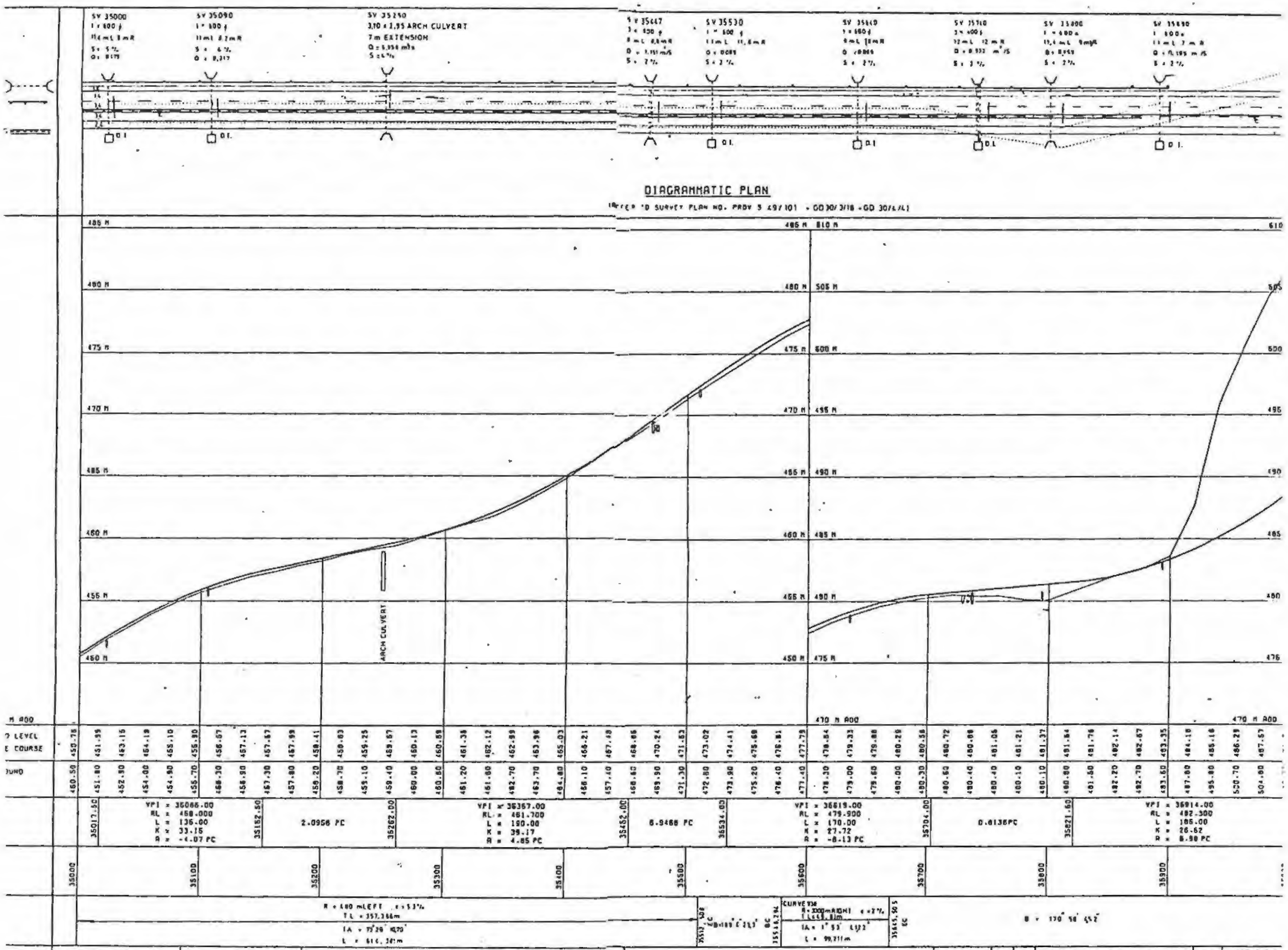
LONGITUDINAL SECTION

FROM km 34.00 TO km 35.00

SCALE
HOR. 1 2000
VERT. 1 200

DRAWING
GD 9

2-16/37



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CHECKED BY. L E T S

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CAPE PROVINCIAL ADMINISTRATION
DEPARTMENT OF ROADS
TRUNK ROAD 2/15 KOMGHA RIVER - GRAHAMSTOWN

LONGITUDINAL SECTION
FROM km 35.00 TO km 36.00

SCALE
HOR. 1 2000
VERT. 1 200

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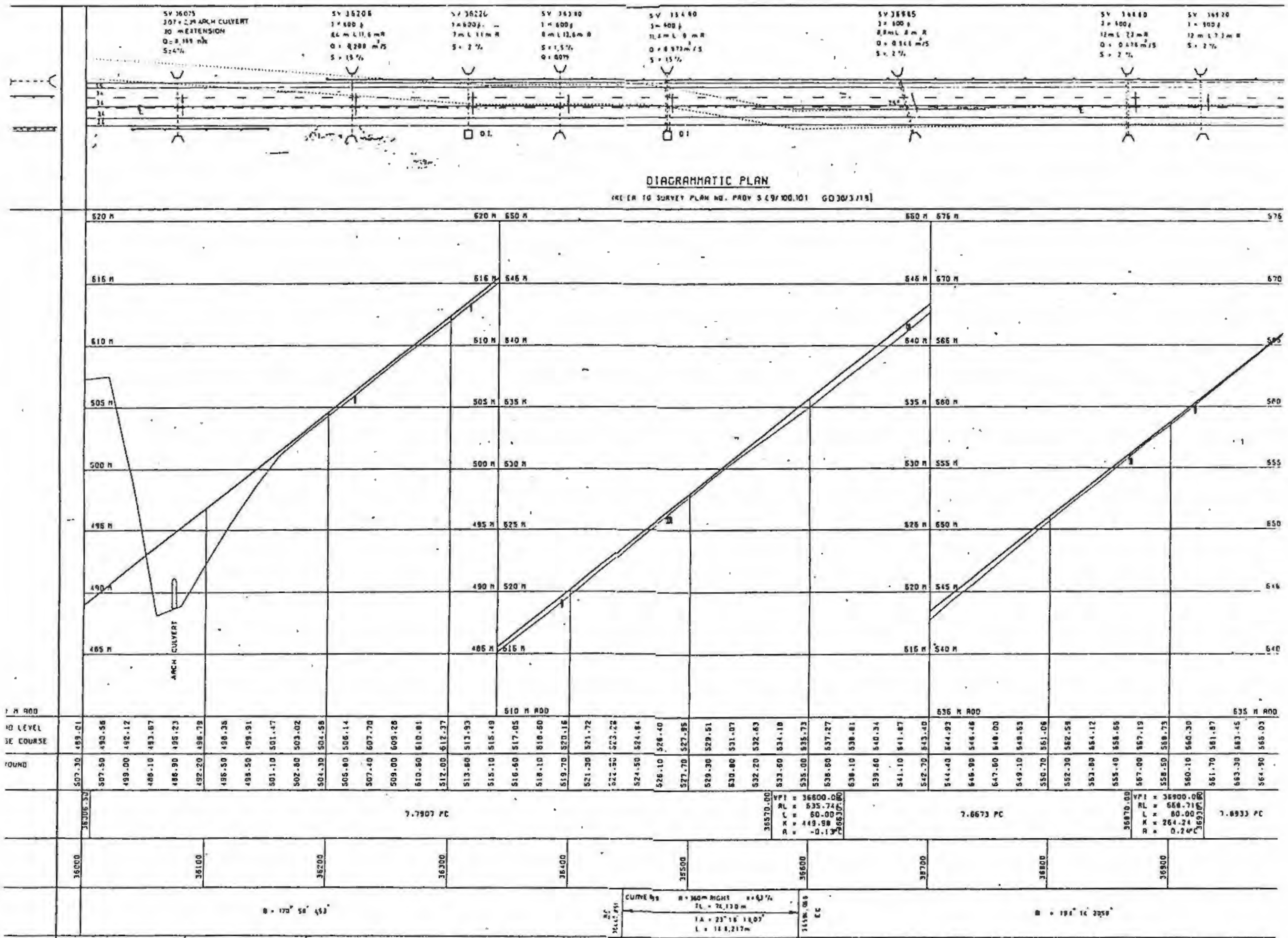

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CHECKED BY: L E T S	DATE	

LONGITUDINAL SECTION
FROM km 36.00 TO km 37.00

SCALE
HOR. 1 2000
VERT. 1 200

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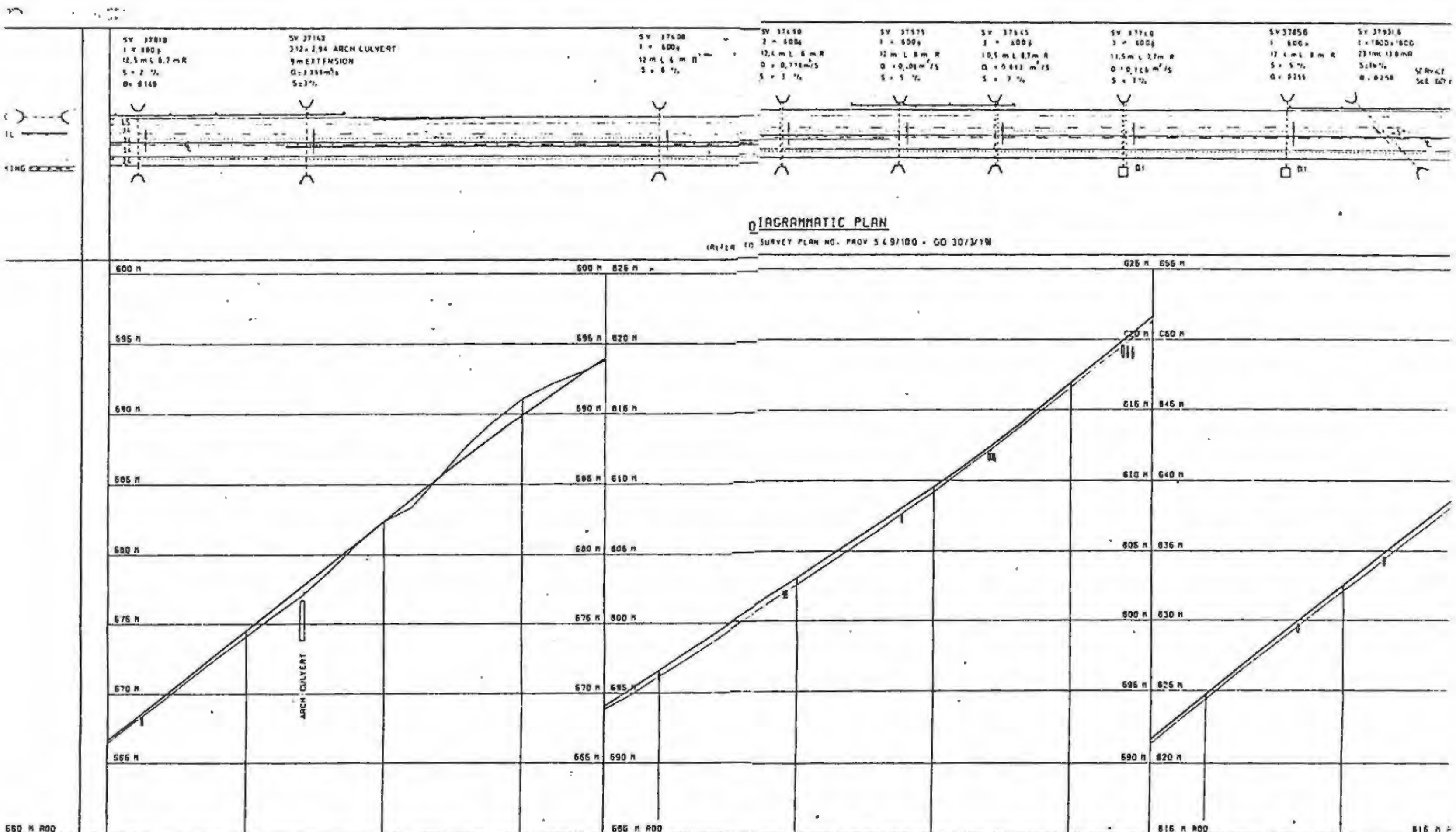
GD 9/



560 M ROD

585 M ROD

615 M ROD

615 M

ROAD LEVEL BASE COURSE	GROUND ℄
566.61	566.40
568.19	568.00
569.77	569.50
571.35	571.10
572.92	572.60
574.50	574.10
576.08	575.60
577.66	577.00
579.24	578.80
580.82	580.70
582.40	582.40
583.96	583.40
585.40	585.50
586.90	587.70
588.15	589.60
589.89	591.10
591.29	592.10
592.67	592.90
594.01	593.80
595.32	594.90
596.62	596.20
597.91	597.40
599.21	598.70
600.50	600.00
601.79	601.30
603.09	602.60
604.38	603.90
605.68	606.20
606.97	606.60
608.26	607.90
609.56	609.20
610.92	610.70
612.34	612.10
613.84	613.40
615.39	615.10
616.95	616.80
618.50	618.20
620.06	619.70
621.62	621.30
623.17	622.90
624.73	624.40
626.29	626.00
627.84	627.50
629.40	629.00
630.96	630.60
632.51	632.10
634.07	633.60
635.63	636.20
637.18	636.70
638.74	638.30

7.8933 PC

37197.50

VPI = 37290.00
RL = 589.500
L = 186.00
K = 130.03
A = -1.42 PC

37382.50

C.4708 PC

37592.60

VPI = 37630.00
RL = 611.500
L = 75.00
K = 57.14
A = 1.31 PC

37667.60

7.7831 PC

37000 37100 37200 37300 37400 37500 37600 37700 37800 37900

BC 37177.261

CURVE 840

R = 380 m LEFT e = 6.3%
TL = 265.218 m
I.A. = 85° 40' 7.56"
L = 435.532 m

37612.795 EC

θ = 128° 34' 130"

DESIGNED BY. L E T S
DRAWN BY.
CHECKED BY. L E T S

PROVINCIAL ROADS ENGINEER
DATE

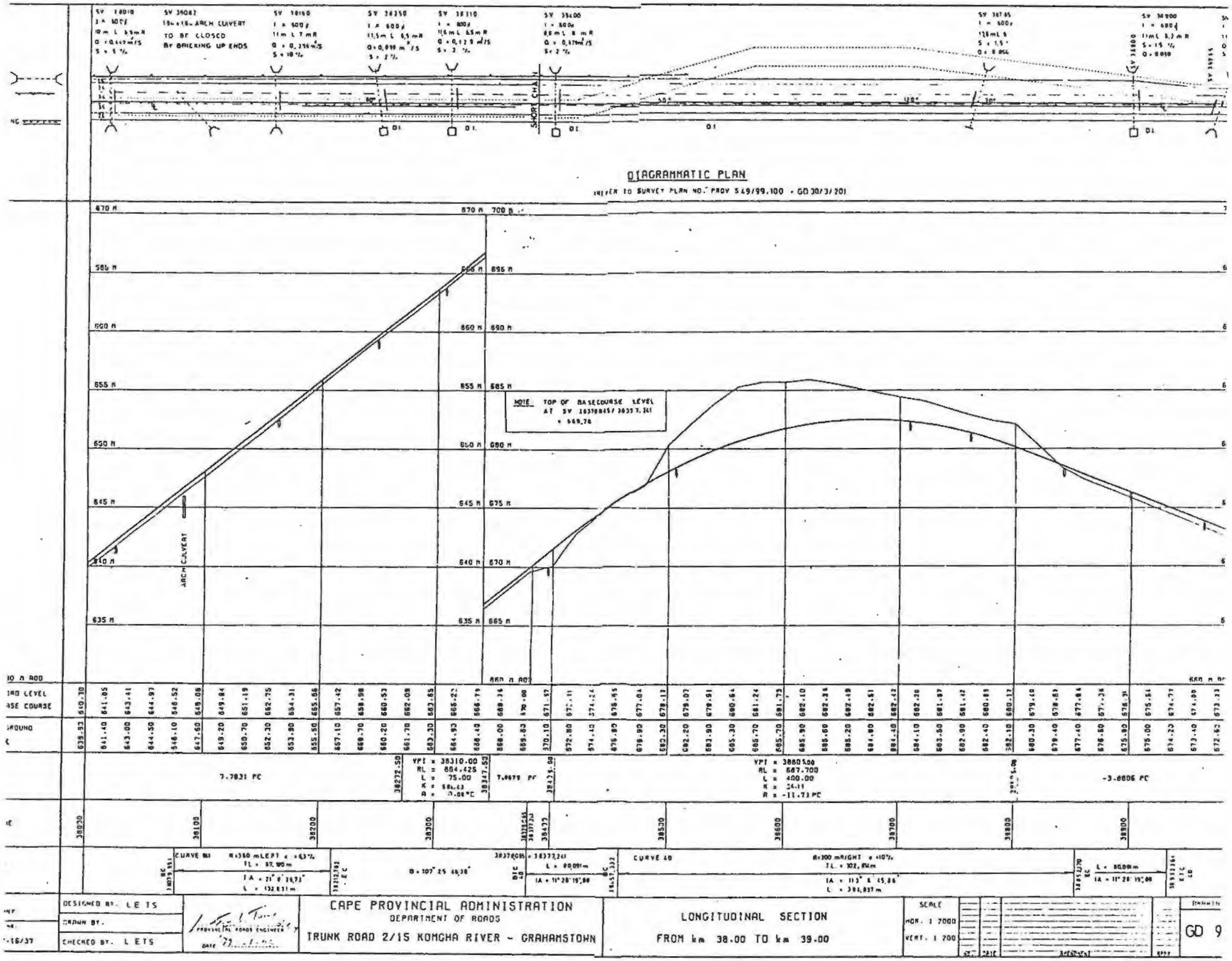
12-15/37

CAPE PROVINCIAL ADMINISTRATION
DEPARTMENT OF ROADS
TRUNK ROAD 2/15 KOMGHA RIVER - GRAHAMSTOWN

LONGITUDINAL SECTION
FROM km 37.00 TO km 38.00

SCALE
HOR. 1 2000
VERT. 1 200

GD 7



DESIGNED BY. L E T S
DRAWN BY.
CHECKED BY. L E T S

PROVINCIAL ROADS ENGINEER
DATE '77

CAPE PROVINCIAL ADMINISTRATION
DEPARTMENT OF ROADS
TRUNK ROAD 2/15 KOMGHA RIVER - GRAHAMSTOWN

LONGITUDINAL SECTION
FROM km 38.00 TO km 39.00

SCALE
HOR. 1 2000
VERT. 1 200

GD 9

APPENDIX 5

Formulae For Body Fat Predictions

1. Sum the four skinfolds and convert to a common logarithmic value (base 10).

2. Substitute the logarithmic value in one of the following appropriate regression formulae to obtain a predicted body density:

<u>Age</u>	<u>Formulae</u>
20-29	$D = 1.1631 - (0.0632 \times L)$
30-39	$D = 1.1422 - (0.0544 \times L)$
40-49	$D = 1.1620 - (0.0700 \times L)$

Where D = predicted body density ($g.ml^{-1}$)
L = common log of the sum of the four skinfolds

3. Calculate the relative body fat.

$$RBF = 100 \left(\frac{4.57}{D} - 4.142\right)$$

Where RBF = Relative Body Fat (%)

4. Calculate the absolute body fat

$$ABF = \frac{RBF \times BM}{100}$$

Where ABF = Absolute Body Fat (kg)
BM = Body Mass (kg)

5. Calculate lean body mass.

$$LBM = BM - ABF$$

Where LBM = Lean Body Mass (kg)

APPENDIX 6

"Cont 30" Computer Printout

"Manual" Computer Printout

```
            ON-LINE PHYSIOLOGICAL DATA
                ========================

EXPERIMENT: LAB
CONDITION: 1

SUBJECT NAME:                (M)              AGE:  23      MASS (KG):  85

MAXIMAL OXYGEN UPTAKE (ML/KG/MIN):  58.7

DATE: 3.10.87                                 TIME OF DAY: 12H00

BAROMETRIC PRESSURE (MM HG):  729.17          RELATIVE HUMIDITY (%):  73

THE COLUMN HEADED 'TIME' SHOWS THE ELAPSED TIME FROM THE START
OF THE EXPERIMENT TO THE START OF THE CURRENT SAMPLE PERIOD.
THE NUMBER IN BRACKETS IS THE SAMPLE DURATION IN SECONDS.

-------------------------------------------------------------------------------------------------------------------------------
NO      TIME        R VO2   VO2  VCO2   R   VI(STPD) HR    F   TEMP  FEO2    FECO2  VE-O2 VE-CO2   Q    SV   O2 PU   VT    SPEED
                    ML/KG   L/M  L/M          L/M   B/M  BR/M                        L/100ML      L/M  ML/B  ML/B  L/BR   KM/HR
-------------------------------------------------------------------------------------------------------------------------------

 1 00:06:45( 60 )  40.1   3.41  3.13  .92   69.76   47    47  17.4  .1611  .0454   2.05  2.23   23.3  485  70.97  1.48   9.94

  %VO2 MAX=  68.3

 2 02:12:52( 60 )  40.7   3.46  3.17  .92   74.82   47    50  17.5  .1637  .0429   2.16  2.36   23.6  491  72.11  1.5    9.52

  %VO2 MAX=  69.3

 3 00:19:33( 60 )  47.2   4.01  3.85  .96   92.17   47    54  17.5  .1661  .0422   2.3   2.39   26.5  552  83.77  1.71   9.12

  %VO2 MAX=  80.4

 4 00:26:06( 60 )  47.5   4.04  3.82  .95   95.47   47    56  17.6  .1674  .0405   2.37  2.5    26.6  555  84.26  1.7    9.09

  %VO2 MAX=  80.9
```

```
       SUBJECT:

TEST CONDITION: 1

      VE(ATPS) = 84.8 L
      VE(ATPS) = 84.8 L/MIN
          PH2O = 13.6 MM HG
   STPD FACTOR = .87
      VE(STPD) = 73.5 L/MIN
           VO2 = 3.6 L/MIN
           VO2 = 42.4 ML/KG/MIN
          VCO2 = 3.62 L/MIN
             R = 1.01
   V.E. FOR O2 = 2.04 L/100ML O2
  V.E. FOR CO2 = 2.03 L/100ML CO2
CARDIAC OUTPUT = 24.4 L/MIN
 STROKE VOLUME = 157 ML/BT
  OXYGEN PULSE = 23.3 ML/BT
       SUBJECT: WAYNE SWANEPOEL

TEST CONDITION: 2

      VE(ATPS) = 81.6 L
      VE(ATPS) = 81.6 L/MIN
          PH2O = 13.6 MM HG
   STPD FACTOR = .87
      VE(STPD) = 70.7 L/MIN
           VO2 = 3.32 L/MIN
           VO2 = 39.1 ML/KG/MIN
          VCO2 = 3.19 L/MIN
             R = .96
   V.E. FOR O2 = 2.13 L/100ML O2
  V.E. FOR CO2 = 2.22 L/100ML CO2
CARDIAC OUTPUT = 22.9 L/MIN
 STROKE VOLUME = 145 ML/BT
  OXYGEN PULSE = 21 ML/BT
       SUBJECT: WAYNE SWANEPOEL

TEST CONDITION: 3

      VE(ATPS) = 104.8 L
      VE(ATPS) = 104.8 L/MIN
          PH2O = 13.6 MM HG
   STPD FACTOR = .87
      VE(STPD) = 90.8 L/MIN
           VO2 = 3.95 L/MIN
           VO2 = 46.5 ML/KG/MIN
          VCO2 = 3.95 L/MIN
             R = 1
   V.E. FOR O2 = 2.3 L/100ML O2
  V.E. FOR CO2 = 2.3 L/100ML CO2
CARDIAC OUTPUT = 26.2 L/MIN
 STROKE VOLUME = 158 ML/BT
  OXYGEN PULSE = 23.9 ML/BT
       SUBJECT: WAYNE SWANEPOEL

TEST CONDITION: 4

      VE(ATPS) = 106.9 L
      VE(ATPS) = 106.9 L/MIN
          PH2O = 13.6 MM HG
   STPD FACTOR = .87
      VE(STPD) = 92.6 L/MIN
```

APPENDIX 7

Calculations Used To Determine Derived Data For The Overground Condition.

Computation Procedures

1. Expired Volume ($\dot{V}E$)(ATPS)

$\dot{V}E$ (ATPS) (L) = $(V_2 - V_1) \times 0.9876$

Where: V_1 = Initial volumeter reading (L)

V_2 = Final volumeter reading (L)

0.9876 = Volume conection factor.

2. Minute Volume ($\dot{V}E$ (ATPS):

$$\dot{V}E\ (ATPS)\ (L.min^{-1}) = \frac{(\dot{V}E/(ATPS)(L)\ X\ 60)}{\text{Collection time (s)}}$$

3. Partial pressure of Water vapour (PH_2O):

$$PH_2O\ (mmHg) = 2.718\ (2.303\ [8.10765-(\frac{1750.286}{235 + t})])$$

Where: t = gas temperature (°C)

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

$$\text{STPD factor} = \frac{273}{t+273} \quad X \quad \frac{(PB - PH_2O)}{700}$$

Where: t = ambient temperature (°C)

PB = corrected barometric pressure (mmHg)

PH_2O = water vapour pressure (mmHg)

5. Minute Volume ($\dot{V}E$) (STPD):

$\dot{V}E$ (STPD) (L.min^{-1}) = $\dot{V}E$ (ATPS)(L.min^{-1}) X STPD factor.

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

$$\dot{V}O_2\ (L.min^{-1}) = \dot{V}E\ (STPD)(L.min^{-1})\ X\ (0.265\ FEN_2 - FEO_2)$$

Where $0.265 = \dfrac{\text{Fraction of inspired oxygen}}{\text{Fraction of inspired nitrogen}}\ \dfrac{(FIO_2)}{FIN_2}$

FEN_2 = Fraction of expired nitrogen:

$1 - (FEO_2 - FECO_2)$

FEO_2 = Fraction of expired oxygen

$FECO_2$ = Fraction of expired carbon dioxide

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

$$\dot{V}O_2\ (ml.kg^{-1}.min^{-1}) = \frac{\dot{V}O_2\ (Lmin^{-1})\ X\ 1000}{\text{Body mass (kg)}}$$

8. Carbon dioxide production $\dot{V}CO_2$:

$$\dot{V}CO_2\ (L.min^{-1}) = VE\ (STPD)(L.min^{-1})\ X\ FECO_2$$

9. Respiratory exchange ratio (R):

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

10. Ventilatory equivalent for oxygen ($\dot{V}$.E. for O_2):

$$\dot{V}.E.\ \text{for}\ O_2\ (L.100ml\ {O_2}^{-1}) = \frac{\dot{V}E(STPD)(L.min^{-1})}{\dot{V}O_2(L.min^{-1})\ X\ 10}$$

11. Ventilatory equivalent for carbon dioxide ($\dot{V}$.E. for CO_2):

$$\dot{V}.E.\ \text{for}\ CO_2\ (L.100ml\ {CO_2}^{-1}) = \frac{\dot{V}E(STPD)(L.min^{-1})}{\dot{V}CO_2(L.min^{-1})\ X\ 10}$$

APPENDIX 8

Pilot Test Results

Table IX: Related variables' responses for pilot (test - retest) conditions (* represents significant difference).

Variable	Test Response	Retest Response	Significance ($p < 0.05$)
$\dot{V}O_2$ Max ($ml.kg^{-1}.min^{-1}$)	72.93	73.83	
Predicted Speed 3.8% ($km.hr^{-1}$)	12.20	13.15	
Predicted Speed 7.5% ($km.hr^{-1}$)	9.82	10.85	
Actual Speed 3.8% ($km.hr^{-1}$)	13.17	12.48	
Actual Speed 7.5% ($km.hr^{-1}$)	11.23	11.25	
Relative Body Fat (%)	9.71	9.71	
Absolute Body Fat (kg)	6.73	6.75	
Lean Body Mass (kg)	63.37	63.22	
Body Mass (kg)	70.10	69.97	

Table X: Related variables' responses for the field and laboratory conditions (Pilot Test 1) (* represents a significant difference).

Variable	Field	Laboratory	Significance
Heart Rate ($b.min^{-1}$)	170.25	169.25	
$\dot{V}O_2$ ($ml.kg.^{-1}.min^{-1}$)	53.63	55.55	
$\dot{V}E$ ($l.min^{-1}$)	82.73	91.31	
R	0.92	0.95	
$\dot{V}CO_2$ ($l.min^{-1}$)	3.54	3.79	
Temperature (°C)	16.33	16.00	
Barometric Pressure (mmHg)	723.15	720.29	
Relative Humidity (%)	71.00	75.66	

Table XI: Related variables' responses for the field and laboratory conditions (Pilot Test 2) (* represents a significant difference).

Variable	Field	Laboratory	Significance ($p < 0.05$)
Heart Rate ($b.min^{-1}$)	163.00	162.66	
$\dot{V}O_2$ ($ml.kg.^{-1}.min^{-1}$)	52.14	54.1	
$\dot{V}E$ ($l.min^{-1}$)	81.22	82.81	
R	0.94	0.92	
$\dot{V}CO_2$ ($l.min^{-1}$)	3.51	3.53	
Temperature (°C)	15.33	15.66	
Barometric Pressure (mmHg)	722.23	721.92	
Relative Humidity (%)	76.33	70.66	

Table XII: Related variables response for pilot (test -retest) conditions in the field (* represents a significant difference).

Variable	Test Response	Retest Response	Significance ($p < 0.05$)
Total Running Time (s)	1195.33	1223.66	
Local RPE	12.58	11.66	
Central RPE	12.08	11.00	
Overall RPE	12.08	11.25	
Heart Rate ($b.min^{-1}$)	170.25	163.00	*
$\dot{V}O_2$ ($ml.kg.^{-1}.min^{-1}$)	53.63	54.06	
$\dot{V}E$ ($l.min^{-1}$)	82.73	81.22	
R	0.92	0.94	*
$\dot{V}CO_2$ ($l.min^{-1}$)	3.54	3.51	
Temperature (°C)	16.33	15.33	
Barometric Pressure (mmHg)	723.15	722.23	
Wind Speed ($m.s^{-1}$)	2.23	1.50	
Relative Humidity (%)	71.00	76.33	
Factor E	27.25	27.00	
Factor P	18.00	17.00	
Factor A	20.25	19.50	
Total SD Score	65.25	63.25	

Table XIII: Related variables' responses for the pilot (test - retest) conditions in the laboratory (* represents a significant difference).

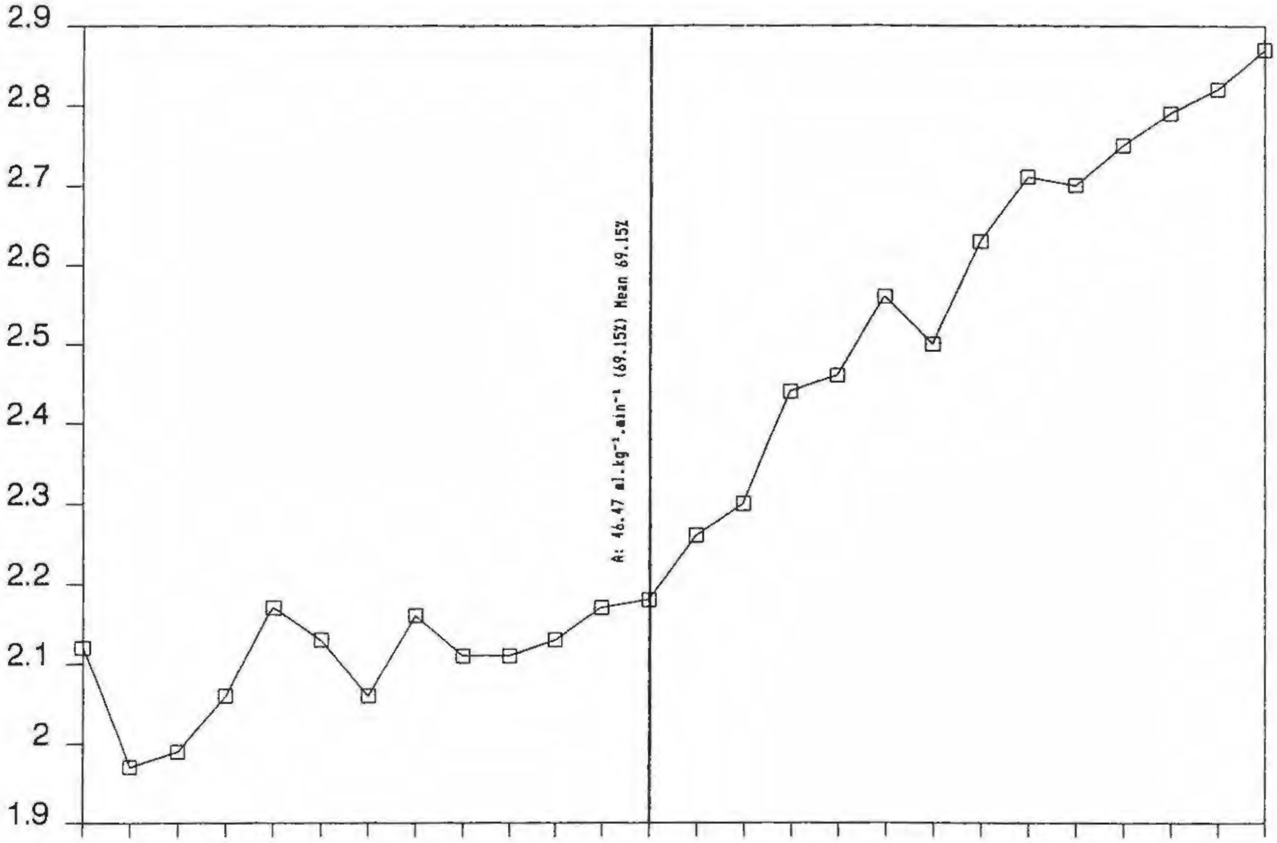
Variable	Test Response	Retest Response	Significance ($p < 0.05$)
Local RPE	13.42	12.17	*
Central RPE	11.33	11.66	
Overall RPE	12.42	12.25	
Heart Rate (b.min^{-1})	169.25	162.66	
$\dot{V}O_2$ (ml.kg.$^{-1}$.min^{-1})	55.55	54.10	
$\dot{V}E$ (l.min^{-1})	91.32	82.81	*
R	0.95	0.92	*
$\dot{V}CO_2$ (l.min^{-1})	3.79	3.53	*
Temperature (°C)	16.00	15.66	
Barometric Pressure (mmHg)	720.29	721.92	
Relative Humidity (%)	75.66	70.66	
Factor E	18.00	17.75	
Factor P	13.25	14.25	
Factor A	16.25	17.25	
Total SD Score	45.00	49.25	

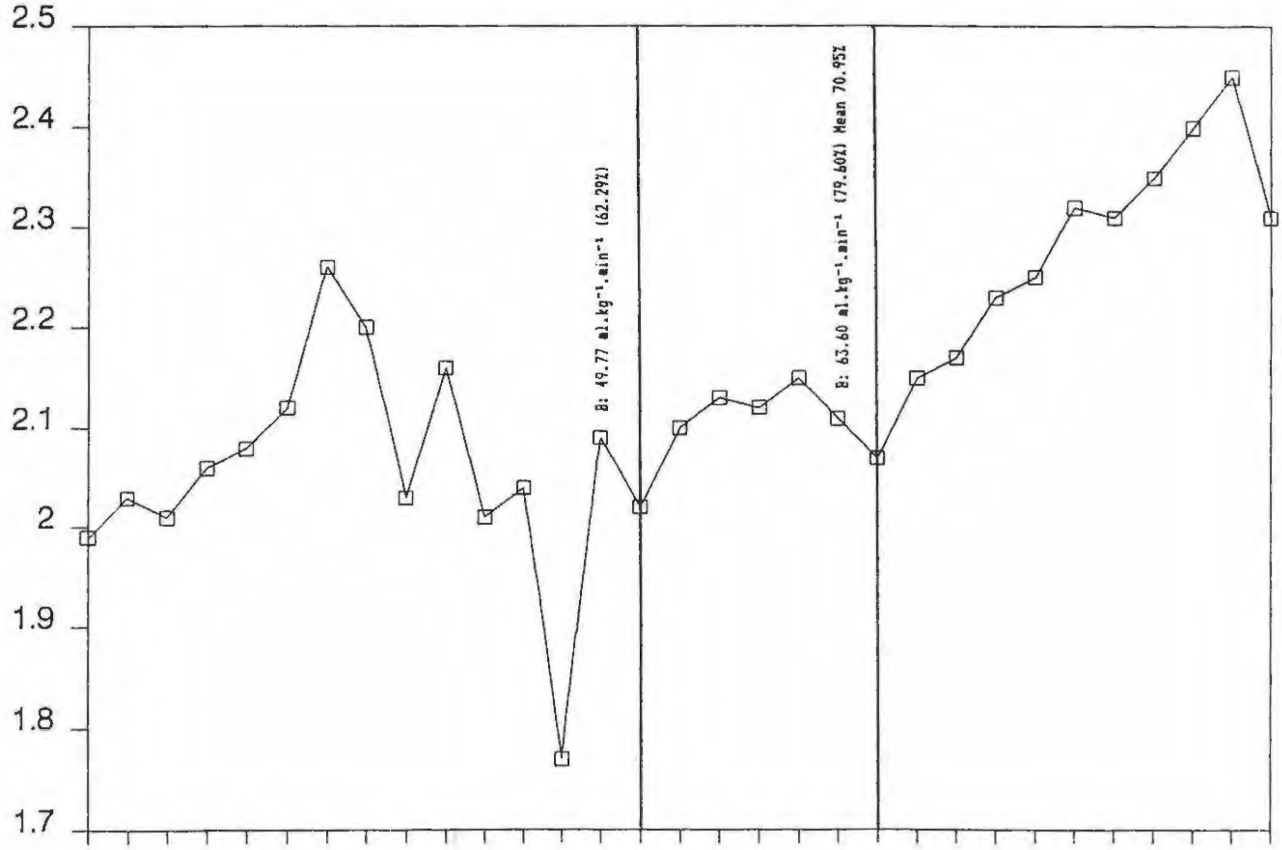
Table XIV: Significance of heart rate responses using two-factor analysis of variance with repeated measures.

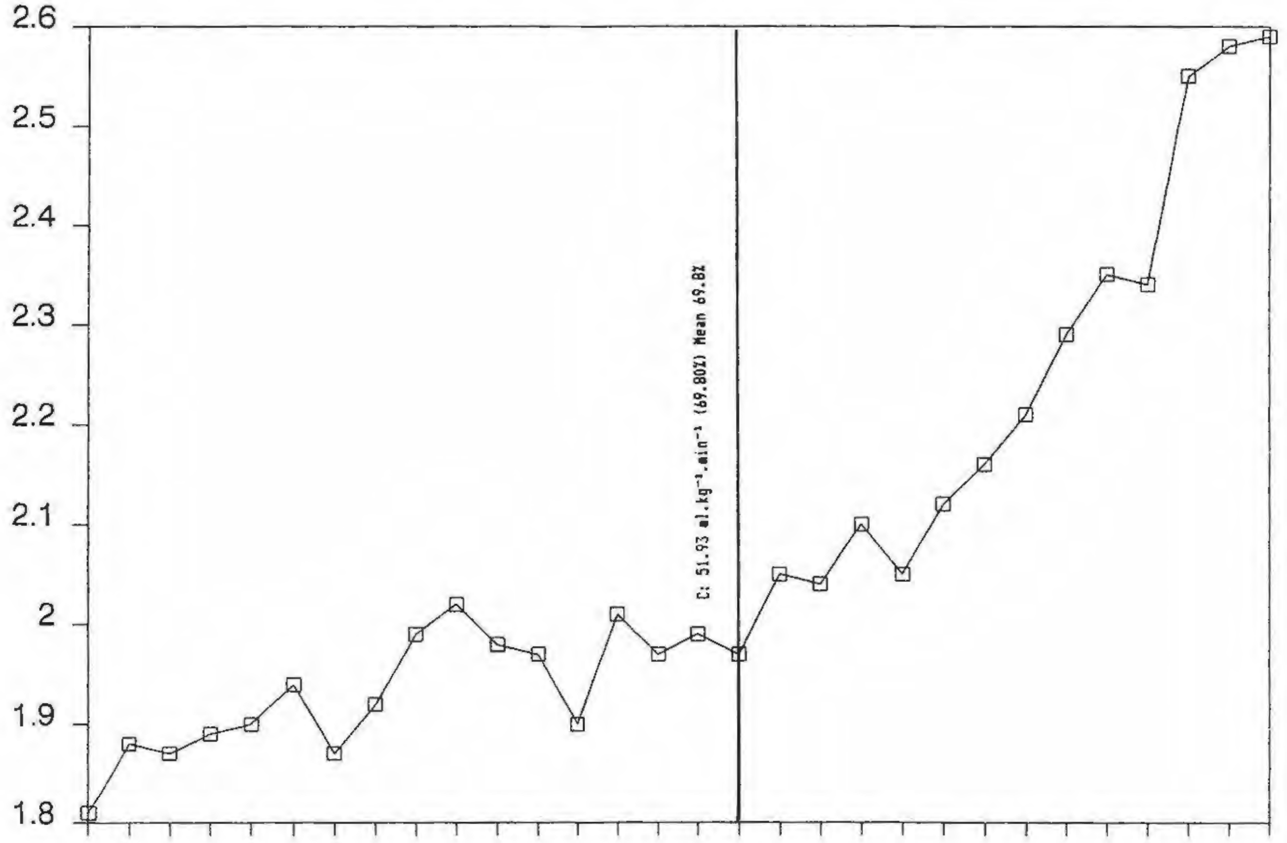
	Fc (df)	Fo	Significance
Time	2.29 (7;35)	135.072	Difference
Medium	4.10 (2;10)	1.477	No difference
Subjects	1.84 (14;70)	1.582	No interaction

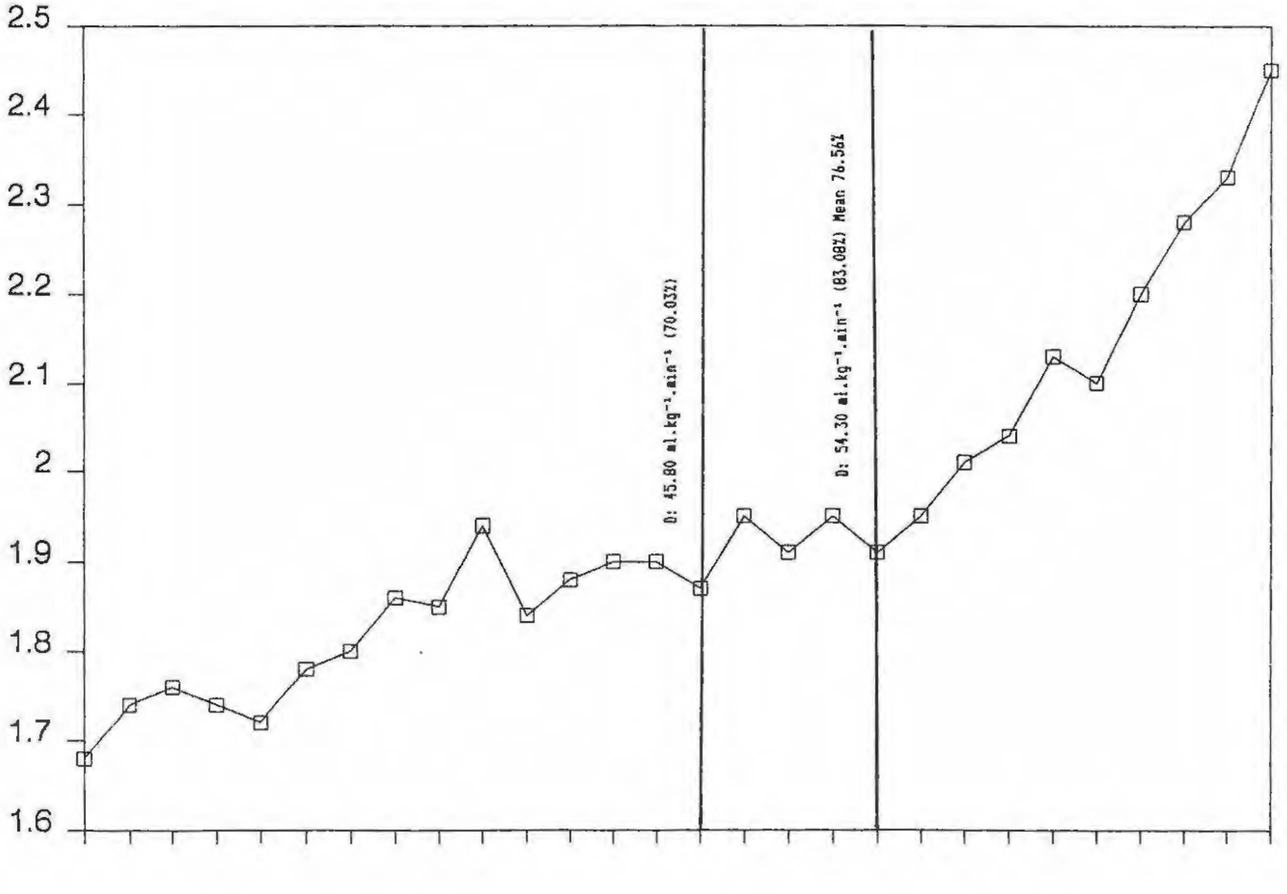
APPENDIX 9

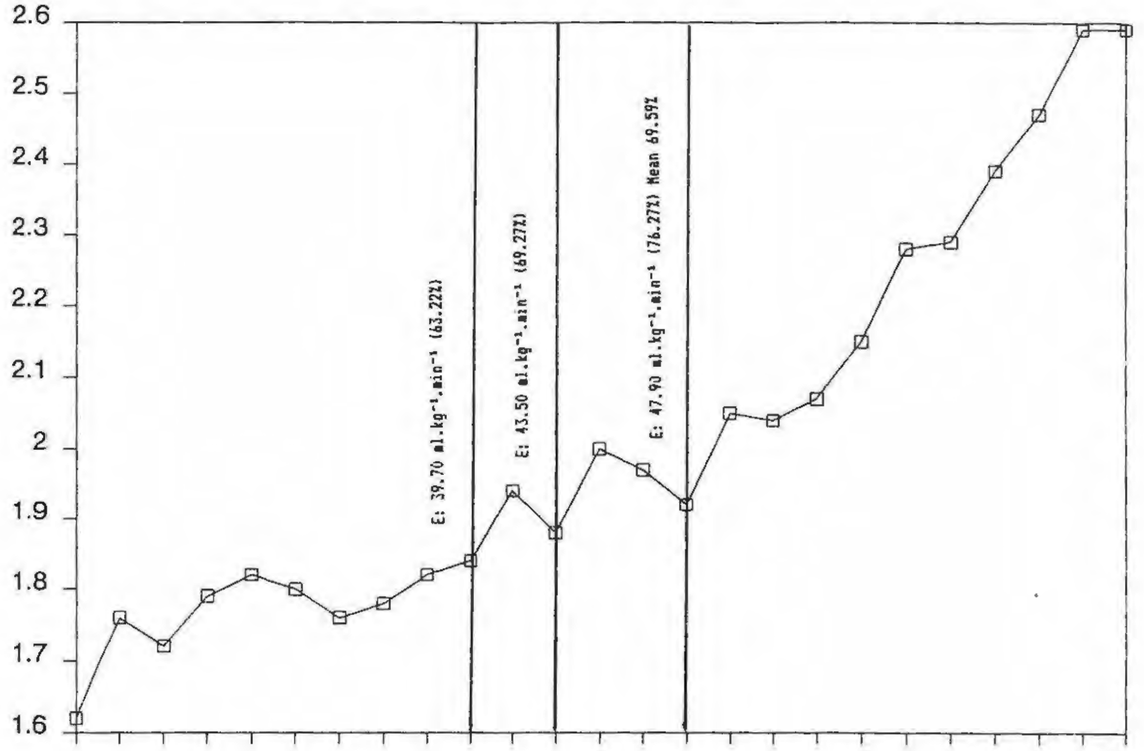
Figures 21 to 31: Estimations of Anaerobic Threshold from $\dot{V}O_2$ max data (x axis = time in 3 s intervals, y axis = $\dot{V}E - O_2$ in $1.100ml^{-1}$)

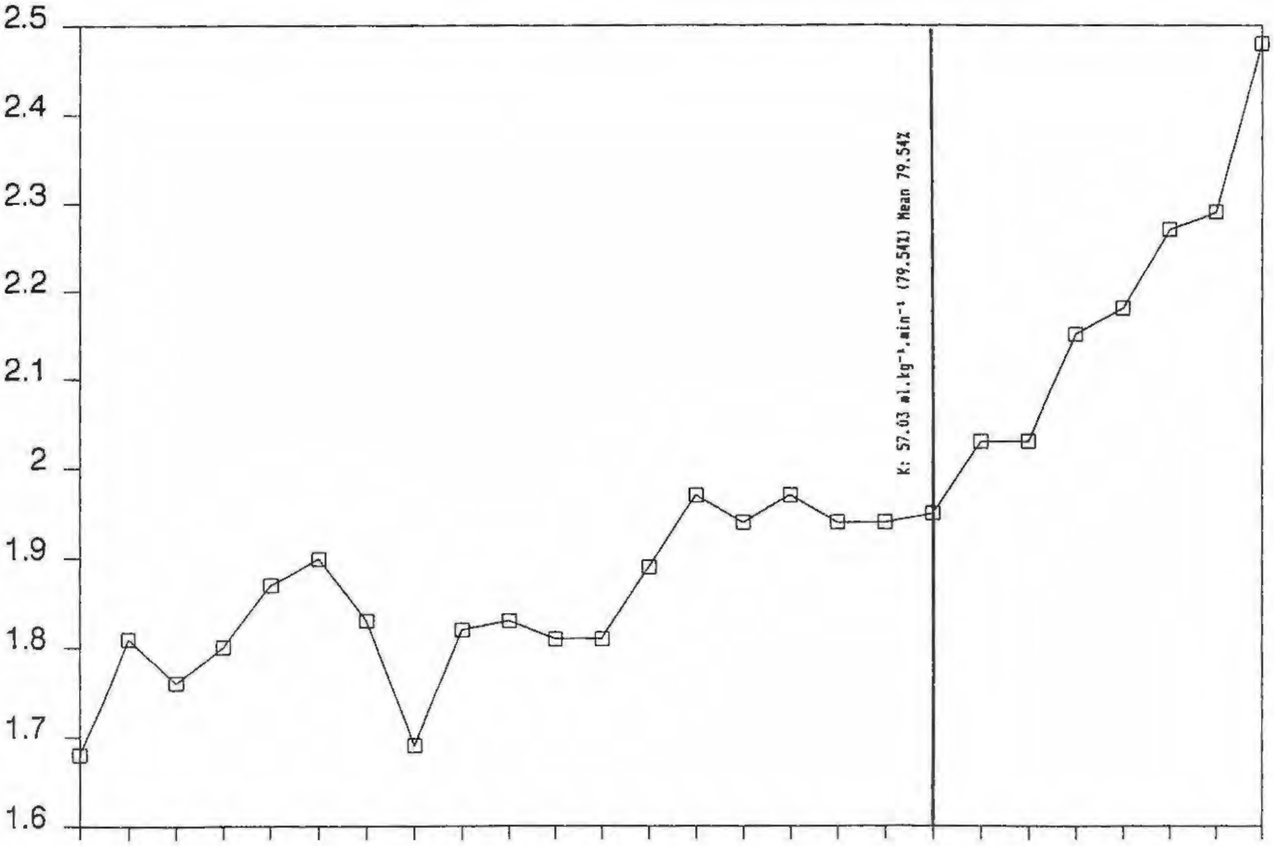

2.9
2.8
2.7
2.6
2.5
2.4
2.3
2.2
2.1
2
1.9
A: 46.47 ml.kg^{-1}.min^{-1} (69.15%) Mean 69.15%

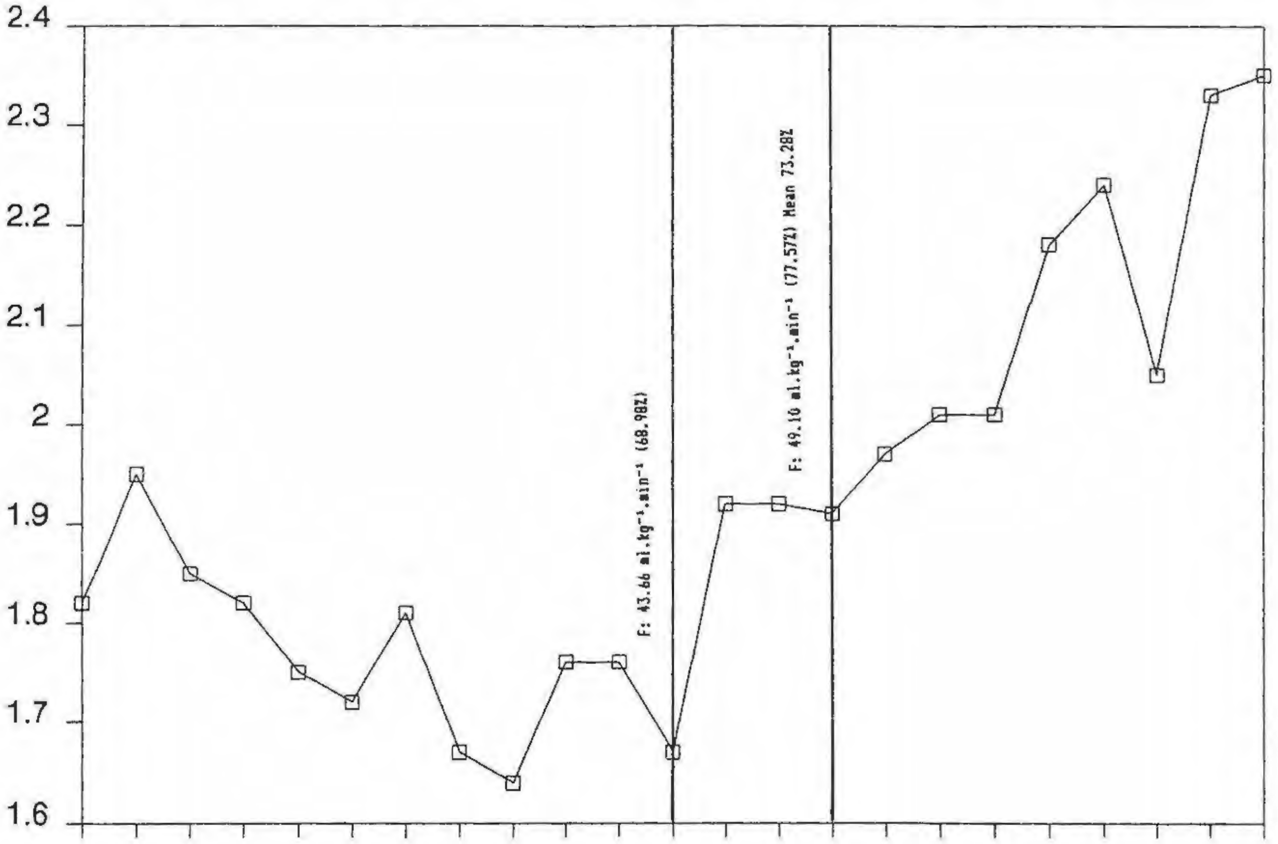

2.5
2.4
2.3
2.2
2.1
2
1.9
1.8
1.7
B: 49.77 ml.kg^{-1}.min^{-1} (62.29%)
B: 63.60 ml.kg^{-1}.min^{-1} (79.60%) Mean 70.95%

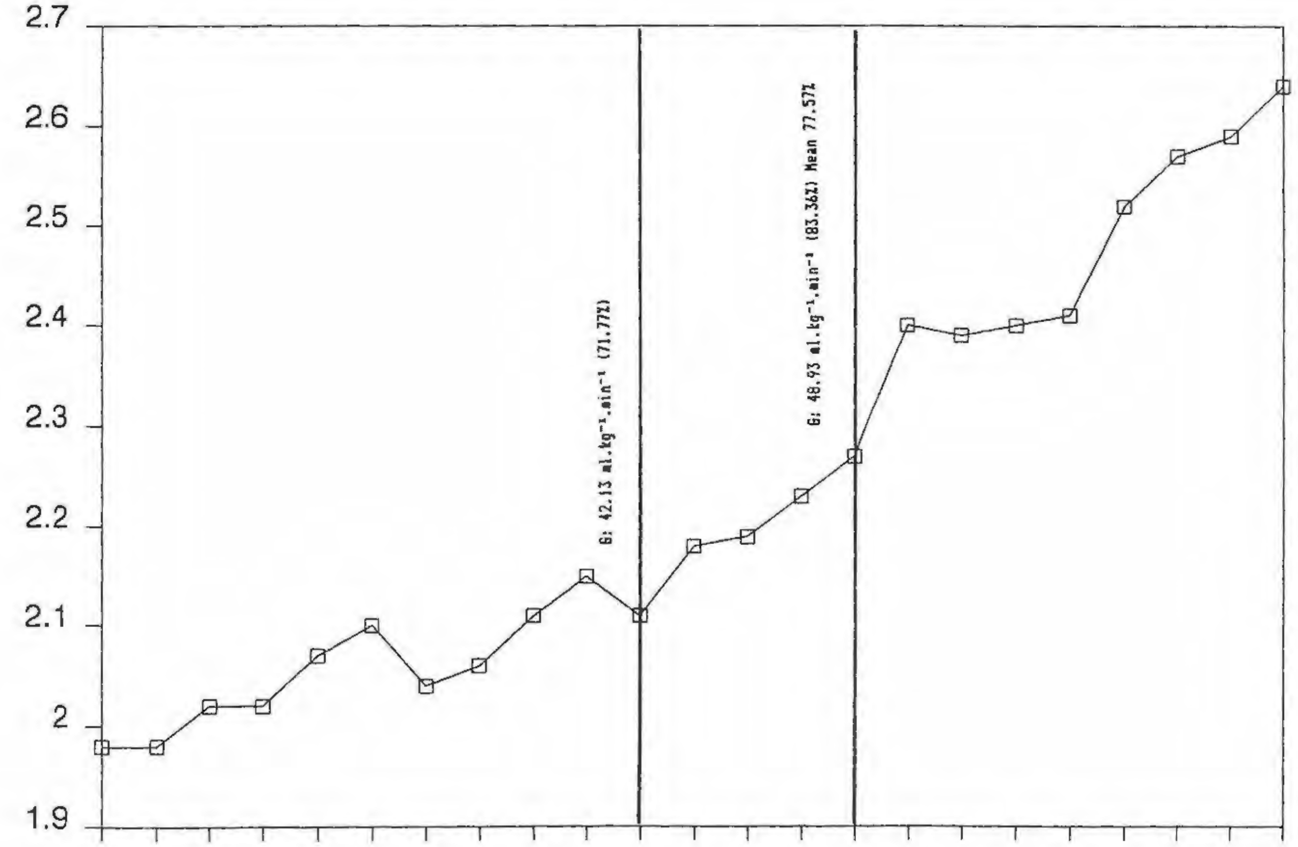

2.6
2.5
2.4
2.3
2.2
2.1
2
1.9
1.8
C: 51.93 ml.kg^{-1}.min^{-1} (69.80%) Mean 69.8%

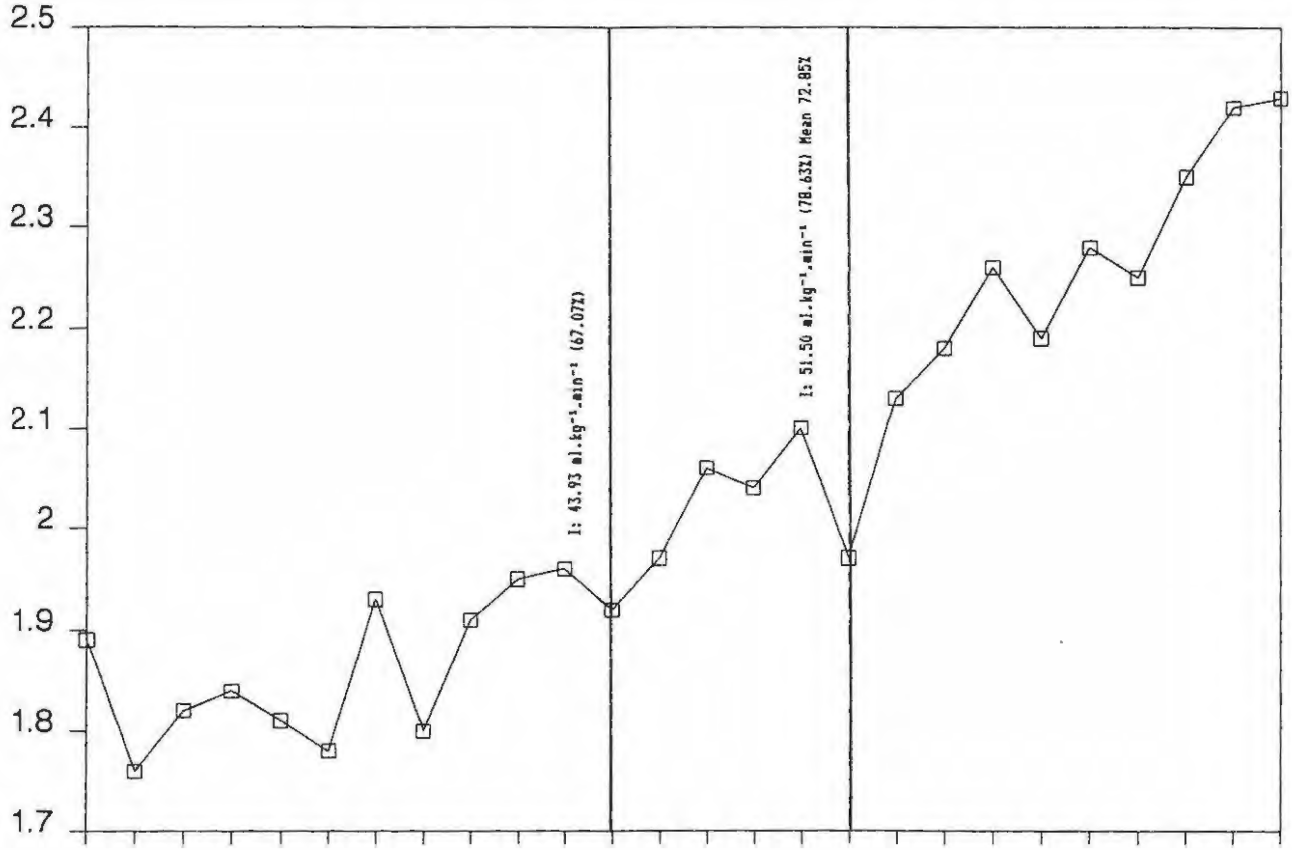

2.5
2.4
2.3
2.2
2.1
2
1.9
1.8
1.7
1.6
D: 45.80 ml.kg^{-1}.min^{-1} (70.03%)
D: 54.30 ml.kg^{-1}.min^{-1} (83.08%) Mean 76.56%

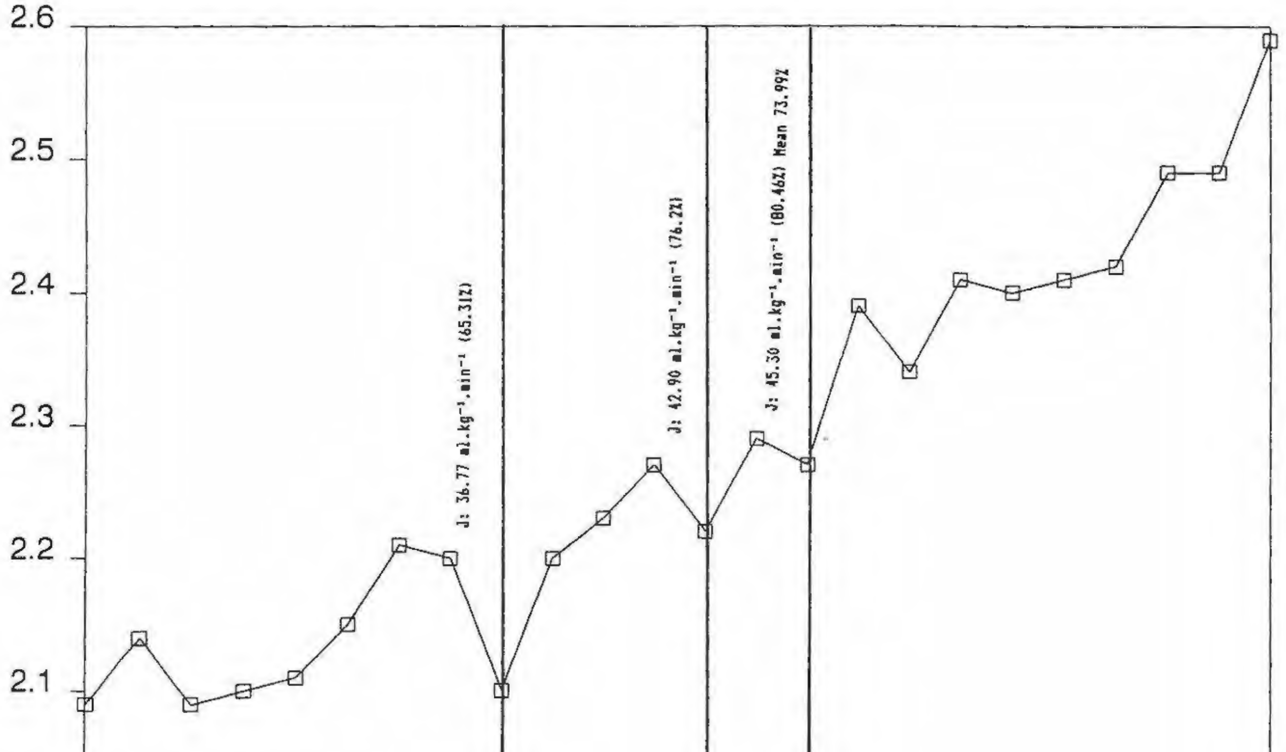

2.6
2.5
2.4
2.3
2.2
2.1
2
1.9
1.8
1.7
1.6
E: 39.70 ml.kg^{-1}.min^{-1} (63.22%)
E: 43.50 ml.kg^{-1}.min^{-1} (69.27%)
E: 47.90 ml.kg^{-1}.min^{-1} (76.27%) Mean 69.59%

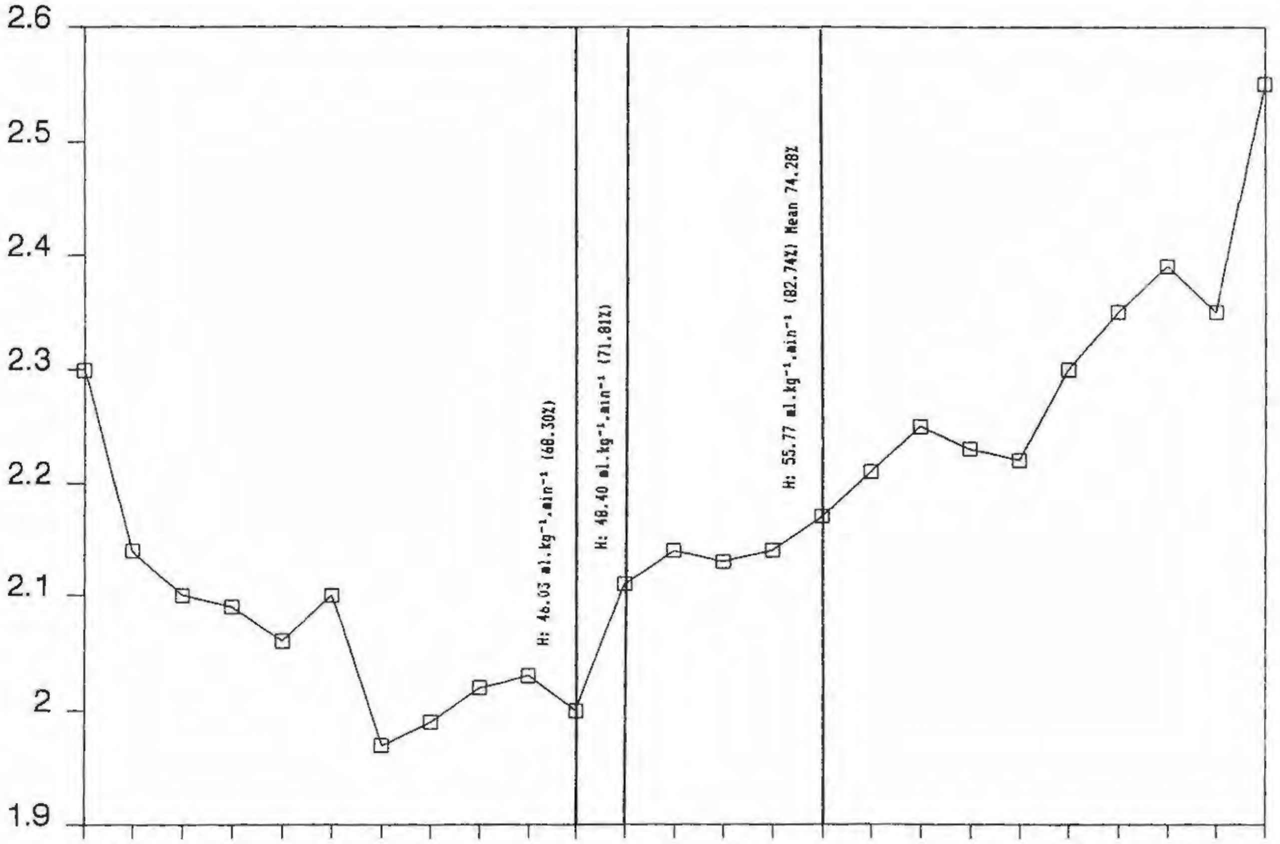

2.5
2.4
2.3
2.2
2.1
2
1.9
1.8
1.7
1.6
K: 57.03 ml.kg^{-1}.min^{-1} (79.54%) Mean 79.54%


2.4
2.3
2.2
2.1
2
1.9
1.8
1.7
1.6
F: 43.66 ml.kg⁻¹.min⁻¹ (68.98%)
F: 49.10 ml.kg⁻¹.min⁻¹ (77.57%) Mean 73.28%


2.7
2.6
2.5
2.4
2.3
2.2
2.1
2
1.9
G: 42.13 ml.kg⁻¹.min⁻¹ (71.77%)
G: 48.93 ml.kg⁻¹.min⁻¹ (83.36%) Mean 77.57%


2.5
2.4
2.3
2.2
2.1
2
1.9
1.8
1.7
I: 43.93 ml.kg^{-1}.min^{-1} (67.07%)
I: 51.50 ml.kg^{-1}.min^{-1} (78.63%) Mean 72.85%


2.6
2.5
2.4
2.3
2.2
2.1
2
J: 36.77 ml.kg^{-1}.min^{-1} (65.31%)
J: 42.90 ml.kg^{-1}.min^{-1} (76.2%)
J: 45.30 ml.kg^{-1}.min^{-1} (80.46%) Mean 73.99%


2.6
2.5
2.4
2.3
2.2
2.1
2
1.9
H: 46.03 $ml.kg^{-1}.min^{-1}$ (68.30%)
H: 48.40 $ml.kg^{-1}.min^{-1}$ (71.81%)
H: 55.77 $ml.kg^{-1}.min^{-1}$ (82.74%) Mean 74.28%

APPENDIX 10

Perceptual And Physiological Raw Data

```
                              DATA-BASE FILE: OLIVIER MA 1
                              ============================

NUMBER OF SUBJECTS = 11

NUMBER OF VARIABLES = 56

VARIABLE 1: LOCAL F2          VARIABLE 2: LOCAL F4          VARIABLE 3: LOCAL FX          VARIABLE 4: LOCAL L2
VARIABLE 5: LOCAL L4          VARIABLE 6: LOCAL LX          VARIABLE 7: LOCAL X           VARIABLE 8: CENTRAL F2
VARIABLE 9: CENTRAL F4        VARIABLE 10: CENTRAL FX       VARIABLE 11: CENTRAL L2       VARIABLE 12: CENTRAL L4
VARIABLE 13: CENTRAL LX       VARIABLE 14: CENTRAL X        VARIABLE 15: OVERALL F2       VARIABLE 16: OVERALL F4
VARIABLE 17: OVERALL FX       VARIABLE 18: OVERALL L2       VARIABLE 19: OVERALL L4       VARIABLE 20: OVERALL LX
VARIABLE 21: OVERALL X        VARIABLE 22: HR F2            VARIABLE 23: HR F4            VARIABLE 24: HR FX
VARIABLE 25: HR L2            VARIABLE 26: HR L4            VARIABLE 27: HR LX            VARIABLE 28: HR X
VARIABLE 29: VO2 F2           VARIABLE 30: VO2 F4           VARIABLE 31: VO2 FX           VARIABLE 32: VO2 L2
VARIABLE 33: VO2 L4           VARIABLE 34: VO2 LX           VARIABLE 35: VO2 X            VARIABLE 36: VE F2
VARIABLE 37: VE F4            VARIABLE 38: VE FX            VARIABLE 39: VE L2            VARIABLE 40: VE L4
VARIABLE 41: VE LX            VARIABLE 42: VE X             VARIABLE 43: R F2             VARIABLE 44: R F4
VARIABLE 45: R FX             VARIABLE 46: R L2             VARIABLE 47: R L4             VARIABLE 48: R LX
VARIABLE 49: R X              VARIABLE 50: VCO2 F2          VARIABLE 51: VCO2 F4          VARIABLE 52: VCO2 FX
VARIABLE 53: VCO2 L2          VARIABLE 54: VCO2 L4          VARIABLE 55: VCO2 LX          VARIABLE 56: VCO2 X
```

VARIABLE	SUBJECT									
	1	2	3	4	5	6	7	8	9	10
1	11.5	10.5	12	10	7	8.5	7.5	10.5	9	8.5
2	13	12	15.5	12	8.5	14	12.5	14.5	11.5	12
3	12.25	11.75	13.75	11	7.75	11.25	10	12.5	10.25	10.25
4	12	10	13.5	9	7	11	8	9.5	12	9.5
5	14.5	12.5	18	10.5	11.5	13.5	12	15	15	13.5
6	13.25	11.25	15.75	9.75	9.25	12.25	10.5	12.25	13.5	11.5
7	12.75	11.5	14.75	10.38	8.5	11.75	10.25	12.38	11.88	10.88
8	13	11.5	9.5	9.5	7	9.5	8	9	9.5	9.5
9	12	13	13.5	13.5	8	13.5	12	12.5	13	11.5
10	12.5	12.25	11.5	11.5	7.5	11.5	10	10.75	11.25	10.5
11	10.5	9.5	10.5	11.5	7.5	11.5	8.5	8.5	11.5	9.5
12	11	12.5	14	13	10.5	12.5	13	13.5	14.5	13.5
13	10.75	11	12.25	12.25	9	12	10.75	11	13	11.5
14	11.63	11.63	11.88	11.88	8.25	11.75	10.38	10.88	12.13	11
15	12	10.5	10.5	9.5	7	9.5	8	10.5	9	9.5
16	12	13	14.5	12.5	8	13.5	12	13.5	12	11.5
17	12	11.75	12.5	11	7.5	11.5	10	12	10.5	10.5
18	11.5	9.5	12	9.5	7.5	11.5	8	9.5	12	9.5
19	13	12.5	16	12.5	11.5	13.5	13.5	15	15	13.5
20	12.25	11	14	11	9.5	12.5	10.75	12.25	13.5	11.5
21	12.13	11.38	13.25	11	8.5	12	10.38	12.13	12	11
22	168	168.5	162	143	141	139	156.5	162.5	141	146
23	170.5	179	173.5	151.5	151	154	167.5	169.5	147	158.5
24	169.25	173.75	167.75	147.25	146	146	162	166	144	152.25
25	169.5	163.5	159.5	138.5	139	145	152	159	140.5	142.5
26	172.5	178	172.5	142.5	152.5	161.5	168	169	154.5	150.5
27	171	170.75	166	140.5	145.25	153.25	160	164	147.5	146.5
28	170.13	172.25	166.88	143.28	145.63	149.63	161	165	145.75	149.38
29	47.45	54	58.8	46.4	40.8	42.35	40.75	50.75	41.15	41.95
30	47	57.3	57.2	47.6	42	50.75	46.8	50.25	44.35	44.1
31	47.23	55.65	58	47	41.4	46.55	43.78	50.5	42.75	43.03
32	49.65	53.85	59.85	45.55	41.75	44.9	40.4	49.1	41.8	38.9
33	48.8	55.75	65.4	50.8	43.75	47.9	47.35	53.4	45.55	44.8
34	49.23	54.8	62.63	48.18	42.75	46.4	43.88	51.25	43.68	41.25
35	48.23	55.23	60.32	47.59	42.08	46.48	43.83	50.88	43.22	42.44
36	64.65	81.05	99.75	56.3	47.65	67.75	72.1	72.85	51.6	65.55
37	61.7	88.35	100.85	59.75	43.65	81.1	91.7	73.85	56.9	69.45
38	63.18	84.7	100.3	58.03	45.65	74.43	81.9	73.35	54.25	67.6
39	75.16	81.13	99.51	64.72	49.71	74.82	72.29	70.79	58.48	60.74
40	74.76	90.66	126.75	74.95	54.44	83.72	93.82	82.74	68.59	73.28
41	74.96	85.9	113.13	69.84	52.07	79.27	83.06	76.76	63.53	67.01
42	69.07	85.3	106.22	63.94	48.86	76.85	82.46	75.06	58.89	67.31
43	.88	.94	.92	.87	.89	.93	.99	.93	.86	.89
44	.88	.97	.95	.87	.86	.94	.99	.92	.85	.87
45	.88	.96	.94	.87	.88	.94	.99	.93	.87	.88
46	.95	.95	.94	.93	.89	.91	.92	.96	.94	.83
47	.94	.96	.98	.97	.89	.93	.96	.98	.96	.86
48	.95	.96	.96	.95	.89	.92	.94	.97	.95	.85
49	.92	.96	.95	.91	.89	.93	.97	.95	.91	.87
50	2.66	3.73	4.04	2.9	2.37	3.29	3.41	3.23	2.48	2.85

```
VARIABLE !                    S U B J E C T
         !   1        2        3        4        5        6        7        8        9        10
------------------------------------------------------------------------------------------------------
   51    !   2.62     4.1      4.08     2.98     2.35     4.01     3.95     3.21     2.74     2.97
   52    !   2.64     3.92     4.06     2.94     2.36     3.65     3.68     3.22     2.61     2.91
   53    !   3.11     3.77     4.18     3.11     2.38     3.47     3.15     3.25     2.8      2.96
   54    !   2.99     3.93     4.8      3.6      2.5      3.74     3.84     3.55     3.13     3.41
   55    !   3.05     3.85     4.49     3.35     2.44     3.6      3.5      3.4      2.96     3.18
   56    !   2.85     3.89     4.28     3.15     2.4      3.62     3.59     3.31     2.79     3.05
```

```
VARIABLE !                          S U B J E C T
         !    11
----------------------------------------------------------------------------------------------------------------------
    1    !    10
    2    !    12
    3    !    11
    4    !    11.5
    5    !    13
    6    !    12.25
    7    !    11.63
    8    !     9
    9    !    11.5
   10    !    10.25
   11    !    11
   12    !    12
   13    !    11.5
   14    !    10.88
   15    !     9.5
   16    !    11.5
   17    !    10.5
   18    !    11.5
   19    !    12
   20    !    11.75
   21    !    11.13
   22    !   145.5
   23    !   160
   24    !   152.75
   25    !   150
   26    !   162
   27    !   156
   28    !   154.38
   29    !    45.65
   30    !    49.55
   31    !    47.6
   32    !    43.55
   33    !    53
   34    !    48.28
   35    !    47.94
   36    !    50.7
   37    !    61.55
   38    !    56.13
   39    !    53.94
   40    !    67.82
   41    !    60.88
   42    !    58.51
   43    !      .9
   44    !      .93
   45    !      .92
   46    !      .89
   47    !      .91
   48    !      .9
   49    !      .91
   50    !     2.64
```

```
VARIABLE !                         S U B J E C T
         !    11
------------------------------------------------------------------------------------------------------------------------
    51   !    3.23
    52   !    2.94
    53   !    2.69
    54   !    3.34
    55   !    3.02
    56   !    2.98
```

APPENDIX 11

Scoring Method For The Semantic Differential Attitude Scale

INTERESTING	7	6	5	4	3	2	1	BORING	E
STRENUOUS	1	2	3	4	5	6	7	EFFORTLESS	P
UNENJOYABLE	1	2	3	4	5	6	7	ENJOYABLE	E
PASSIVE	1	2	3	4	5	6	7	ACTIVE	A
UNEVENTFUL	1	2	3	4	5	6	7	EVENTFUL	A
PLEASANT	7	6	5	4	3	2	1	UNPLEASANT	E
SEVERE	1	2	3	4	5	6	7	UNDEMANDING	P
SLOW	1	2	3	4	5	6	7	FAST	A
LIGHT	7	6	5	4	3	2	1	HEAVY	P
WORTHLESS	1	2	3	4	5	6	7	WORTHWHILE	E
RUGGED	1	2	3	4	5	6	7	GENTLE	P
DYNAMIC	7	6	5	4	3	2	1	STATIC	A

APPENDIX 12

Raw Data: Semantic Differential Attitude Scale

Overground Scales

	E	P	E	A	A	E	P	A	P	E	P	A	SUM
Subjects	7	4	7	3	5	7	5	4	4	7	4	7	61
	6	4	7	2	5	7	6	5	5	6	6	6	65
	7	3	7	6	5	7	3	5	3	7	3	6	62
	7	6	7	6	2	7	4	5	5	7	4	7	67
	7	7	7	2	6	7	5	5	5	7	4	6	68
	6	3	6	4	4	6	3	4	3	6	4	6	55
	7	5	7	2	3	6	2	5	3	7	2	6	55
	6	6	7	7	1	5	6	5	6	7	6	7	68
	5	5	6	3	6	6	4	4	4	6	5	6	61
	5	4	7	2	2	7	3	5	3	7	4	6	55
	7	3	7	2	7	7	3	4	3	7	2	7	59

Treadmill Scales

6	4	7	3	5	6	4	4	4	6	4	7	60
2	3	3	5	3	4	3	6	2	5	4	3	34
5	2	4	4	3	4	3	5	2	7	5	2	46
6	3	5	6	6	3	3	1	3	3	2	5	46
5	5	5	3	4	5	5	4	5	6	4	5	56
3	2	4	5	2	2	2	4	2	3	3	5	37
3	2	3	4	2	2	2	5	2	3	4	5	37
7	2	6	2	5	6	3	4	6	7	5	7	60
3	5	4	3	3	4	4	4	4	6	5	6	51
1	5	1	3	1	3	5	3	5	5	5	3	40
2	3	2	6	1	2	1	6	2	4	4	5	38

APPENDIX 13

Data Collection Sheets For The Field And Laboratory Conditions

Field Testing

Name:

Date:

Time:

Mass:

Temp (°C):

Barometric Pressure (mmHg):

Relative Humidity (%):

Wind Speed ($m.s^{-1}$):1. 2.

0 - 2 predicted speed ($km.h^{-1}$):

2 - 4 predicted speed ($km.h^{-1}$):

km	Predicted time (min & s)	Actual time (min & s)	RPE Local	RPE Central	RPE Overall	Heart rate ($b.min^{-1}$)
1						
2						
3						
4						

Bag	FEO_2	$FECO_2$	Initial Volume (l)	Final Volume (l)
1				
2				
3				
4				

Lab Testing (Field simulation)

Name:

Date:

Time:

Mass:

Temp (°C):

Barometric Pressure (mmHg):

Relative Humidity (%):

3.8% predicted speed (km.h^{-1}):

equivalent voltage:

time (min. and s):

7.5% predicted speed (km.h^{-1}):

equivalent voltage:

time (min. and s):

km	Time (min & s)	Voltage	RPE Local	RPE Central	RPE Overall	Heart rate (b.min^{-1})
1						
2						
3						
4						

APPENDIX 14

Differentiated RPE Instructions

"You are now going to take part in a work test. You will be running while we measure various physiological funtions. We also want you to try and estimate how hard you feel the work is; that is, we want you to rate the degree of perceived exertion you feel. You will be asked to point to a number on the scale presented which corresponds to your rating of perceived exertion. The first will be a local muscular rating pertaining to feelings or sensations of strain in the exercising muscles and joints. The second rating involves sensations or feelings from the cardiorespiratory system. Lastly you will be asked to provide and overall rating. This will involve an integration of the previous two ratings with whatever weighting you deem appropriate. Try to estimate as honestly and objectively as possible. Don't underestimate the degree of exertion you feel, but don't overestimate it either. Try to estimate it as accurately as possible. When you are asked to rate your work, you should do so by giving the numerical value on the scale in front of you which indicates your evaluation of your local, central and overall perceived exertion respectively, at that moment. A rating of 6 corresponds with feelings of exertion while standing quietly, while a rating of 20 reflects maximal exertion."

The investigator then verbally explained the distinctions between local, central and overall factors, and subjects were asked to note the verbal anchors, bearing in mind that a rating of 6 corresponds to standing quietly, while a rating of 20 reflects maximal exertion.

Subjects were then asked to re-read the instructions. Following this, each subject was encouraged to ask questions should anything be unclear.