THE EFFECTS OF ENDURANCE TRAINING UPON RATINGS OF PERCEIVED EXERTION

by

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Abstract

The purpose of this investigation was to examine differences in ratings of perceived exertion (RPE) at equivalent percentages of subjects maximal work capacity (equivalent relative workloads), before and after endurance training. Experimental (N=13) and control (N=13) groups comprised of healthy male subjects (x age=21.2 years, \( \text{VO}_2 \text{max}=50.4 \) \text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1} ) volunteered to participate in the study. All subjects completed progressive treadmill tests at approximately the same time of day, prior to and at the termination of the 9-week study period. Running commenced at 8 \text{km} \cdot \text{hr}^{-1} and increased by 0.8 \text{km} \cdot \text{hr}^{-1} per minute to volitional fatigue. Values for RPE were obtained at 30 second intervals. The exercise program consisted of treadmill running, 3 days per week, at workloads which were systematically progressed (heart rate=171.5 ± 5.7, x ± SD). Statistical analysis to measure changes in RPE over time was performed using a 2x2x5 ANOVA with repeated measures on the third factor. Reductions in RPE averaged 14% and 17% at a given \( \text{VO}_2 \) and velocity, respectively, in the training group. At equivalent relative workloads, decreases in RPE averaged 7.2% for \( \text{VO}_2 \) and 12.8% for velocity. When modifications in RPE in the control group were considered, the changes in RPE in the training group were not significant (p<0.05). These findings emphasize the necessity of a control group in studies which employ RPE as a dependent variable. Despite the decrements in RPE in the control group, changes in RPE in the training group did approach significance at fixed velocities (p<0.08) and
relative velocities (p<0.06). These decreases were greatest at moderate workloads (55-75% of maximal capacity), and appeared to be due to a reduction in local effort cues. It was concluded that the influence of training upon RPE at relative workloads is dependent upon the magnitude of corresponding physiological adaptations. The results also support the view that the changes in RPE which become apparent with training are related to the method of analysis which is used.
Table of Contents

Abstract ................................................................. ii
List of Tables .......................................................... v
List of Figures .......................................................... vi
Acknowledgements ...................................................... vii
I.  INTRODUCTION ...................................................... 1
II. REVIEW OF THE LITERATURE ........................................ 8
   I.  DEVELOPMENT AND USE OF RATING SCALES ..................... 8
   II.  PHYSIOLOGICAL BASIS FOR RPE ................................. 18
   III. NON-PHYSIOLOGICAL INPUT INTO RPE ......................... 43
   IV.  THE EFFECTS OF EXERCISE UPON RPE ......................... 48
III. METHODS ............................................................ 58
    SUBJECTS ........................................................... 58
    PROCEDURES ....................................................... 59
    TRAINING REGIMEN ................................................. 60
    MEASUREMENTS ..................................................... 60
    STATISTICAL ANALYSES ............................................ 62
IV.  RESULTS ........................................................... 63
V.  DISCUSSION ......................................................... 76
VI. SUMMARY AND CONCLUSIONS ....................................... 89

BIBLIOGRAPHY ........................................................... 92
APPENDIX A - BORG 15-POINT SCALE FOR RATING PERCEIVED
   EXERTION ........................................................... 108
APPENDIX B - 9-POINT SCALE FOR RATING PERCEIVED EXERTION 109
APPENDIX C - BORG 10-POINT SCALE FOR RATING OF PERCEIVED
   EXERTION ........................................................... 110
List of Tables

1. Physical Characteristics of Subjects ..................64
2. Summary of Hypothesized Physiological Training Effects .................................................65
3. Summary of Non-Hypothesized Physiological Training Effects .........................................66
4. Summary of Training Effects Upon Selected Perceptual Variables .....................................67
5. Summary of Effort Ratings .................................69
6. Percent Reductions in RPE Following 9 Weeks of Training ..................................................71
7. Summary of Hypothesis Testing ..........................71
List of Figures

1. Mean RPE at Absolute Workloads Based Upon VO2 ..........72
2. Mean RPE at Relative Workloads Based Upon VO2 ..........73
3. Mean RPE at Absolute Workloads Based Upon Velocity ...74
4. Mean RPE at Relative Workloads Based Upon Velocity ...75
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I. INTRODUCTION

Subjective, self-reported estimates of effort expenditure may be quantified using ratings of perceived exertion (RPE). As an investigative tool, RPE have proved to be a useful adjunct for studies in exercise physiology. RPE have been employed to examine issues involving the hormonal (Schnabel et al., 1982), metabolic (Horstman, 1977) and circulatory (Williams et al., 1981) response to exercise, supplementing objectively measured variables. Nevertheless, RPE have not been used extensively in applied sport science. The pertinence of RPE for exercise prescription has been recognized (Borg, 1982), and suggests that exercise intensity may be regulated through effort evaluation. However, it has not been shown that effort evaluation may be used to control pace during competition. Despite evidence that RPE can be used to predict maximal performance capacity (Morgan and Borg, 1976), the relationship between athletic achievement and the perception of effort is not well understood.

It has been proposed that sport performance (Morgan et al., 1976) and behaviour (Rejeski, 1981) are governed through an integration of real and imagined physiological and perceptual cues. In other words, during sport and athletics, how individuals respond is often dependent upon what they think they are doing, as well as what they are actually doing. This hypothesis is supported by research (Banister, 1979; Ikai and Steinhaus, 1961; Kilbom et al., 1983) which has shown that perceptual limitations may function as critical determinants of
performance. In addition, it appears that an ability to accurately monitor effort may be one criterion for successful participation in athletics (Morgan, 1977; Morgan and Pollock, 1977). Collectively, these observations imply that some aspect of effort perception may have specific ramifications with respect to exercise performance.

Since athletes appear to process incoming stimuli differently from their non-active counterparts (Ryan and Walter, 1967), it may be anticipated that training affects the sensory response to exercise. Several reports (Ekblom and Goldbarg, 1971; Kilbom, 1971; Knutgen et al., 1973; Knutgen et al., 1982; Lewis et al., 1980; Pandolf et al., 1975) have noted that subsequent to training, RPE are lower for absolute submaximal workloads. Previous longitudinal research (Docktor and Sharkey, 1971; Ekblom and Goldbarg, 1971; Kilbom, 1971) failed to observe modifications in the RPE reported by trained subjects when exercise intensity before and after training was equated in terms of heart rate (HR) or relative metabolic stress (%VO2max). However, the exclusion of control groups in these studies limits the validity of their findings. Furthermore, relative exercise intensities which are expressed in terms of VO2max or HR are unable to account for lactate production, catecholamine elevation, ventilatory hyperpnea (Astrand and Rodahl, 1977) or neuromuscular alterations (Stamford and Noble, 1974). These variables may be affected by training, and could influence RPE. Rejeski et al. (1982) disputed the validity of an operational definition of training effects based exclusively upon
cardiovascular adjustments. In their study, trained cyclists who wore toe-clips were able to demonstrate lower RPE values at a higher VO2max, compared to when toe-clips were not used. By showing that peripheral adaptations may reduce RPE during maximal exercise, their finding challenges the interpretation of previous results which have defined training effects solely in terms of cardiovascular parameters. Comprehension of the conflicting evidence regarding the effects of exercise upon RPE could be improved by establishing the theoretical basis for these adaptations. To date, few authors have addressed this issue. The purpose of the present investigation was to examine the effects of endurance training upon RPE at workloads which are equated on a relative basis, before and after training. A second objective was to compare the changes in RPE at workloads based upon VO2 to the changes in RPE observed when workload was measured in terms of velocity. Hypothetical explanations for these changes are also discussed. If training is found to lower the RPE which are associated with equivalent relative workloads, a potential link will have been identified between the perception of effort and athletic performance.

The Problem

Previous studies which have investigated differences in RPE as a function of physical conditioning have not included control groups, and have only used cardiovascular variables as a measure of fitness. Therefore, the current study will attempt to
determine if a significant difference exists between RPE, at the same relative workloads, based upon VO2 and velocity, before and after aerobic training.

Significance

Clarification of the effects of physical training upon the perception of effort could improve current understanding of the factors which contribute to athletic performance. This knowledge could have important implications for training and competition practices.

Limitations

1) Ratings of perceived exertion are influenced by the effects of non-physiological variables. Although differences in the age and sex of the subjects, and the time of day of testing were controlled for in this study, other factors such as motivation were not.

2) The artificial environment (laboratory) of the testing will limit the value of making inferences, based upon the current findings, about exercise in a field setting.
Delimitations

This study will be delimited to:

1) A sample size of 15.

2) The specificity of the sample group (young, male, college students).

3) Sea level conditions.

4) Laboratory conditions and treadmill training.

5) To a protocol which involves evaluating RPE during a progressive treadmill test, as opposed to a treadmill test conducted at a continuous workload.
Hypotheses

1) The 9-week training program employed in this study will result in an increased work capacity, measured by:

   A) \( \dot{\text{VO}}_2\text{max} (\text{l} \cdot \text{min}^{-1}) \) [training group (TG) > control group (CG)]
   B) AerT (\text{l} \cdot \text{min}^{-1}) (TG>CG)
   C) AerT (%\( \dot{\text{VO}}_2\text{max} \)) (TG>CG)

2) The 9-week training program employed in this study will result in reduced RPE, measured at:

   A) Given levels of \( \dot{\text{VO}}_2 \) (TG>CG)
   B) Equivalent relative levels of \( \dot{\text{VO}}_2 \) (TG>CG)

3) The 9-week training program employed in this study will result in reduced RPE, measured at:

   A) Given running velocities (TG>CG)
   B) Equivalent relative running velocities (TG>CG)
Definition of Terms and Symbols Used

AerT (Ventilatory aerobic threshold)—The aerobic threshold is the oxygen consumption immediately prior to that at which pyruvate production exceeds pyruvate oxidation, resulting in the first significant elevation in blood lactate during incremental exercise. Since aerobic threshold was evaluated using respiratory exchange variables, it is an indirect measure of metabolic events. For this reason, it is defined as the ventilatory aerobic threshold. In many of the studies which have been cited, this physiological point was, in fact, described as the anaerobic threshold. This study has selected the term aerobic threshold in compliance with the guidelines for terminology suggested by Skinner and McClellan (1980) and Kinderman et al. (1979).

Excess CO₂ (Excess carbon dioxide)—Extra carbon dioxide excreted from the lungs, due to the buffering of blood acidemia.

\( \dot{V}O_2\text{max} \) (Maximal oxygen consumption)—The greatest difference between the volume of inspired oxygen entering the lungs and the volume of oxygen leaving the lungs during maximal exercise.

\( \dot{V}E \) (Minute ventilation)—The volume of air inspired or expired during one minute.

RR (Respiratory rate)—The frequency of breathing.

HR (Heart rate)—A measurement of cardiac frequency.

AerT-%\( \dot{V}O_2\text{max} \) Aerobic threshold, expressed as a percentage of \( \dot{V}O_2\text{max} \).

RPE (Ratings of perceived exertion)—Subjective, self-reported estimates of effort expenditure.

RPE-%\( \dot{V}O_2\text{max} \) Ratings of perceived exertion at a percentage of maximal oxygen consumption.

RPE-AerT Ratings of perceived exertion at the ventilatory aerobic threshold.

\( V_{\text{max}} \) Maximal running velocity.

Equivalent Relative Workloads—Exercise workloads which may differ in absolute value, but are the same when compared to the maximal workload which is capable of being performed.
II. REVIEW OF THE LITERATURE

I. Development And Use Of Rating Scales

Initial experimental work involving the subjective perception of effort was reported by Fullerton and Cattell (1892). Two subjects were requested to exert one-half and twice as great a force on a hand dynamometer as a standard force which had been presented to them. The attempts were unsuccessful, and due to an inability to explain the findings, experimentation was discontinued.

Stevens and Mack (1959) were the next to conduct research into scales of apparent force. Their study involved the use of three different scaling procedures. These included ratio production (the subject must attempt to exert a force which is a given ratio of a reference force), magnitude production (the subject must exert a force which is a given magnitude of a reference force) and magnitude estimation (the subject must estimate the magnitude of a force which is presented to him, in comparison to a reference force). Two different methods of force application were also utilized. These included force on a grip dynamometer, and force applied passively to skin. The authors found that in all instances, the apparent magnitude of subjective force grew exponentially with the applied force. A range of 1.3-3.1 was exhibited as the exponent of the function, with mean values of 1.7 and 1.1 obtained for active and passive
application, respectively. Eisler (1962) also found subjective force to increase as a function of physical force, and calculated the value of the exponent to be 1.65. Hueting (1965) replicated these results in a similar study. In contrast, Cooper et al. (1979) observed a linear relationship to exist between percentage of relative effort and percentage of maximum force in the adductor pollicis and quadriceps muscles during isometric contractions. However, the upper limit of force application was arbitrarily set, which may have inadvertently depressed the rating of force at near maximum force. An exponent above 1.0 was shown to describe the relationship between percentage of relative effort and percentage of maximum force during isometric contractions of the quadriceps.

Bakers and Tenney (1970) investigated the perception of respiratory sensations and found that the estimated magnitude of pressure, volume and ventilation was highly correlated with the actual magnitude of these variables. Both actively and passively applied respiratory pressures were shown to grow exponentially, with exponents of 1.48 and 1.35, respectively. These values are similar to the previously cited values for active and passive force application. It was concluded that respiratory sensations are quantitatively assessed in a manner which is analogous to force application in the limbs.

Unlike the earlier studies involving isometric exercise, Borg (1962) studied the perception of effort during aerobic work employing large muscle masses. He produced a 21-point
categorical rating scale for RPE, with various verbal expressions corresponding to different levels of the scale. This scale was based upon a correlation between RPE and heart rate (HR), which was found to be 0.80-0.90 during light to heavy exercise performed on a bicycle ergometer. At a later date (Borg, 1970), a 15-point graded category scale was derived to increase the linearity between the ratings and the workload (Appendix A). Using this scale, RPE values have been shown to be approximately one-tenth of exercise HR values for healthy, middle-aged men performing moderate to heavy exercise (Borg, 1973). In forming the new scale, some of the verbal expressions were changed, and the mid-point was lowered. By compressing the lower degrees to compensate for non-linearity, the sensitivity of the scale was slightly reduced (Lollgen et al., 1975).

Prior to use of the scale during any experimental testing, each subject is instructed to rate their degree of exertion as accurately and naively as possible, and the test procedures are then explained. During the physical work test, the subject is presented with the scale on a large card and is requested to indicate the number associated with the effort he perceives (Borg, 1970).

Alternate scales have also been utilized for the measurement of RPE. A second category scale of 9 points (Appendix B) has been used by some investigators (Robertson et al., 1979a; Robertson et al., 1979b; Stamford and Noble, 1974).
When used to assess self-reported effort during exercise, the RPE values obtained from this scale have been shown to correlate highly \( r=0.92 \) with those on the 21-point Borg scale (Robertson et al., 1979a). Stevens and Mack (1959) have developed a ratio scale method for measurement of RPE. Using this technique, a subject is required to perform or rate a level of exercise which is perceived as some fraction of a reference stimulus. Using this scale, there is no indication of the relative magnitude of the RPE. That is, while it is possible to compare one level of RPE to another, it will be impossible to ascertain whether that level is high, moderate or low (Borg, 1972). This factor makes inter-individual comparisons difficult to perform (Borg, 1962). In addition, ratio scaling methods may limit data interpretation because of the differential interaction of perceptual recognition and certain psychometric variables such as memory span (Borg and Lindblad, 1976).

Recently, Borg (1982) has developed a 10-point category scale with ratio properties (Appendix C) which permits the use of decimals in RPE determinations. Using this scale, perceived exertion was shown to increase exponentially with respect to physical work. An exponent of 1.6 was obtained for this function during bicycle ergometer exercise. This finding is similar to those found in the previously cited force application studies. The verbal expressions which are used with the scale are set so that the semantic intensity grows according to a power function. For this reason, this scale may be particularly useful for measuring the perception of effort during anaerobic
activity. This is because certain physiological measures such as lactic acid and pulmonary ventilation, which reflect anaerobic metabolism, grow according to a power function with exercise intensity (Noble, 1982). Using this scale, increases in RPE have been shown to coincide closely with incremental elevations in blood lactate (Noble et al., 1981).

Subsequent to the development of rating scales designed for use in the subjective assessment of exertion, extensive research was undertaken to test the reliability and validity of RPE. Mihevic and Morgan (1980) have postulated that the threshold for detection of changes in exercise intensity lies near an absolute workload of approximately 15-20W. Michael and Eckhardt (1972) exercised 6 male subjects (3 trained, 3 untrained) for fifteen minutes at a work intensity which subjects considered to be "hard" at 0% slope on a treadmill. Before testing, all subjects were exercised several times on the treadmill to become acquainted with the apparatus. When asked to reproduce an equivalent level of work at a 10% slope on the treadmill, no significant difference was found between the exercise intensities using the two different protocols. No differences were observed in the relative intensities selected by the trained and untrained subjects. All runners selected workloads which elicited approximately 80% of their maximal oxygen consumption, and corresponded to a HR of 170 beats per minute. These findings demonstrated the reliability of RPE despite variations in protocol.
In an attempt to control for sequential effects, Skinner et al. (1973b) compared RPE when workloads were progressively increased with RPE when the same workloads were randomly assigned. One group of subjects began exercising at 150 kg·min⁻¹, with the workload being increased by 150 kg·min⁻¹ every 2 minutes until a self-imposed maximum. In the random test, each subject exercised for 2 minutes at 150 kg·min⁻¹, at which time the workload was increased to a value of 200, 450, 600, 750 or 900 kg·min⁻¹, to be maintained until a steady state was reached. At this point, the workload was returned to baseline, and a subsequent workload was implemented. It was found that there were no significant differences between the two groups with respect to RPE at a given workload, and that small variations in intensity could be detected even when presented in random order.

Lollgen et al. (1975) exercised subjects on a bicycle ergometer, varying the pedalling rates between 40 and 100 KPM on separate occasions. A test-retest reliability coefficient of 0.92 was established. However, measurements of RPE were found to be more highly variable at increasing pedalling rates. This information coincides with the findings of Borg (1973) which indicated that coefficients between HR and RPE were lower when using hard to very hard workloads.

Using the Borg 15-point scale, Stamford (1976) evaluated the reliability and validity of the perceptual responses of 14 sedentary females. The subjects were previously unfamiliar with
assessing varying levels of exertion. This was considered to be appropriate for tests of reliability and validity. Each subject was presented with work tasks of either treadmill walking, treadmill running, cycling or stool stepping on four separate occasions, each a minimum of 48 hours apart. During each of the tests, the exercise intensities were varied, and randomly presented. HR was allowed to return to normal following each level of exercise within a task. In addition, RPE were recorded at regular periods of 1 or 2 minutes (interval) or during the final minute of each workload (terminal). Using this test-retest procedure, the RPE values which were elicited proved to be reproducible (r=0.76) during intense (>90% VO2max) and less severe exercise. This was found to be true for both interval and terminal measurements. A high linear relationship was exhibited between HR response and RPE. The findings indicated that RPE readings were reliable and valid, independent of exercise intensity.

Using a 7-point rating scale, Hogan and Fleishman (1979) conducted a field study involving the subjective evaluation of the metabolic cost of 30 occupational and 41 recreational tasks (N=26). Effort ratings were found to be accurate estimations of the actual metabolic demands of the tasks. Correlations of 0.81 and 0.83 were found between the mean perceptual ratings and the true energy cost of the occupational and recreational activities, respectively. A follow-up investigation by the same authors replicated the findings of the previous study. It was concluded that a high reliability and validity existed for
perceived effort ratings, independent of the sex or previous rating experience of the sample group.

Purvis and Cureton (1981) have recently shown that RPE measurements obtained every 30 seconds during a progressive, load-incremented bicycle ergometer test are similar at the aerobic threshold of all subjects tested. Aerobic threshold was measured by averaging the oxygen consumption values at the time of departure from linearity of fractional expired oxygen (FEO2), minute ventilation (V̇E), ventilated carbon dioxide (V̇CO2) and respiratory quotient (R) values. They concluded that there were no differences in the perceived intensity corresponding to the aerobic threshold in different individuals. This demonstrated the reliability of RPE measurements at the aerobic threshold.

Using a motor-driven laddermill, Pandolf et al. (1978) reported that for positive (concentric) work an increase of 10.0 beats per minute in HR was associated with a 0.9 rise in RPE, as would be predicted by Borg's scale. However, for negative (eccentric) work, an RPE increase of only 0.5 was associated with the 10 beat increase. This was attributed to the fact that exertion for negative work was higher than for positive work at the same HR and oxygen consumption (VO2), because of the uncomfortable and unusual nature of the work. As a result of the high degree of initial discomfort, it was suggested that a limit was placed upon increases in RPE. These results suggest that the Borg scale may only be valid for use in protocols which involve concentric exercise.
Borg and Linderholm (1970) compared the reproducibility of work capacity based upon HR with work capacity based upon RPE. On two separate occasions, work capacity at heart rates of 130 and 170 beats per minute, and RPE values of 13 and 17 were determined. Re-testing was conducted 2-4 weeks after the initial test, to minimize the effect of memory upon RPE. The sample consisted of both healthy subjects, and patients who suffered from a variety of cardiovascular-related diseases. Test-retest coefficients were 0.93 and 0.98, respectively, in the patients and 0.88 and 0.97, respectively, in the healthy subjects. Workloads which were produced based upon effort perception demonstrated correlations of 0.80 and 0.94, respectively, in the first group, and 0.91 and 0.98, respectively, in the second. These results demonstrated that the reproducibility of work capacity based upon RPE is as good as that based upon HR. The values for reliability observed in this study are similar to the test-retest correlation coefficient of 0.91 which was obtained by Cooper et al. (1979), using isometric muscle contractions.

Smutok et al. (1980) exercised 10 moderately fit ($\dot{VO}_{2\text{max}} = 55 \text{ ml\cdot kg}^{-1}\cdot \text{min}^{-1}$) subjects on a treadmill at speeds of 4.7, 6.5, 9.7, 11.3 and 12.9 km\cdot hr$^{-1}$. Exercise was performed for 5 minutes at each workload, and RPE and HR values were measured during the last minute spent at each level of work. The subjects were then allowed to control the speed of the treadmill, and were randomly assigned RPE values which corresponded to the numbers which they had previously selected.
at each of the work levels. Four minutes were allowed to adjust the treadmill speed to match the assigned RPE value. For RPE >10, no difference was found between the HR or \( \dot{V}O_2 \) at equivalent RPE values when the exercise trial and self-regulated exercise bouts were compared. Although speed was reliably regulated at RPE <10, HR and \( \dot{V}O_2 \) demonstrated significant differences (p<0.05). It was suggested that the differences in HR may have been due to greater HR variability within subjects at low exercise intensities. The authors concluded that RPE could be reliably used to self-prescribe exercise at HR values exceeding 150 beats per minute.

Using a test-retest analysis, Komi and Karppi (1977) observed correlation coefficients of 0.37-0.75 for RPE, between the first and second tests. The lowest coefficients were found at exercise intensities below 50% of maximal HR values. Teghtsoonian (1977) and his co-workers used their laboratory to test the perception of the muscular effort of male club-cyclists who exercised regularly. It was noted that workload detection thresholds appeared to be sensitive to fatigue. This may help to explain any existing increases in variability in RPE at high intensity workloads. Noble (1979) demonstrated that RPE using the Borg scale do not parallel changes in HR during recovery from a voluntary run to exhaustion on a treadmill. The author suggested that a more valid scale which more closely approximates metabolic responses during recovery from exercise needs to be developed. Ulmer et al. (1977) also raised doubts about the validity of the Borg scale, because it is based solely
upon the correlation between HR and perceived exertion. Their research on well-trained endurance athletes shows that RPE is more highly correlated with what they consider to be the stress (workload) of exercise than the strain (HR).

Morgan (1977) has warned that a danger in using cross-sectional data on psychophysical category scales such as Borg's method for RPE measurement is that researchers must presume that verbal categories are appraised in a similar manner by all subjects. He also points out that a difficulty in conducting longitudinal studies in psychophysical work is that it is difficult to prevent subjects from realizing that RPE values are expected to be lower following training. The investigator must discourage subjects from making conscious efforts to provide the expected responses.

II. Physiological Basis For RPE

Considerable research in the area of RPE has been directed towards the identification of the sensory cues which provide direct input into the effort sense. A survey of the literature reveals that numerous physiological and neuromuscular parameters have been proposed as contributors to effort perception during exercise performed at a variety of intensities, modes, durations and environmental conditions. The earliest investigations were primarily concerned with isolating cues which could be universally shown to predominate the cognitive evaluation of
Ekblom and Goldbarg (1971) were the first to distinguish between factors affecting the perception of effort which arise in the active muscles and/or joints (peripheral) and those which are manifested in a more generalized cardio-pulmonary response (central). Borg's initial proposal, that RPE covaries directly with HR, has been challenged by a number of investigators. Parenthetically, the proliferation of proposed cues for the perception of effort resulted from research concerned with validation of the RPE-HR relationship. In addition to HR, central parameters which are purportedly linked to effort perception include respiratory rate (RR), VE and VO2.

Following Borg's original report of a correlation of 0.85 between RPE and HR, numerous other studies have demonstrated the existence of a strong linear relationship between these two variables. This association has been noted for both male and female subjects (Skinner et al., 1969; Skinner et al., 1973a; Stamford, 1976), of varying fitness levels (Bar-Or, 1972; Michael and Eckhardt, 1972; Skinner et al., 1973a) while using either bicycle or treadmill exercise (Borg, 1973; Skinner et al., 1973a), intermittent or continuous exercise (Edwards et al., 1972) and either arm or leg work (Sargeant and Davies, 1973). Since maximal HR declines with age, it would be expected that RPE would be higher at a given HR in older subjects. This has been verified by reports in the literature (Artsila et al., 1977; Bar-Or, 1977; Borg and Linderholm, 1967).
While HR and RPE may be highly correlated, at no point has it been implied that these measures are causally related. The RPE scale was designed to follow the HR response to increasing exercise intensity, and these variables are probably indirectly related through their common dependence upon physical strain. A number of sources have reported that the connection between HR and RPE can be disturbed when exercise is performed under irregular conditions. For example, it is possible to manipulate HR through the use of parasympathetic and sympathetic blocking agents without affecting the RPE at a given percentage of VO2max (Ekblom and Goldbarg, 1971; Davies and Sargeant, 1979). When performing at the same HR, RPE is greater for eccentric than concentric exercise (Pandolf et al., 1978). The relationship between HR and RPE is subject to displacement during recovery from a marathon run (Noble et al. 1979). When exercising subjects in hot environments, alterations in HR are not consistently reflected in perceptual responses (Kamon et al., 1974; Noble et al., 1973b; Pandolf et al., 1972), although this finding has been disputed (Skinner et al., 1973a).

Evidence from studies which have studied adaptations in RPE and HR following endurance training also challenges the postulated relationship between these variables. Lewis et al. (1980) found that following 11 weeks of training, RPE remained the same even though HR was reduced during submaximal exercise involving untrained limbs. Describing the effects of a 34-week conditioning program upon sedentary, elderly subjects, Sidney and Shephard (1977) reported that while post-training HR
responses were reduced at an absolute workload, RPE remained unchanged. Furthermore, at the same HR, treadmill exercise evoked lower effort ratings than bicycle ergometer work. At a given HR, discrepancies in perceptual response as a function of exercise mode have also been noted elsewhere (Michael and Hackett, 1972).

Unique from a methodological perspective, a study by Morgan et al. (1976) evaluated perceptual and metabolic responses to exercise by using hypnosis. During the experiment, reactions to suggestion of uphill work were investigated by monitoring the responses of 4 treatment groups. The different conditions included: an awake state (control), suggestion of uphill work in an awake state, a hypnotic state (control), and suggestion of uphill work in a hypnotic state. Steady-state exercise was performed at 100 W·min⁻¹ for 20 minutes. Hypnotic suggestion of uphill work elicited increases in effort ratings, although HR and VO₂ remained stable. However, elevations in VE were found to parallel the alterations in RPE, suggesting that this factor may be an important determinant of the perceptual response to exercise. These results were essentially identical to those obtained by the same authors on a previous occasion (Morgan et al., 1973) except that a stronger relationship was exhibited between HR and RPE.

Numerous other reports also support the role of VE and/or RR as sensory cues which have impact upon the perception of effort. Correlation coefficients ranging from 0.52-0.94 have
been demonstrated between RPE and both $\dot{V}E$ and RR (Edwards et al., 1972; Kamon et al., 1974; Morgan and Pollock, 1977; Noble et al., 1973b; Pandolf et al., 1972; Sargeant and Davies, 1973; Skinner et al., 1969; Smutok et al., 1980). After examining a number of physiological variables, Noble et al. (1973b) found $\dot{V}E$ and RR to be the best predictors of RPE, in either a hot or neutral environment. Edwards et al. (1972) have noted that unlike HR or $\dot{V}O_2$, $\dot{V}E$ has afferent nervous system input, which can be consciously monitored.

Wigertz (1970) analysed the dynamic characteristics of the ventilatory and HR responses of 11 highly trained ($\dot{V}O_2\text{max} = 63.8$ ml·kg$^{-1}$·min$^{-1}$) athletes who cycled at varying workloads (mean = 650 kpm/min). Although changes in $\dot{V}E$ were delayed with respect to shifts in exercise intensity and HR, the perception of peak exercise intensity corresponded more closely to peak $\dot{V}E$ than the actual time of maximum exercise intensity.

Attempts have been made to test the relationship between $\dot{V}E$ and RPE by examining the ventilatory response of subjects during exercise, while breathing hypoxic and hyperoxic mixtures. Theoretically, these procedures should affect respiratory drive at a given workload, and help to differentiate between the perceptual effects of dypsnea or hyperpnea and other physiological inputs. Pedersen and Welch (1977) observed that both RPE and $\dot{V}E$ were significantly lower during progressive bicycle exercise when subjects inspired gas mixtures containing 50% and 80% O2. In contrast, Allen and Pandolf (1977) 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 latter finding is difficult, since the incidence of decrements in ventilation as a consequence of breathing oxygen-enriched gases has been well established (Wilson and Welch, 1975). Gerben et al. (1972) and Robertson et al. (1979c) have confirmed that RPE and VE increase concomitantly when subjects inspire hyperoxic gas, although elevations in RPE may only become apparent at higher workloads (Robertson et al., 1979c).

Studies involving red blood cell (RBC) reinfusion (Robertson et al., 1979c; Williams et al., 1978; Williams et al., 1981) have been based upon the rationale that by withdrawing a given volume of blood and reinfusing it at a later date, hemoglobin concentrations will be augmented, thereby increasing the oxygen carrying capacity of the blood (Williams, 1981). If VE and RPE are related, then it would be expected that increased arterial oxygen content (CaO2), which reduces the stimulus for ventilation, would be reflected in similar adaptations in RPE. Using a double-blind experimental design, Williams et al. (1978) failed to show alterations in RPE following induced erythrocythemia in 16 long-distance runners. However, the volume of reinfused RBC (200 ml) and the elapsed time between withdrawal and reinfusion (3 weeks) were both below the recommended requirements for increasing CaO2 (Gledhill, 1982). When 5-mile run time was measured following the reinfusion of 920 ml of blood which had been stored for an 8-
week period, the same authors (Williams et al., 1981) observed reductions in RPE at a given pace. Nevertheless, no report of the effects of reinfusion upon ventilation was made in either study. Robertson et al. (1979c) exercised subjects on a bicycle ergometer at 45 and 70% of their VO2max. Following reinfusion, VE was depressed at both work intensities, but RPE were significantly modified only at the higher workload. Again, the results suggest that the onset of the ventilatory signal to effort perception is related to the relative exercise intensity of the work being performed. This observation has been reported by previous investigators (Cafarelli and Noble, 1976; Edwards et al., 1972; Horstman et al., 1979b; Morgan and Pollock, 1977). It appears that the point at which VE begins to significantly contribute to the perception of effort is near the aerobic threshold (Robertson, 1982).

The relationship between perceived respiratory resistance and added respiratory work may be described by a power function with an exponent of 1.6 (Gamberale, 1978). Mechanisms which underlie the perception of ventilatory stress appear to be related to factors which originate from sensations within the chest wall (Bakers and Tenney, 1970). While the proper functioning of ventilation is regulated by chemoreceptor activity at rest, during exercise, control of ventilation is partially assumed by mechanoreceptors in the chest wall, lungs and airways (Robertson, 1982). Respiratory pressure, volume and ventilation may all be perceived with a high degree of accuracy (Bakers and Tenney, 1970). Changes in lung volume, lung
pressure and respiratory muscle tension are all determined by tidal volume (Robertson, 1982). This is supported by the findings of Burdon et al. (1982), who compared the effects of elevations in respiratory stimulation with changes in the perceived magnitude of increasing respiratory loads. It was concluded that increases in sensory magnitude were proportional to and dependent upon increases in the inspiratory muscle force developed. More recently, Mahutte et al. (1983) have proposed that during normal respiration, the brain sets the necessary muscle pressure to overcome resistance and elastance for each breath, and then monitors rates of change in flow. They suggest that when a critical lag in flow rate is sensed, an added respiratory load is detected (Mahutte et al., 1983). Whether this theory, which considers the detection of resistive respiratory loads at rest, is applicable to an exercise setting, is unclear. Therefore, any model which attempts to explain the manner in which respiratory effort is perceived must be considered to be tentative.

It has been suggested that any impact that VE or HR exert upon RPE may be eliminated in terms of relative metabolic demand (Sargeant and Davies, 1973). Correlations of 0.76-0.97 have been reported between VO2 and RPE (Edwards et al., 1972; Sargeant and Davies, 1973; Smutok et al., 1980). Individual differences in VO2 which may exist at equivalent absolute workloads disappear at the same %VO2max in lean or obese (Skinner et al., 1973a), sedentary or active (Skinner et al., 1969) and trained or untrained (Ekblom and Goldbarg, 1971)
subjects. Similar results are obtained when continuous and intermittent exercise protocols are compared (Edwards et al., 1972). Increases in maximal aerobic power (MAP) following induced erythrocythemia may result in reductions in RPE for a given workload, but these are abolished at comparable exercise intensities (Robertson et al., 1979c). However, other reports indicate that the relationship between RPE and \( \dot{V}O_2 \) may be spurious. When exercise intensity and relative metabolic demand are held constant, RPE fluctuates as a function of pedalling frequency on a bicycle ergometer (Pandolf and Noble, 1973; Stamford and Noble, 1974). At uniform \( \dot{V}O_2 \) levels, RPE is higher for negative than positive work (Henriksson et al., 1972; Pandolf et al., 1978). Suggestion of uphill work in a hypnotic state results in elevations in RPE, but not in \( \dot{V}O_2 \) (Morgan et al., 1973). Previous reviews of the literature (Borg and Noble, 1974; Mihevic, 1981) have noted that while \( \dot{V}O_2 \) grows linearly with respect to workload, RPE increases according to a positively accelerating function which closely approximates VE and blood lactate response curves. The comparison of exercise at equivalent relative exercise intensities does not account for physiological responses such as lactate production, ventilatory hyperpnea, and catecholamine elevation, which may differ between individuals (Astrand Rodahl, 1970). On this basis, it cannot be concluded that \( \dot{V}O_2 \) is consciously monitored per se. It is more plausible that \( \dot{V}O_2 \), like HR, is indirectly related to RPE, since the input of certain physiological parameters such as VE and blood lactate are linked to relative metabolic demand.
Studies which have focused upon the factors involved in the perception of isometric muscular work have cited local cues such as mechanoreceptor and chemoreceptor sensitivity (Cain and Stevens, 1971; Stevens and Krimsley, 1977), and tendon, skin, joint and ligament receptors (Cain, 1973). However, these same factors have also been shown to exert significant input into the perceptual response during aerobic exercise performed on a bicycle ergometer (Ekblom et al., 1975; Gandevia and McCloskey, 1976; Henriksson et al., 1972; Pandolf and Noble, 1973; Stamford and Noble, 1974). Support for the role of kinesthetic or proprioceptive feedback may also be inferred from the findings of a variety of comparative studies. Several investigators have shown that effort ratings differ at equivalent power outputs and metabolic rates when pedalling frequency is modulated on a bicycle ergometer (Cafarelli, 1977; Edwards et al., 1972; Lollgen et al., 1977; Lollgen et al., 1980; Pandolf and Noble, 1973; Stamford and Noble, 1974). Similarly, during treadmill exercise at the same oxygen consumption, RPE may vary, depending on whether the work is achieved through constant (steady-state) or irregular (progressive) exercise (Davies and Sargeant, 1979). These studies suggest that RPE is related to the degree of strain which is experienced in the active musculature. If this construct is valid, then it would be expected that differences in the RPE associated with the performance of a given task would be partially explainable in terms of mechanical efficiency. Pandolf et al. (1978) found that at the same relative metabolic cost, effort was perceived to be greater during eccentric than
concentric exercise. This was attributed to the uncomfortable, unusual nature of negative work compared to positive work. Efficiency is known to be greater for running than walking (Donovan and Brooks, 1977; Pugh, 1971); for a given HR, RPE is significantly greater during treadmill walking than treadmill running (Noble et al., 1973a). These findings and those from other reports (Cafarelli et al., 1977; Campbell et al., 1976; Molbech and Johansen, 1969; Winsmann and Goldmann, 1976) help to confirm that sensations originating in the working muscles are important determinants of RPE. The extent to which local neuromuscular components contribute to the overall perception of effort is less clear, and remains speculative until these inputs can be quantified.

The exact mechanism by which these factors are cognitively appraised is uncertain. Recently, Cafarelli (1982) presented a comprehensive review of this issue. It was proposed that a feedforward mechanism from the motor cortex to the sensory cortex, and feedback from peripheral receptors operate both independently and in some complex, integrated manner to evaluate the parameters of any muscle contraction.

Using a variety of exercise modalities (Ekblom and Goldbarg, 1971; Gamberale, 1972; Horstman et al., 1979a), intensities (Morgan and Pollock, 1977), environmental conditions (Horstman, 1977), fitness levels (Ekblom and Goldbarg, 1971), and continuous or intermittent exercise protocols (Edwards et al., 1972), strong correlations between RPE and blood lactate
concentrations have been demonstrated. During incremental exercise, both blood lactate and RPE exhibit a similar, positively accelerating function when plotted against time (Borg, 1962; Gamberale, 1972).

Pandolf et al. (1972) compared the response curves for perceived exertion with those of HR, \( \dot{V}_E \), \( \dot{V}_O_2 \), RR, rectal temperature and skin temperature, in both hot and neutral environments. At the highest workloads (> 69% \( \dot{V}_O_2\text{max} \)) all respiratory responses plateaued, while RPE accelerated most rapidly during these stages of exercise. Due to a large oxygen deficit and a more pronounced anaerobic energy yield, it was concluded that RPE may be partially monitoring anaerobic metabolites during high intensity exercise. However, no measurement of variables associated with anaerobic metabolism was attempted.

Lewis et al. (1980) trained sedentary young men (N=10) for 30 minutes per day, 4 days per week, for 11 weeks at 75-80% \( \dot{V}_O_2\text{max} \). Post-training RPE values were found to be lower at a given submaximal workload, but only in the trained limbs. This is consistent with the expected lactate response to training, where lower blood lactate concentrations have been found with trained but not untrained limbs (Klausen et al., 1972; Ridge et al., 1976).

In contrast to the several studies which have implicated blood lactate concentration as a factor which influences the perception of effort, studies which have investigated the
effects of breathing hyperoxic gas mixtures during exercise do not consistently support a strong relationship between these variables. Pedersen and Welch (1977) observed that during progressive bicycle exercise while breathing 21%, 50% and 80% O2, concomitant reductions in RPE and blood lactate were of different magnitudes. However, Allen and Pandolf (1977) exercised subjects for 5 minutes on a treadmill at 50% and 80% of their MAP, breathing 21% and 80% O2. While breathing 80% O2, at both 50% and 80% MAP, lower blood lactate values were paralleled by similar declines in RPE.

The results from some previous research have not shown any correlation between RPE and blood lactate. Stamford and Noble (1974) were unable to show that arterial lactate concentrations during exercise at 960 kgm·min⁻¹ and pedalling rates of 40 rpm differed from those at 60 rpm when work time was held constant. However, RPE were significantly lower at the slower pedalling speed. On the basis of this finding, the authors concluded that local muscle strain was not reflected by blood lactate as a perceptual cue. However, the data was collected from a highly fit group of subjects (V\text{O}_2\text{max} = 61.4 \text{ ml·kg}^{-1}·\text{min}^{-1}), and the exercise intensities which were employed may have been insufficient to stimulate a lactate response. Exercise was performed at or less than 65% V\text{O}_2\text{max}, and this intensity has been shown to be below the aerobic threshold of certain highly trained individuals (Costill, 1970; Kinderman et al., 1979). That this was the case is supported by the fact that negligible increases in blood lactate were observed during the exercise
periods. In addition, it has been noted elsewhere (Mihevic, 1981) that a 9-point scale was utilized to measure effort perception in the study, which may preclude the meaningful integration of these results with other research which has been conducted using the Borg scale or standard ratio-scaling procedures. Nevertheless, this information suggests that blood lactate levels only affect the perception of effort once a critical exercise intensity threshold has been achieved. Kay and Shephard (1969) were also unable to demonstrate a significant correlation between RPE and blood lactate (r=0.15). However, it was argued (Mihevic, 1981) that this may merely have reflected the restricted perceptual values which were obtained, since the relationship between RPE and lactate was only analysed at a single exercise intensity (80% MAP).

Although some evidence supports the role of lactate concentration as a potent stimulus for the perception of effort, the mechanism by which this influence might be mediated is vague. It has been suggested that pain and discomfort in the working muscles may be related to the stimulation of free nerve endings due to the metabolic acidosis which is induced by elevations in muscle lactate concentrations (Kay and Shephard, 1969; Pandolf, 1978; Stamford and Noble, 1974). Experimental research does not support this position. Poulus et al. (1974) demonstrated that the infusion of NaHCO3 to correct for acidemia during progressively increasing exercise intensities to exhaustion on a bicycle ergometer has no impact upon subjective estimates of fatigue. Kostka and Cafarelli (1982) found that
neither induced acidosis (NH4Cl) or alkalosis (NaHCO3) had any effect upon effort sensations during moderate exercise (50% VO2max). However, during heavy exercise (80% VO2max), acidosis increased sensory intensity by 20% after 15 minutes. Thus, although the evidence is conflicting, it appears as though blood lactate concentrations may influence perceived exertion by some presently unidentified pathway, rather than through a reduction in pH.

Early attempts to analyse the sensory dimension of effort expenditure also reported as association between RPE and circulating catecholamines (Docktor and Sharkey, 1971; Frankenhaeuser, 1969). Like blood lactate and RPE, norepinephrine excretion exhibits a positively accelerating function when plotted against relative work intensity (Howley, 1976). While elevations in norepinephrine may occur at low submaximal exercise intensities (Howley, 1976), they only become prominent during intense activity (Astrand, 1970; Frankenhaeuser, 1969; Howley, 1976). The beginning of the steep increase in catecholamine concentration appears to be located at a workload near 70% VO2max (Galbo et al., 1975; Haggendal et al., 1970; Schnabel et al., 1982). It has been postulated that the point at which catecholamine levels are augmented coincides with a decrease in muscle glycogen availability (Pequignot et al., 1980; Schnabel et al., 1982). It has been shown (Bell et al., 1975) that glucose ingestion prior to exercise does produce a reduction in RPE during prolonged work. The authors suggested that input from glucose receptors may be consciously monitored.
by subjects during exercise. Since muscular fatigue has been attributed to muscle glycogen depletion (Bergstrom et al., 1967; Hermansen et al., 1967), it may be that catecholamines are related more to the perception of fatigue than the perception of effort, per se. The importance of differentiating between the constructs of exertion and fatigue has been emphasized previously (Borg, 1962; Rejeski, 1981). Similarly, studies (Kamon et al., 1974; Pandolf et al., 1972) which have implicated skin or core temperature as perceptual cues affecting RPE may have failed to discriminate between perceived effort and perceived discomfort.

Consequent to the identification of the physiological cues which purportedly affect the perception of effort, numerous attempts have been made to assess the relative contribution of central versus local factors to RPE. Originally (Ekblom and Goldbarg, 1971), it was proposed that local factors dominate effort perception during work with small muscle groups, but that perceptual cues could be complemented by central inputs when large muscle groups are employed. However, it has been shown that local components may still provide the most intense sensory stimulus, irrespective of the size of the muscle mass which is recruited (Horstman et al., 1979b; Pandolf and Noble, 1973; Stamford and Noble, 1974).

To effectively distinguish between the magnitude of the peripheral versus central cues, differentiated ratings of perceived exertion have been utilized (Pandolf, 1982). When
using this technique during cycling or treadmill running, subjects are requested to report separate estimates for the degree of effort which they are experiencing below the waist (local) and above the waist (central). In addition, an interpretation of the overall effort which is expended to perform the work is recorded. While undifferentiated exertion may be representative of non-physiological variables and generalized physiological events, differentiated reports more closely reflect discreet physiological symptoms (Robertson et al., 1979b).

During cycling exercise, it has been shown that overall and local effort consistently override central sensations (Cafarelli et al., 1977; Gamberale, 1972; Knuttgen et al., 1982; Mihevic et al., 1982; Pandolf, 1977; Robertson et al., 1979a; Young et al., 1982). At high speeds of walking while carrying loads, local RPE is higher than overall RPE, and central RPE is lower than overall RPE (Robertson et al., 1982a). During treadmill exercise, central factors exert a proportionally greater influence (Kay and Shephard, 1969; Pandolf et al., 1975). Pandolf et al. (1975) have suggested that on a relative basis, more high-glycolytic, fast-twitch motor units are activated during cycling than running. Consequently, greater afferent input into the reticular activating system from peripheral pain receptors, muscle spindles and Golgi tendon organs may occur during cycling than running (Pandolf et al., 1975). This may help to explain the differences in sensory inputs between the two forms of exercise.
Young et al. (1982) used manipulations in altitude to investigate differentiated RPE. They point out that when comparing exercise at altitude to that at sea level, a given absolute workload places a relatively greater metabolic demand upon the body. Furthermore, at the same relative intensity, exercise at altitude results in increased ventilation, but no changes are observed in HR, cardiac output, stroke volume, or blood lactate. In their study of differentiated RPE at sea level, acute and chronic exposure to altitude, subjects cycled for 30 minutes at a workload which elicited 85% VO\textsubscript{2}max during each condition. Despite decreases in the absolute cost of each relative exercise intensity during acute high altitude exercise, local RPE did not differ from the values obtained at sea level. However, during chronic exposure to high altitude, local RPE was reduced and central RPE became the dominant cue. Central RPE values during chronic altitude exposure were not significantly different from those obtained during exercise at sea level or acute altitude. Alterations in local RPE were found to parallel changes in blood lactate, which did not differ between sea level and acute altitude, but were reduced subsequent to chronic altitude exposure. Based on these findings, it was suggested that the perception of central effort is related to relative exercise intensity, whereas local muscular effort is more dependent upon the absolute metabolic demands of the work being performed. The results from this study should be interpreted cautiously. Following chronic exposure to altitude, blood lactate values were reported to be less than 2mM/litre during
cycling which had been previously designed to elicit 85% \( \dot{V}O_2 \text{max} \). This finding is unusual, particularly when the low fitness level of the subjects is considered. Furthermore, following acclimatization, it would be expected that a given relative exercise intensity would correspond to a greater absolute workload. That this occurred is supported by the fact that overall effort perception was higher after 18 days at altitude, although this change was not significant. The authors reported that exercise on the 18th day of high altitude was performed at the same absolute and relative exercise intensity as during acute altitude exposure. Therefore, the results suggest that a large decrease in blood lactate occurred at the same absolute and relative workload following chronic altitude exposure, and that no acclimatization occurred. The possible mechanisms for these unusual results are unclear. However, if as expected, absolute workloads could actually be performed with less metabolic stress, then the decrements in local RPE and blood lactate following chronic altitude exposure would be explainable. In this case, central RPE would be most closely related to absolute exercise intensity, and local RPE to relative exercise intensity.

A recent study by Mihevic et al. (1982) supports the proposal that central and local RPE are related to the absolute and relative intensity of exercise, respectively. In this experiment, subjects cycled under normoxic and hyperoxic conditions. Test protocols included cycling at 75% \( \dot{V}O_2 \text{max} \) (normoxic), 75% normal \( \dot{V}O_2 \text{ max} \) breathing 70% \( O_2 \), and 75%
hyperoxic VO2max, breathing 70% VO2. Central RPE was elevated during the third condition, when the workload was absolutely higher, but relatively equivalent to the first condition. Overall and local RPE were greater during the second condition, when the absolute workload was the same, but was relatively less than during the first condition.

Horstman et al. (1979b) have also compared perceptual responses during exercise at altitude (4300m) to that performed at sea level. They monitored RPE during 6 minutes of exercise at 60, 80 and 95% VO2max, and at 5 minute intervals during exercise to exhaustion at 85% VO2max. In the lower range of submaximal exercise, RPE was significantly less for equivalent relative workloads at altitude than at sea level, eventhough VE was elevated by 12%. These differences were reduced and eventually eliminated as the exercise progressed towards maximal levels, or as prolonged exercise continued until exhaustion. The authors concluded that local factors such as muscular strain exert greater influence upon effort perception at exercise intensities which do not greatly stress central factors, while central factors exert greater influence at higher levels of work.

The observations from both of the altitude studies give further evidence to support the notion that a critical work threshold must be achieved before central cues significantly affect the perception of effort. Robertson (1982) has noted that RPE begins to parallel VE when exercise exceeds 50% VO2max,
which is approximately the same metabolic rate at which peak tidal volume is achieved. The transmission of signals from mechanoreceptors in the respiratory muscles to the sensorimotor cortex is consciously monitored when the tidal volume exceeds 700 ml (Wolkove et al., 1981). Cafarelli and Noble (1976) have reported that ventilatory volume must increase by a minimum of 30 litres per minute if effort perception is to be significantly affected. Salamon et al. (1977) have shown that the psychophysical power function which describes the relationship between lung volumes and effort perception is different above and below the functional residual capacity (FRC). In addition, the exponents for the judgement of respiratory volumes were found to be greater for expiratory than inspiratory muscles. This was true even when tidal volume rather than FRC was used as a reference. Expiratory muscles are recruited primarily during forced expiration (West, 1979). These findings may partially explain the greater relative input of VE into effort perception at higher workloads. They also indicate that central effort perception is related to the absolute rather than the relative cost of the exercise which is being performed. A critical absolute work threshold must be achieved as a prerequisite to the onset of the central signal. Above this point, the intensity of the central stimulus increases proportionately as a function of the absolute rather than relative increases in ventilation.

With respect to the source of local effort perception, the altitude studies reported conflicting results. At equivalent
relative exercise intensities, Young et al. (1982) found no differences between the perception of local muscle exertion during exercise at sea level or acute altitude. Apparently, local RPE was related to blood lactate levels rather than physical strain. In contrast, Horstman et al. (1979b) observed a reduction in RPE during low-intensity exercise at altitude. This was presumably due to diminished local muscle tension, because the absolute workload was less for a given relative intensity of exercise. This apparent contradiction can probably be explained in terms of differences in the sample groups and exercise protocols which were used. In the first instance, unfit subjects (VO$_2$max =42 ml·kg$^{-1}$·min$^{-1}$) cycled at 85% VO$_2$max at sea level and altitude. Although the demands of a given exercise at altitude may have been absolutely less, it is conceivable that local muscle strain while performing at 85% VO$_2$max would still be perceived as near maximal in individuals who were unaccustomed to exercise. By comparison, Horstman et al (1979b) selected subjects who were more fit (VO$_2$max =49 ml·kg$^{-1}$·min$^{-1}$). Reductions in RPE were found at 60 and 80% VO$_2$max when exercise was conducted at altitude. These lower exercise intensities, particularly in better conditioned subjects, may have been below the threshold at which maximum physical strain would be perceived. Consequently, reduced strain in the working muscles during exercise at altitude may have been more easily detected. These findings imply that the proportion of local sensory input which is derived from sources associated with blood lactate or neuromuscular factors may also
be a function of the relative exercise intensity.

That physical strain in the exercising muscles has a superior impact upon the perception of effort at low work levels, and blood lactate greater influence during intense activity is supported by the findings of Robertson et al. (1979b). In their experiment, 50 male subjects performed 3 separate bicycle ergometer tests, with a constant power output of 840 kpm/min. Pedalling rate was randomly set at 40, 60, or 80 rpm. Central, peripheral and overall RPE was higher at 40 rpm than at 60 or 80 rpm, even though lactic acid was similar between pedalling rates. It has been previously shown (Cafarelli, 1977; Henriksson et al., 1972; Pandolf and Noble, 1973) that the magnitude of the local signal for effort perception increases as a function of the static work which is performed. At lower speeds, bicycle ergometer work requires higher intensity, slower muscular contractions than work performed at higher pedalling rates (Cafarelli et al., 1977; Hermansen and Saltin, 1969; Petrofsky et al., 1974). Therefore, at lower cycling rates, the amount of muscle mass which is recruited would be less than at higher frequencies (Cafarelli, 1977; Pandolf and Noble, 1973; Stamford and Noble, 1974). Under these circumstances, the muscles would be operating at a higher relative workload. Cafarelli (1977) has also shown slower pedalling rates to be more effortful than faster rates, in the absence of metabolic differences.

The previously discussed literature has shown strong
correlations between blood lactate and local RPE during intense activity. These findings are corroborated by the results of a study by Robertson et al. (1982b). These authors found that signals of exertion during isolated limb exercise were linked to blood pH and plasma buffering. At 80% VO2max, induced alkalosis (NaHCO3) produced significantly lower local RPE in the exercising limbs when compared to a control group who received a placebo (CaCO3). This was found to be true whether arm cranking or leg pedalling were utilized. However, at 40% VO2max, local RPE did not differ between the treatment group and those receiving the placebo. Physical strain in the working muscles may also be perceptually prominent at higher workloads if mechanical efficiency is poor. This was demonstrated by Horstman et al. (1979a) who found local RPE to more markedly dominate central RPE when walking was compared to running, at 80% VO2max.

In summary, data from studies which have examined both differentiated and undifferentiated RPE during exercise support a two-factor theory for physiological input into the effort sense. During low levels of activity, physical strain in the working muscles appears to be the primary stimulus for effort perception. When work intensity exceeds the lactate threshold, incremental elevations in blood lactate complement peripheral input from the neuromuscular mechanisms. Once a critical absolute ventilatory threshold is reached, central input also contributes to effort perception. In most instances, peripheral input predominates over central cues, although it has been shown
that pronounced central cues may predominate the effort sense. In terms of magnitude, central signals have been reported (Cafarelli et al., 1977; Robertson et al., 1979a) to vary from 30-70% of local signals over a wide, range of submaximal intensities. Thus the sensory integration process apparently involves a weighted averaging of dominant regional signals (Robertson et al., 1979a).

Although the findings from the majority of the literature which has been reviewed may be accommodated by this model, two investigations have provided noticeably differently results. Mihevic et al. (1981a) showed that when highly fit subjects (V\textsubscript{O2max} = 66.5 ml·kg\textsuperscript{-1}·min\textsuperscript{-1}) self-regulate their running pace at perceptually comfortable (62% V\textsubscript{O2max}) and hard (79% V\textsubscript{O2max}) levels, local RPE is higher than central RPE only during the hard run. Current understanding of the mechanisms which determine physiological input into the effort sense prevents meaningful interpretation of these results. Lollgen et al. (1980) found that when cycling at zero workload, 70% V\textsubscript{O2max}, or maximal intensities, RPE was not always related to any of the central (HR, VE, VO\textsubscript{2}) or local (muscle lactate, blood lactate, NAD, glycogen, ATP, CP) cues which were monitored. However, RPE was linked to central factors at high speeds of limb movement, even during unloaded pedalling. A relationship between central RPE and speed of limb movement, independent of workload, has also been shown elsewhere (Croisant, 1982). These studies highlight both the complexity of effort perception, and the need for a better understanding of the physiological components upon
which it is based.

III.

Non-Physiological Input Into RPE

Clearly, the perception of effort cannot be adequately described in terms of physiological input alone. Morgan (1973b) has calculated that physiological variables are able to account for only 67% of the total variance in RPE. Intuitively, the influence which various psychometric and personality variables such as motivation exert upon RPE would be accentuated during strenuous exercise. In practice, this does not appear to be the case. When physiological cues are intense, the performer may find it unrealistic to alter RPE (Rejeski, 1980). Rejeski and Ribisl (1980) found that during moderate exercise lasting 20-30 minutes, RPE was affected by the anticipated duration of the treadmill run. However, towards the termination of exercise, when internal cues were maximized, the role of external cues in determining RPE was less appreciable.

Many other investigators have also focused upon the distortion of RPE as an artifact of competition between internal and external cues. During exercise ranging from 40-80% VO2max, RPE have been shown to be stable during 3-digit subtraction (Pyne, 1980) and 1-2 digit addition (Stamford et al., 1979) which were designed to be distracting. Improvements in running time over equal-length courses on cross-country trails versus a
track have been attributed to differences in external attention requirements (Pennebaker and Lightner, 1980). Auditory input such as music and mechanical noise do not affect RPE (Caspersen, 1974). 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.

Researchers who attempt to measure effort perception during physical performance tests should be cognizant of the finding that psychomotor and mental performance tasks, including RPE, are affected by the time of day (Faria and Drummond, 1979; Wojtczak et al., 1978). The degree to which these results may be ascribed to the influence of circadian rhythms or tiredness is uncertain. Initially, Martin (1981) observed different perceptual responses during prolonged exercise following sleep deprivation. In a subsequent study (Martin and Haney, 1982), no difference was found in self-selected work intensity on a treadmill following 30 sleepless hours. In the earlier study, subjects estimated their perception of effort for a given task, whereas in the latter report, they were requested to replicate a previously administered workload. Due to subjective expectancy of lower readings, the results from the first investigation may have been biased (Martin and Haney, 1982).

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

Evidence suggests that effort perception varies with the age (Arstila et al., 1975; Bar-Or, 1977; Borg and Linderholm, 1976) and sex (Arstila et al., 1977; Rejeski, 1980) of subjects. Perceptual ratings by women do not fluctuate as a function of menstrual cycle phase (Stephenson et al., 1982). It may be that due to cultural training, women do not have sufficient experience with fatigue-like symptoms (Rejeski, 1980). With advancing years, RPE is higher for a given relative exercise intensity (Arstila et al., 1977). In contrast to these findings, Sidney and Shephard (1977) found no significant differences to exist between young and old or male and female subjects when work was expressed as a relative percentage of MAP. Differences in RPE may also be observed when comparing variations in the state of health of certain individuals (Borg and Linderholm, 1970).
Environmental manipulations may also create alterations in RPE. Horstman (1977) found RPE to be significantly lower when performing exercise at 5 degrees celsius when compared to the same test performed at 25 degrees celsius. This reduction in RPE paralleled an increase in $\dot{V}E$ and $\dot{V}O_2$, and decreases in RQ and venous lactate concentration at 5 degrees celsius. The quality of the inspired air during exercise also appears to be a determinant of RPE. Air ionization and pollution (Sovijarvi et al., 1979) or elevated ozone levels (Mihevic et al., 1981b) increase RPE at a given workload.

Numerous investigations have shown that the nature of the exercise test itself may influence RPE. While pre-exercise warm-up may not influence the results which are obtained (Aronchiuk and Burke, 1976; Wojtczak et al., 1978), a minimal degree of previous exercise experience is necessary to gauge RPE accurately (Horstman et al., 1979c).

Despite a plateau in most physiological variables during steady-state exercise, RPE continues to rise (Noble et al., 1973a; Pandolf et al., 1972). This relationship between RPE and exercise duration has been noted elsewhere (Borg, 1962; Davies and Sargeant, 1979). Ventilation steadily increases without levelling off during heavy long-term exercise at a constant workload (Martin et al., 1979). A logical hypothesis would be that the sustained elevations in RPE during prolonged exercise are generated by this ventilatory drift. In support of this view, Cafarelli et al. (1977) found that central factors grew
more dramatically than local factors as a function of exercise duration. Nevertheless, as previously discussed, during extended activity, symptoms of fatigue may be incorporated into RPE, and reduce the validity of these readings. In addition to perceptual responses occurring prolonged steady-state exercise, it has also been demonstrated that workload detection thresholds are sensitive to fatigue (Teghtsoonian et al., 1977).

Weiser and Stamper (1977) have made an attempt to assess the relative input of various psychometric and physiological factors which correlate with the ability to maintain steady-state work on a bicycle ergometer. In order of increasing magnitude, leg fatigue, motivation, perceived effort, general fatigue and cardiopulmonary distress were found to enter into a regression equation which accounted for 76% of the variance in exercise time maintained by the subjects in the study. However, Jackson et al. (1981) have demonstrated that the physiological and psychological correlates of exercise performance are different in a field setting than in the lab. Dishman (1978) has previously reported that as much as 18% of performance variance in the 12-minute run may be accounted for by motivation.

Pandolf et al. (1975) have produced a hierarchical model for perceived exertion which consists of 4 different levels of subjective reporting. It suggests that the discrete symptoms of physiological stress contribute to a higher "subordinate" level of perception which entails local muscular exertion, general
exertion, and cardio-pulmonary exertion. These factors act as sources of input to the "ordinate" level, which is composed of physical exertion, motivation and task aversion. The highest ("superordinate") order of the model is represented by undifferentiated exertion, which probably corresponds to the measured readings from Borg's scale (Pandolf, 1978). The model is based upon the findings of Kinsman et al. (1973) who identified bicycling fatigue, task aversion and motivation as three subjective groupings associated with prolonged, strenuous exercise.

IV. The Effects Of Exercise Upon RPE

Since the perception of effort is largely governed by physiological input, it is not surprising that an interest has been generated in the effects of exercise upon RPE. Previous authors (Morgan et al., 1976; Rejeski, 1981) have inferred that physical performance may be related as much to an individuals self-perceptions of ability as to their actual performance capacity. Dishman and Getman (1981) have shown that 20 weeks of isotonic or isokinetic training can produce not only significant improvements in VO2max, but increases in psychic vigor, assessed using the Profile of Mood States evaluation. Certain individuals are known to either chronically reduce or augment the intensity of their perceptions, including their perception of effort (Robertson et al., 1977). Athletes have been shown to have a greater tendency to reduce perceptual ratings than their
non-active counterparts (Ryan and Foster, 1967). In view of these observations, it is apparent that a theoretical framework based upon both physiological and psychological considerations may exist to support the concept of training-induced alterations in RPE. Certain physiological variables such as maximal HR and MAP are known to be determined, in part, by genetic endowment. Thus it may be expected that heredity could serve as an obstacle to significant adaptations in the perceptual response to exercise. After administering a number of submaximal and maximal workloads on a bicycle ergometer to 6 monozygous and 8 dizygous twins, Komi and Karppi (1977) were unable to show significantly different intra-pair variances in RPE between groups. This was assumed to be indirect evidence that RPE was not significantly influenced by heredity.

Kilbom (1971) has shown that following an aerobic exercise program, the metabolic cost of a given submaximal activity will be unchanged or slightly decreased. It was also found that when expressed as a relative percentage of maximal work capacity, the metabolic demands of a particular task were reduced. On this basis, it would be anticipated that the performance of a standard workload would be perceived as being less effortful. Whether differences in perceptual estimates of exertion could be expected at equivalent exercise intensities following training is less clear.

Numerous studies have investigated the effects of exercise upon RPE by using a longitudinal approach. Lewis et al. (1980)
observed a significant reduction in RPE at a fixed workload, following an 11-week training program conducted at 75-80% \( \dot{V}O_2\text{max} \). In a controlled study, Pandolf et al. (1975) found RPE to be lower at a specified HR or \( \dot{V}O_2 \) following 3 weeks of low intensity, long duration activity. Linderholm (1967) was able to demonstrate that 4 months of intensive exercise could result in a modified evaluation of effort at an absolute workload. Six weeks of rapid walking, stair climbing and stool-stepping have been shown to result in decrements in RPE during submaximal exercise in subjects suffering from rheumatoid arthritis (Ekblom and Goldbarg, 1975). Using a large sample (N=37), Knuttgen et al. (1973) reported decreased RPE values at a workload of 150 W when each of 3 treatment groups followed disparate interval training regimens. The total time of high intensity exercise was 15 minutes per session, and the program was conducted over a period of 1-3 months. Collectively, these studies suggest that rapid adjustments in the perceptual response to activity occur when exercise programs of varying intensity and duration are administered. No attempt was made to correlate RPE with relative exercise intensity in any of these investigations.

In contrast to these findings, Sidney and Shephard (1977) found that 23 elderly subjects reported augmented RPE values at a given workload following 34 weeks of training. Although unable to explain their results, the authors noted that a preliminary study involving the same sample had coupled self-reports of above average activity with low endurance capacity. This may signify that older subjects lack sufficient experience
with intensive exercise to accurately gauge effort expenditure.

In 1971, a series of 3 articles were published which indicated that although reductions in RPE are visualized at an absolute workload following training, no changes occur with respect to relative exercise intensity. Docktor and Sharkey (1971) examined the perceived exertion of 5 healthy but non-athletic college men following 5 weeks of conditioning. Three times per week, training commenced with treadmill walking at 5 mph, followed by 1% elevations in the treadmill grade until a HR of 180 bpm was achieved. Following training, the time required to attain HR values of 150 and 180 bpm was increased, and therefore occurred at a higher absolute workload. No differences in RPE were observed during the 6th minute of exercise or at a HR of 150 bpm, post-training. This illustrates that following training, increased workloads will be associated with any given estimate of exertion, in the range of moderate to intense exercise. This may not be the case during lighter activity, in this instance, achieved during the 6th minute of exercise.

Using a more rigorous training program (5-7 days per week of outdoor running, intensity unreported), Ekbloom and Goldbarg (1971) examined changes in RPE when intensity of exercise was adjusted relative to \( \dot{V}O_2\text{max} \). At submaximal workloads, RPE was found to be 1.5-2.0 points lower following the 8 week training program, but maximum RPE did not differ. When related to relative HR or \( \dot{V}O_2 \), RPE was unchanged. For a given oxygen
deficit or blood lactate concentration, no differences in RPE were observed following training. However, problems in the experimental design of this study prevent meaningful interpretation of the results. While training consisted mostly of outdoor running, both pre- and post-testing were conducted on a bicycle ergometer. This technique ignores the principle of the specificity of training. In addition, the results showed that during exercise at a given level of conditioning and specific \( \dot{VO}_2 \), perceptually, bicycling was more difficult than running. This would tend to minimize the effects of training, at a given \( \dot{VO}_2 \) during the post-test. Finally, although it was concluded that no changes in RPE were observed at 25, 50 and 75% \( \dot{VO}_2 \text{max} \) following training, the authors state that these workloads were only approximated during the testing sessions.

Kilbom (1971) trained female subjects for 7 weeks, dividing the sample into 3 groups who participated in variations of an interval training program. Exercise was performed on a bicycle ergometer, at a load which corresponded to 70% \( \dot{VO}_2 \text{max} \). Effective work time in all groups was held constant at 18 minutes. Training frequency was designed to be 3 times per week, but averaged 2.5 times per week. Mean exercise HR values ranged from 141-166 bpm. MAP increased by 11% and submaximal HR values were reduced by 10-15 bpm. Following training, RPE was lower at submaximal workloads, but was unchanged in relation to HR. Overall, no difference in RPE occurred at exhaustion, but a reduced subjective rating was observed in the oldest group of subjects.
It is known that exercise HR may be affected by such factors as caffeine (Atkinson, 1977) and time of day (Cohen et al., 1977). Unless these and other factors which affect HR are controlled for, the validity of drawing conclusions concerning changes in RPE at a single or even multiple HR following training is questionable. No report of any attempt to regulate these potentially confounding variables was made in these studies.

There has yet to be any evidence presented in the literature to describe the possible time course of training-induced alterations in RPE. The duration of the training period in these studies was short, ranging from 5-8 weeks. To date, a long-term evaluation of the effects of training upon RPE has not been undertaken. Possibly, adaptations in sensory perceptions at a given relative exercise intensity are more latent than corresponding physiological modifications. The degree to which changes in RPE which are solicited during training are influenced by the frequency and intensity of training is equally uncertain. Training frequency varied from 2.5-7 days per week, and training intensity from 141-180 bpm in the studies under discussion. This area requires further research.

Burkhardt and his associates (Burkhardt et al., 1982) randomly assigned 18 untrained college females to arm training (AT) or leg training (LT) groups. Prior to and following the program, MAP was assessed. Exercise was conducted at 50% VO2max for 21 sessions. Following training, a comparison was made of
both groups for both modes of exercise, at the same relative workload (50% $\dot{VO}_2$max). Overall RPE was lower on the arm test than the leg test for AT, and lower on the arm test for AT than LT. In other words, although exercising at the same metabolic rate, the perception of effort was diminished in the trained limbs. Using a cross sectional approach, Rejeski et al (1982) compared the effects of using toe-clips during a bicycle ergometer test to volitional fatigue in runners versus competitive cyclists. Subjects were tested under 2 conditions, toe-clip and no toe-clip, with 1 week separating the two tests. While working maximally, the trained cyclists demonstrated reductions in RPE eventhough $\dot{VO}_2$max was elevated with respect to the no toe-clip condition. This was attributed to an increase in motor efficiency, which was derived through cycle training. Similar changes were not observed in the group of runners. The results from these investigations support the concept that following training, RPE is reduced at a given relative workload. Doll et al. (1980) had subjects perform 8 tests to volitional fatigue on a treadmill, implementing variations in speed increment protocols. They discovered that significant differences in RPE existed at similar levels of $O_2$, between tests. In light of these findings, the suitability of evaluating variations in RPE solely on a metabolic basis must be re-examined. Relative exercise intensities based upon %MAP do not account for adaptations in physiological responses such as lactate production, ventilatory hyperpnea and catecholamine elevation (Astrand and Rodahl, 1970). These results and those
obtained elsewhere (Stamford and Noble, 1974) indicate that training may typically involve neuromuscular adjustments as well as cardiovascular gains.

Other cross-sectional investigations have demonstrated that fit and unfit subjects rate the effort required to perform standard workloads equally (Bar-Or, 1977; Bar-Or et al., 1972; Michael and Eckhardt, 1972; Morgan, 1977; Morgan and Pollock, 1977; Patton et al., 1977; Skinner et al., 1969). Michael and Eckhardt (1972) requested trained and untrained subjects to choose a treadmill work level which they considered to be "hard" at 0% slope. They were then asked to reproduce an equivalent work bout, with the treadmill re-set at a 10% grade. No differences were detected between groups in either of the workloads selected. Patton et al. (1977) found no differences in RPE during a 6 minute run at 6 mph on a treadmill in military conscripts who differed in fitness level. However, following 6 weeks of training, an 11% reduction in RPE occurred for all subjects during submaximal exercise. In a study performed upon athletes at the 1972 American Olympic wrestling team trials, Morgan (1977) discovered that no differences in RPE existed between successful and unsuccessful candidates. This was despite the fact that successful individuals had a higher VO2max, and a lower submaximal HR than their counterparts, at the same workload. It is difficult to interpret these findings. A common characteristic of all of these investigations is that they evaluated differences in RPE at low to moderate absolute workloads. As described previously, it may be that in certain
individuals, differences in RPE as a consequence of training are only manifested during intense activity. Wilbert et al. (1974) have previously suggested that any dissimilarities between the perceptual response of various groups appear only in higher ranges of exercise intensity. Morgan and Pollock (1977) observed that elite and college level runners had the same perception of effort at various workloads even though they were experiencing different degrees of physical stress. However, at speeds above 10 mph, the less fit runners did rate their effort expenditure significantly higher.

Rosentswieg and Williams (1979) tested the effort perception of 18 professional hockey players during treadmill exercise. The run was initiated at a 0% grade at a speed of 3.3 mph. At every minute thereafter, a 1% grade increase was implemented until a HR of 180 bpm was achieved. The players rated the maximal workload as "somewhat hard", registering a mean RPE value of 13.06 on the Borg scale. Theoretically, exercising at a HR of 180 bpm should have demanded "very hard" work from the players (Rosentswieg and Williams, 1977). The authors suggested that the players were sufficiently accustomed to highly vigorous exercise to exhibit lower RPE values for a given workload.

Further research into training-related changes in RPE is required. The literature which has been reviewed strongly suggests that RPE will be reduced at a given submaximal workload, following physical conditioning. This appears to be
particularly true in the higher ranges of exercise intensity. In support of the proposal that reductions in RPE exist when exercise is equated on a relative basis before and after training, it is known that fit individuals have aerobic thresholds which are substantially higher than sedentary individuals (Costill, 1970; Davis et al., 1979; Kindermann et al., 1979; Londeree and Ames, 1975). Since it has been shown that effort evaluations are similar between subjects at the aerobic threshold (Purvis and Cureton, 1981), this implies that well-trained individuals will rate a higher relative exercise demand to be easier. Part of the problem in reaching a conclusion on the issue of RPE trainability centres upon agreement as to what should be recognized as a "significant" decrement in RPE. Morgan (1977) has pointed out that a reduction of 1-2 RPE units on the Borg scale translates to a 10-20% change, which could potentially be very significant in endurance events such as the marathon. It would be of value to give this issue further consideration.
III. METHODS

Subjects

Thirty-five healthy male subjects agreed to participate in the study as members of either a training or control group. With the exception of three individuals, all subjects were physical education undergraduate students at the University of British Columbia. Each volunteer was accustomed to exercise, but none were trained. Prior to participation in the study, the subjects were advised of the nature of the testing and training procedures, and the potential risks which were involved. Signed, informed consent was obtained from each subject who participated in the study. No explanation was offered regarding the significance of or purpose for the perceptual ratings to be recorded during testing. The subjects appeared to believe that physiological measurements were to be evaluated as the dependent variables. Those subjects who commented upon the use of the perceptual ratings assumed that they were being utilized to monitor the progression of the exercise test, and to serve as an indicator of physical stress to alert the investigators to the onset of fatigue. Upon completion of the study, subjects were permitted access to their results, and a description of the research and its findings was offered.
Procedures

At the outset of the study, each subject performed an exercise session on a treadmill to become familiar with this apparatus. Within the following 2 days, subjects underwent a progressive treadmill run to volitional fatigue. During this test, running commenced at 8 km·hr⁻¹ (5 mph). At 1 minute intervals thereafter, the speed of the treadmill was increased by 0.8 km·hr⁻¹ (0.5 mph). Prior to the test, subjects were instructed as to the use of the Borg scale (Borg, 1970) and were administered 5 minutes of treadmill running to provide physiological warm-up. Constraints placed upon the availability of the subjects and the treadmill prevented certain combinations of subjects from participating in the exercise program. Apart from this restriction, assignment of the subjects to either the training (N=20) or control (N=15) group was performed randomly. Those in the control group were requested to maintain their normal activity level for the subsequent 9-week period. During the post-test, all subjects performed a treadmill run using a protocol which was identical to that used during the initial test. Both tests were conducted at approximately the same time of day. Subjects in the training group were re-tested within 3 days of the final training session.
Training Regimen

The 9-week training program involved treadmill running at a frequency of 3 days per week. Independent activity was not restricted. Preceding each training session, subjects performed a brief warm-up, comprised of stretching and light to moderate jogging. The initial week of training consisted of 20 minutes of exercise performed $0.8 \text{ km/hr}^{-1}$ (0.5 mph) above the individual ventilatory aerobic threshold. During each of the subsequent 4 weeks, subjects were required to increase their time of exercise by 3 minutes, so that by the end of the 5th week of training, each subject ran for 32 minutes at this velocity. At this time, individual training velocities were increased by $0.8 \text{ km/hr}^{-1}$ (0.5 mph) and exercise duration was reset at 23 minutes. During each consecutive week, subjects were again required to run for an additional 3 minutes, so that by the end of the 9th week of training, exercise was performed for 32 minutes at the re-adjusted workrate. This program was selected to provide the subjects with an intense training stimulus.

Measurements

Data was obtained for both the training and control groups, both before and after a 9-week period. Expired gases were collected and analysed (Beckmann Metabolic Measurement Cart), and measurements were fed into a data acquisition system
(Hewitt-Packard 3052A) for determination of 15 second respiratory gas exchange variables. Heart rates were calculated during the last 10 seconds of exercise at each workload, from an ECG trace (Avionics 4000). Ventilatory aerobic threshold (AerT) measurements were assessed using the point of non-linear increase in Excess CO2 (\( \dot{V}C02-RQ-V02 \)), and were not considered to be valid unless agreed upon by 2 separate investigators. Oxygen consumption (\( \dot{V}O2 \)) values at the AerT were evaluated by averaging the four 15-second \( \dot{V}O2 \) readings collected at the workload prior to this increase. \( \dot{V}O2\)max and maximal ventilation (\( \dot{V}E\)max) values were calculated from the 4 highest consecutive \( \dot{V}O2 \) and \( \dot{V}E \) readings, respectively. Maximal velocity (\( V\)max) was considered to be the highest velocity which a subject could maintain for greater than 15 seconds. Effort ratings which were reported at the onset of \( \dot{V}O2\)max were recorded as maximum RPE (RPEmax). Body composition values were determined using an underwater weighing technique (Katch and McArdle, 1977). Exercise HR values were measured manually via the carotid pulse, immediately following the termination of exercise.

Perceptual readings were recorded using the scale and procedures devised by Borg (1970), and were collected at the 25th and 55th seconds of exercise at each workload. Following the initial reading selected by the subject, the previous reading indicated was pointed to at the appropriate time, and the subjects communicated any changes in the direction and magnitude of the ratings via hand signals. Values for RPE at 55, 65, 75, 85 and 95% \( V\)max and \( \dot{V}O2\)max were determined by
interpolating between minute values for RPE, velocity and \( \dot{V}O_2 \), and were recorded to the nearest \( 1/10 \)th of a unit.

**Statistical Analyses**

Differences in the values obtained for \( \dot{V}O_2\max \), AerT, and AerT as \( %\dot{V}O_2\max \) measured pre to post in both the training and control groups were tested using a MANOVA. A second MANOVA was used to analyse changes in body composition, weight, time to volitional fatigue, \( \dot{V}E\max \) and HR at AerT. Maximum RPE and RPE at the AerT data were also included in this analysis. Changes in RPE at absolute and relative work intensities were analysed using a 2x2x5 ANOVA, with repeated measures on the third factor. Separate orthogonal contrasts were used to test for trends in the RPE data recorded at the various proportions of Vmax and \( \dot{V}O_2\max \). The same technique was used to evaluate changes in trends at equivalent absolute and relative work intensities. Statistical significance for all comparisons was accepted at the 0.95 level of confidence.
IV. RESULTS

Due to morbidity or conflicting time commitments, seven subjects in the original training group, and two subjects from the original control group failed to complete the second testing session. Attendance at the training program was excellent, with final members of the training group completing 97% of all scheduled sessions, or performing the workouts at an alternate time. Exercise heart rate values in the training group were 171.5 ± 5.7 bpm (mean ± SD).

Physical Characteristics

Statistics for the physical characteristics of the subjects are presented in Table 1. Initially, subjects in the training group were significantly taller (p<0.01) and heavier (p<0.05) than the subjects in the control group, but no significant differences existed in terms of percent body fat or age.

A significant time main effect was observed for body fat (p<0.0001), and changes in body weight across groups and over time approached significance (p<0.06). When the group by time interaction effect was considered, decreases in body weight in the training group were greater than in the control group (p<0.01). Body fat declined by 2.5% in the training group, and 1.2% in the control group, with the interaction effect approaching significance (p<0.08).
### Table 1 - Physical Characteristics of Subjects

<table>
<thead>
<tr>
<th>Variable</th>
<th>Group</th>
<th>Pre-Training</th>
<th>Post-Training</th>
<th>Time</th>
<th>Group x Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>TG^2</td>
<td>21.1 ± 2.1</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<tr>
<td></td>
<td>CG</td>
<td>21.4 ± 1.9</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Body height (cm)</td>
<td>TG</td>
<td>183.0 ± 5.6</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>CG</td>
<td>176.4 ± 4.7</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Body weight (kg)</td>
<td>TG</td>
<td>79.9 ± 7.4</td>
<td>78.1 ± 6.9</td>
<td>.06</td>
<td>.01</td>
</tr>
<tr>
<td></td>
<td>CG</td>
<td>73.5 ± 6.5</td>
<td>73.8 ± 7.0</td>
<td>.06</td>
<td>.01</td>
</tr>
<tr>
<td>Body fat (%)</td>
<td>TG</td>
<td>13.4 ± 5.5</td>
<td>10.9 ± 4.7</td>
<td>.001</td>
<td>.08</td>
</tr>
<tr>
<td></td>
<td>CG</td>
<td>13.3 ± 5.6</td>
<td>12.1 ± 5.5</td>
<td>.001</td>
<td>.08</td>
</tr>
<tr>
<td>N</td>
<td>TG</td>
<td>20</td>
<td>13</td>
<td>-</td>
<td>-</td>
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<tr>
<td></td>
<td>CG</td>
<td>15</td>
<td>13</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

1. The p values are based upon univariate ANOVAS. Multivariate F=2.75, p<0.04 for Group x Time effects for variables in Tables 1, 3 and 4.
2. TG, training group; CG, control group. Values are means ± SD.

**Performance Measures**

A summary of pre- and post-training performance measures and the probability levels associated with observed changes in these variables are shown in Table 2 and Table 3. Table 2 includes a summary of alterations in performance measures which were hypothesized, and Table 3 contains a synopsis of changes in pertinent but non-postulated performance measures.

The exercise program resulted in a 7.5% improvement in \( \dot{V}O_2\text{max} \) in the training group. When the significant loss in body weight was accounted for, this increase was reduced to 5.9%. These values were higher than the 1-2% elevations in \( \dot{V}O_2\text{max} \).
which were observed in the control group, but no significant group by time interaction effects were found in VO2max expressed in either ml·kg\(^{-1}\)·min\(^{-1}\) or l·min\(^{-1}\). When initial fitness level was blocked for (high,low) and differences in VO2max were analysed using a 2x2x2 ANOVA, the time main effect was significant (p<0.05) and the time by group by level interaction approached significance (p<0.09). Subjects in the training group who were initially at a low fitness level exhibited greater increases in VO2max than subjects who were more fit at the outset of the study, who showed limited change. No differences existed in the degree of change in VO2max between initially fit and unfit control subjects.

Table 2 - Summary of Hypothesized Physiological Training Effects

<table>
<thead>
<tr>
<th>Variable</th>
<th>Group</th>
<th>Pre-Training</th>
<th>Post-Training</th>
<th>Time</th>
<th>Group x Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>VO2max ((l·min^{-1}))</td>
<td>a</td>
<td>TG 3.9 ± 0.5</td>
<td>CG 3.7 ± 0.4</td>
<td>0.06</td>
<td>&gt;0.20</td>
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<tr>
<td>VO2max ((ml·kg^{-1}·min^{-1}))</td>
<td>b</td>
<td>TG 49.4 ± 5.8</td>
<td>CG 51.4 ± 4.6</td>
<td>0.04</td>
<td>0.13</td>
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<tr>
<td>AerT ((l·min^{-1}))</td>
<td>c</td>
<td>TG 3.02 ± 0.3</td>
<td>CG 2.86 ± 0.3</td>
<td>&gt;0.20</td>
<td>0.01</td>
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</tr>
<tr>
<td>AerT ((ml·kg^{-1}·min^{-1}))</td>
<td>d</td>
<td>TG 38.5 ± 4.5</td>
<td>CG 39.6 ± 5.9</td>
<td>&gt;0.20</td>
<td>0.01</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>AerT ((% of VO2max))</td>
<td>e</td>
<td>TG 77.0 ± 5.9</td>
<td>CG 75.9 ± 7.0</td>
<td>0.16</td>
<td>0.17</td>
</tr>
</tbody>
</table>

Multivariate F=2.67, p<.07 for Group x Time effect, variables a,c,e. Multivariate F=4.85, p<.01 for Group x Time effect,
variables b, d, e.

A highly significant (p<0.01) group by time interaction effect occurred for aerobic threshold (AerT). The training group exhibited an 8.0% increase in AerT, which was reduced to 6.3% when weight loss was considered. In the control group, AerT declined by 5% (l·min⁻¹) and 4% (ml·kg⁻¹·min⁻¹), respectively. Expressed in terms of %VO₂max, no significant changes in AerT were observed. Coefficients of correlation (Pearson r) were calculated across levels of %VO₂max within each group. These differed by less than 1 percent from pre- to post-test, averaging 0.89 in the training group, and 0.84 in the control group.

Table 3 - Summary of Non-Hypothesized Physiological Training Effects

<table>
<thead>
<tr>
<th>Variable</th>
<th>Group</th>
<th>Pre-Training</th>
<th>Post-Training</th>
<th>Time Group x Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time-volitional fatigue (mins)</td>
<td>TG</td>
<td>11.6 ± 1.7</td>
<td>12.7 ± 1.5</td>
<td>.001 .09</td>
</tr>
<tr>
<td></td>
<td>CG</td>
<td>12.0 ± 1.8</td>
<td>12.5 ± 2.2</td>
<td></td>
</tr>
<tr>
<td>VEmax (l·min⁻¹,BTPS)</td>
<td>TG</td>
<td>144.9 ± 20.1</td>
<td>152.9 ± 17.8</td>
<td>.01 .09</td>
</tr>
<tr>
<td></td>
<td>CG</td>
<td>134.2 ± 13.1</td>
<td>134.9 ± 17.8</td>
<td></td>
</tr>
<tr>
<td>HR at AerT (bpm)</td>
<td>TG</td>
<td>171.7 ± 9.7</td>
<td>171.7 ± 3.1</td>
<td>&gt;.20 &gt;.20</td>
</tr>
<tr>
<td></td>
<td>CG</td>
<td>173.8 ± 11.5</td>
<td>171.2 ± 10.8</td>
<td></td>
</tr>
</tbody>
</table>

Mean values for maximum ventilation (VEmax) improved by 5.5% in the training group, and less than 1% in the control group. The interaction effect with the control group approached significance (p<0.09). A highly significant (p<0.0001) time
main effect was observed for time to volitional fatigue. The group by time interaction effect for this variable did not achieve statistical significance (p<0.09). Heart rate at the AerT did not vary significantly over time or group, and averaged 87.2% of the maximum HR.

**Perceptual Effects**

Pre- and post-test values for RPEmax and RPE at the AerT are presented in Table 4. A highly significant (p<0.01) interaction effect occurred between groups for RPE at the AerT. Although RPE at the AerT was lower in the control group, this effect was not observed in the training group. RPEmax was found to increase significantly (p<0.001) when averaged over the two groups, but no differences in improvement were found between groups for this variable.

| Table 4 - Summary of Training Effects Upon Selected Perceptual Variables |
|-------------------------------------------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Variable                                       | Group | Pre-Training    | Post-Training   | Time            | Group x Time    |
| RPE at AerT                                    | TG    | 12.5 ± 1.9      | 12.5 ± 2.0      | .02             | .01             |
|                                                | CG    | 13.2 ± 2.6      | 11.5 ± 2.4      |                 |                 |
| RPEmax                                         | TG    | 18.8 ± 1.3      | 19.4 ± 1.1      | .001            | >.20            |
|                                                | CG    | 19.0 ± 1.0      | 19.6 ± 1.0      |                 |                 |

Values for RPE at workloads expressed as a percentage of maximum velocity (Vmax) and VO2max are presented in Table 5.
Changes in RPE at equivalent absolute and relative workloads have been calculated as percent reductions, and are shown in Table 6. Comparing pre- and post-test values, the RPE associated with a given volume of oxygen consumption [Initial $\dot{V}O_2\text{max}$ (pre) versus Initial $\dot{V}O_2\text{max}$ (post)] was significantly reduced ($p<0.01$). The interaction effect for this variable was non-significant, and failed to distinguish between the changes noted in the control and training groups (Figure 1). When the RPE at equivalent relative workloads based upon $\dot{V}O_2$ were examined [Initial $\dot{V}O_2\text{max}$ (pre) versus Final $\dot{V}O_2\text{max}$], no differences were demonstrated over the 9-week period.
Table 5 - Summary of Effort Ratings

<table>
<thead>
<tr>
<th>Variable</th>
<th>Group</th>
<th>Workload</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>55%</td>
</tr>
<tr>
<td>Initial ( VO_{2}\text{max}(pre) ) ((l\cdot min^{-1}) )</td>
<td>TG</td>
<td>7.9 ±1.2</td>
</tr>
<tr>
<td></td>
<td>CG</td>
<td>8.9 ±2.2</td>
</tr>
<tr>
<td>Initial ( VO_{2}\text{max}(post) ) ((l\cdot min^{-1}) )</td>
<td>TG</td>
<td>6.4 ±0.5</td>
</tr>
<tr>
<td></td>
<td>CG</td>
<td>7.5 ±1.5</td>
</tr>
<tr>
<td>Final ( VO_{2}\text{max} ) ((l\cdot min^{-1}) )</td>
<td>TG</td>
<td>6.7 ±0.4</td>
</tr>
<tr>
<td></td>
<td>CG</td>
<td>7.9 ±1.7</td>
</tr>
<tr>
<td>Initial ( V_{\text{max}}(pre) ) ((km\cdot hr^{-1}) )</td>
<td>TG</td>
<td>9.2 ±1.7</td>
</tr>
<tr>
<td></td>
<td>CG</td>
<td>9.2 ±2.4</td>
</tr>
<tr>
<td>Initial ( V_{\text{max}}(post) ) ((km\cdot hr^{-1}) )</td>
<td>TG</td>
<td>6.8 ±0.9</td>
</tr>
<tr>
<td></td>
<td>CG</td>
<td>8.1 ±2.4</td>
</tr>
<tr>
<td>Final ( V_{\text{max}} ) ((km\cdot hr^{-1}) )</td>
<td>TG</td>
<td>7.2 ±1.2</td>
</tr>
<tr>
<td></td>
<td>CG</td>
<td>8.7 ±1.7</td>
</tr>
</tbody>
</table>

1. \( VO_{2}\text{max} \) level during the pre-test, measured at the pre-test
2. \( VO_{2}\text{max} \) level during the pre-test, measured at the post-test
3. \( VO_{2}\text{max} \) level during the post-test, measured at the post-test.
4. Velocity level during the pre-test, measured at the pre-test.
5. Velocity level during the pre-test, measured at the post-test.
6. Velocity level during the post-test, measured at the post-test.
Analysis showed that the RPE reported at a given running velocity were significantly (p<0.001) reduced across groups and over time [Initial Vmax (pre) versus Initial Vmax (post)]. Effort ratings were also diminished at relatively equivalent running velocities [Initial Vmax (pre) versus Final Vmax (post)]. While neither of these trends were found to be significant when the group by time interaction effect was considered, the changes in RPE at comparable absolute (p<0.08) and relative (p<0.06) velocities did approach significance. These results are displayed in Figure 3 and Figure 4.

Trend analysis revealed that in all instances, the relationship between RPE and workload was highly linear. However, a significant quadratic component was also identified in the relationship between RPE and given (p<0.001) or relatively equivalent (p<0.0001) VO2 levels. Changes in the magnitude of these components were not significant over time. No significant quadratic component was found in the relationship between RPE and either absolute or relative running velocity. A highly significant (p<0.001) change occurred in the intensity by condition interaction, when relative velocity was analysed. Inspection revealed that the decreases in RPE from pre- to post-training were greatest at the lower intensities of exercise, and that these differences were reduced as the subjects approached the point of volitional fatigue. This effect did not operate differentially between groups. Although similar trends were exhibited in the absolute velocity and relative VO2 data, these did not achieve statistical significance.
Table 6 - Percent Reductions in RPE Following 9 Weeks of Training

<table>
<thead>
<tr>
<th>Variable</th>
<th>Group</th>
<th>Workload</th>
<th>ANOVA Summary (p:)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>55%</td>
<td>65%</td>
</tr>
<tr>
<td>Δ RPE (% Initial VO2max)</td>
<td>TG</td>
<td>19.8</td>
<td>20.0</td>
</tr>
<tr>
<td></td>
<td>CG</td>
<td>15.7</td>
<td>6.7</td>
</tr>
<tr>
<td>Δ RPE (% VO2max)</td>
<td>TG</td>
<td>15.5</td>
<td>12.5</td>
</tr>
<tr>
<td></td>
<td>CG</td>
<td>10.3</td>
<td>8.6</td>
</tr>
<tr>
<td>Δ RPE (% Initial Vmax)</td>
<td>TG</td>
<td>25.8</td>
<td>24.4</td>
</tr>
<tr>
<td></td>
<td>CG</td>
<td>11.3</td>
<td>7.7</td>
</tr>
<tr>
<td>Δ RPE (% Vmax)</td>
<td>TG</td>
<td>21.6</td>
<td>19.9</td>
</tr>
<tr>
<td></td>
<td>CG</td>
<td>5.3</td>
<td>4.6</td>
</tr>
</tbody>
</table>

Table 7 presents a summary of hypothesis testing. Hypotheses 3A and 3B demonstrated a trend towards significance, but they could not be supported at the 0.95 level of confidence.

Table 7 - Summary of Hypothesis Testing

<table>
<thead>
<tr>
<th>No.</th>
<th>Hypothesis</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>An increased work capacity in the training group, measured by: A) VO2max (l·min⁻¹) (TG&gt;CG) B) AerT (l·min⁻¹) (TG&gt;CG) C) AerT (%VO2max) (TG&gt;CG)</td>
<td>Non-supported Supported Non-supported</td>
</tr>
<tr>
<td>2.</td>
<td>Reduced effort ratings, measured at: A) Given VO2 levels (TG&gt;CG) B) Relatively equivalent levels of VO2 (TG&gt;CG)</td>
<td>Non-supported Non-supported</td>
</tr>
<tr>
<td>3.</td>
<td>Reduced effort ratings, measured at: A) Given running velocities (TG&gt;CG) B) Relatively equivalent running velocities (TG&gt;CG)</td>
<td>Non-supported Non-supported</td>
</tr>
</tbody>
</table>
Figure 1 - Mean RPE at Absolute Workloads Based Upon VO2

- Control (pre)
- Control (post)
- Training (pre)
- Training (post)

RPE

INTENSITY (% INITIAL VO2max)
Figure 2 - Mean RPE at Relative Workloads Based Upon VO2

- Control (pre)
- Control (post)
- Training (pre)
- Training (post)
Figure 3 - Mean RPE at Absolute Workloads Based Upon Velocity
Figure 4 - Mean RPE at Relative Workloads Based Upon Velocity
V. DISCUSSION

The results of this study cannot confirm that the RPE associated with relative workloads, based upon either VO2 or velocity, are affected by endurance training. Nevertheless, at workloads less than 85% of the maximal velocity, a strong trend existed toward significant reductions in RPE. Furthermore, there was a noticeable difference between the probability of this change and the change observed for RPE at a percentage of VO2max. Physiological adaptations, from which modifications in the perception of effort are at least partially derived, are related to the intensity, frequency and duration of training. The impact which manipulations in these training variables have upon RPE has not been assessed. Consequently, it is not known whether greater changes in RPE than those observed in the current study would occur during prolonged training. Perhaps the obtained reductions in RPE at relative workloads based upon velocity would continue and achieve significance if the duration of the program was extended.

In order to provide the subjects in the present investigation with a high-intensity training stimulus, exercise was conducted at workloads above the AerT. As a result, although the 19% decrease observed in percent body fat was non-significant when compared to the control group, this change was greater than that reported in previous studies (Misner et al., 1974; Wilmore et al., 1970) of similar exercise duration, frequency and mode. In contrast, the intensity of the training program was not reflected by significant elevations in VO2max.
This may be attributed to the fact that several of the subjects who were moderately fit during the preliminary test, failed to demonstrate substantial improvements in VO2max. Increases in VO2max in the control group, which were identical in magnitude (1·min⁻¹) to those reported elsewhere (Davis et al., 1979) for control subjects over a 9-week period, may have contributed to this finding as well. Increases in AerT and maximum ventilation, which averaged approximately 6%, also appeared to be limited by the initial fitness level of the subjects. Clearly, more dramatic physiological effects could be produced in a less active sample, particularly if the duration and frequency of the training program were increased. Hypothetically, RPE could show decreases of a corresponding magnitude.

Depending upon the level of physical conditioning of the subjects, AerT may be located at 50-85% VO2max (Costill, 1970; Davis et al., 1979; Dressendorfer et al., 1981; Kindermann et al., 1979; Londeree and Ames, 1975). Davis et al. (1979) reported that AerT, expressed as a percentage of VO2max (AerT-%VO2max), increased by 15% subsequent to 9-weeks of cycle training conducted at VO2 levels 50-70% above the original AerT. The subjects in their study were initially at a low level of physical fitness (VO2max = 31.1 ml·kg⁻¹·min⁻¹), and experienced a 44% increase in AerT expressed as absolute VO2 (1·min⁻¹). Ready and Quinney (1982) observed increases of 70.4% and 19.4% in AerT (1·min⁻¹) and AerT-%VO2max, respectively, following 9 weeks of cycle training at 80% VO2max. However, the change in
AerT-%VO2max was not found to be significant. The subjects in the current study were initially better physically conditioned, based upon VO2max and AerT-%VO2max, than those in either of the cited studies. Consequently, the increase in AerT (l·min⁻¹) which resulted was more modest, and no difference in AerT-%VO2max was observed. It would appear that elevations in AerT-%VO2max are manifested only when the rate of improvement in AerT exceeds that of VO2max. However, data pertaining to the AerT must be interpreted with caution. This study has selected Excess CO2 as a measure of the AerT, while previous results have been based upon a variety of other techniques. Moreover, values for AerT may be affected by the rate of work increase during incremental exercise tests (Hughson and Green, 1982). Therefore, AerT-%VO2max in this study, which occurred at 77% VO2max, may be difficult to compare to AerT-%VO2max in other reports.

Reviews which have discussed sensory cues to perceived exertion (Mihevic, 1981; Robertson, 1982) have favoured the interpretation that %VO2max is an important determinant of RPE during dynamic exercise. The theory that exercise may be prescribed based upon effort evaluation (Borg, 1982; Smutok et al., 1980) assumes that different individuals perceive comparable degrees of physical strain in an analogous manner. This suits the concept that RPE is commensurate with %VO2max. However, the onset of the AerT is associated with sustained elevations in plasma lactate and ventilation (Skinner and McClellan, 1980). Fluctuations in these variables have been
shown to correlate with RPE (Horstman, 1977; Horstman et al., 1979c; Kamon et al., 1974; Noble et al., 1973; Morgan and Pollock, 1977; Pederson and Welch, 1977) and appear to influence effort evaluation. Since AerT-%VO2max may be elevated by training, input from effort cues which are associated with ventilation and/or blood lactate become dominant at different levels of %VO2max. Evidently, RPE cannot always be compatible with a model of effort perception which is based upon blood lactates, ventilation and %VO2max simultaneously.

If perceived effort corresponds closely to AerT, then validation of the relationship between RPE and relative VO2 (RPE-%VO2max) may be contingent upon the homogeneity of the sample group. Within the context of this paradigm, RPE-%VO2max would not be expected to deviate among individuals unless AerT-%VO2max varied as well. Furthermore, comparisons of individuals who do not differ substantially in physical conditioning should yield similar values for RPE at the AerT. This has been confirmed in the literature (Purvis and Cureton, 1981). It has also been shown that RPE are higher at the AerT for well-trained athletes than sedentary subjects, who differ radically in AerT-%VO2max (Simon et al., 1983). Cross-sectional studies which have failed to demonstrate differences in RPE-%VO2max as a function of fitness (Fleming et al., 1982; Horstman et al., 1979c) have not reported values for AerT-%VO2max. In the present study, neither RPE at the AerT or AerT-%VO2max changed in the training group. Decrement in RPE at the AerT were paralleled by a non-significant trend towards reductions in
AerT-%VO2max in the control group. This indicates that RPE were closely related to AerT. Since the 6% difference in correlation between RPE and %VO2max among groups was approximately the same as the 5% decrease in AerT-%VO2max, RPE may also appear to have been related to %VO2max. However, since correlations between RPE and %VO2max were nearly identical before and after testing, this seems unlikely.

The lower RPE at the AerT in the control group could also be attributed to familiarization with the testing equipment and protocol, despite an attempt to control for this confounding variable. Theoretically, this process could effect effort ratings. Inexperience in the performance of an exercise task has been reflected in elevations in RPE during preliminary testing elsewhere (Horstman et al., 1979c). This mechanism could explain the increase in time to volitional fatigue and reductions in RPE at a given VO2 (6.8%) or velocity (5.6%) in the control group, which occurred without significant changes in cardiovascular indices. It may also account for the fact that although the average RPE of subjects in the exercise group were 16.4% and 17% lower, respectively, at a given VO2 or velocity during the post-test, this effect could not be attributed to the training program. Nevertheless, the subjects in each group were equally unfamiliar with treadmill running prior to the study, and familiarization would not be expected to differentially affect RPE-AerT among groups. Conceivably, if training enhances perceptual sensitivity to effort cues such as blood lactates and ventilation, RPE-AerT would be less dependent upon %VO2max, and
the effects of familiarization upon the RPE-AerT relationship would be diminished. This could explain the difference in RPE-AerT which was observed between groups.

An important implication of the postulated relationship between RPE and %\(\dot{V} \text{O}_2\)max is that the effects of training upon effort perception will tend to be obscured when RPE are equated in terms of \(\dot{V} \text{O}_2\)max. Early evidence suggested that when \(\dot{V} \text{O}_2\) or HR are adjusted on a relative basis, RPE do not change (Docktor and Sharkey, 1971; Ekblom and Goldbarg, 1971; Kilbom, 1971; Skinner et al., 1969). Recent data (Burkhardt et al., 1982; Klein, 1982) conflicts with these results. In the present investigation, no significant changes were observed in the RPE reported by the training group, at relative workloads based upon \(\dot{V} \text{O}_2\). Because the mechanisms which regulate perceptual adaptations to exercise training are not presently understood, it is uncertain whether differences in RPE could have been expected from a theoretical perspective. Ventilatory volume, pressure and rate may all be perceived with a high degree of accuracy and exert considerable impact upon effort perception (Bakers and Tenney, 1970; Mihevic, 1981). Compared to non-athletes, endurance athletes have low ventilatory chemoresponses and low exercise VE at equivalent relative work levels, but it is not clear whether this trait is innate or affiliated with training (Martin et al., 1979). Although RPE increases uniformly with relative metabolic rate (Robertson, 1982; Sargeant and Davies, 1973; Skinner et al., 1973a), no afferent nervous system input exists to monitor \(\dot{V} \text{O}_2\) (Edwards et al.,
1972). In addition, no correspondence can be shown between effort and VO2 when the peripheral signal to the effort sense is held constant (Cafarelli, 1978). Catecholamine excretion has also been associated with the evaluation of effort (Docktor and Sharkey, 1971; Frankenhaeuser, 1969; Schnabel et al., 1982) and is purportedly a function of relative metabolic rate (Howley et al., 1970). However, during steady-rate running at the AerT, catecholamine levels progressively increase and appear to be related to glycogen availability (Schnabel et al., 1982). Aerobic training is known to produce an increase in muscle glycogen stores (Bergstrom and Hultman, 1966). It also results in a greater proportion of energy derivation from fats than carbohydrates during submaximal exercise, resulting in a glycogen sparing effect (Holloszy, 1973). Consequently, it would be expected that glycogen depletion would occur at a slower rate in trained individuals, thereby augmenting carbohydrate availability. This would signify a more potent input from the catecholamine-related component of effort perception as exercise progresses. It has previously been demonstrated that endurance training results in decrements in catecholamine levels at workloads of 60, 70 and 80% VO2max and may be responsible for reductions in the central contribution to RPE (Skrinar et al., 1983). In light of these findings, earlier statements that no theoretical basis exists for modifications in RPE at relative levels of VO2 (Mihevic, 1981) may have been premature.

Recently, it has been acknowledged (Rejeski et al., 1982)
that examining training-induced alterations in RPE solely from the point of view of cardiovascular gains may be inadequate. An alternative approach to this issue involves an evaluation of changes in RPE from the perspective of peripherally-mediated adaptations. Few studies have assessed the perceptual response to chronic exercise using this procedure. In this study, a difference of approximately 11% existed between the declines observed in the control and training groups, when RPE were analysed at relative velocities. This trend emphasizes the multi-dimensional nature of physical training. In contrast to the present findings, Skinner et al. (1969) could not discriminate between the RPE values which were reported at a percentage of maximal workload on a bicycle ergometer by physically fit and unfit subjects. The same authors noted that although no differences existed in the work performed at a HR of 150 or RPE of 15 on a bicycle, subjects who were heavier and fatter accomplished less work at these standards on a treadmill (Skinner et al., 1969). Considerable evidence supports the role of sensations arising in tendon, skin, joint and ligament receptors in the perception of effort (Ekblom et al., 1975; Gandevia and McCloskey, 1976; Henriksson et al., 1972; Pandolf and Noble, 1973; Stamford and Noble, 1974). These results imply that it may be inappropriate to compare the sensory response to training occurring in weight-bearing and weight-supported activities. This does not necessarily mean that RPE at relative exercise intensities which are measured in terms of neuromuscular parameters are unaffected by cycle training. When
competitive cyclists become skilled in the use of muscle-specific instruments such as toe-clips, RPE may be lower during maximal exercise (Rejeski et al., 1982). Limb speed and RPE are highly correlated during bicycle exercise at rapid pedalling rates (Croisant, 1982; Lollgen et al., 1980). If proprioceptive feedback responding to limb speed is a stimulus to effort perception which can be modified by training, then bicycle training programs which increase workload exclusive of workrate may have a reduced impact upon RPE. Thus perceptual adaptations to chronic bicycle exercise may depend upon the nature of the training program which is employed.

The current finding, that RPE may be reduced to a greater extent when expressed as a relative percentage of neuromuscular rather than cardiovascular measures, suggests that a greater reduction occurs in local than central cues to effort perception with training. This hypothesis has generally been supported in the literature (Knuttgen et al., 1982; Lewis et al., 1980; Rejeski et al., 1982). Studies have shown that blood lactate levels are lower at the same %VO2 following training (Hermansen et al., 1967; Saltin and Karlsson, 1971). Therefore, due to the higher AerT-%VO2max in trained subjects, there is a theoretical basis for expecting local RPE to be reduced at exercise intensities which are below the elevated AerT but above the initial AerT. Although blood lactates were not measured directly in this investigation, the results do not support the concept of lactate-mediated declines in RPE at relative exercise intensities, subsequent to training. Both the lactate and
effort responses to exercise are described by a positively accelerating function (Borg, 1962; Gamberale, 1972). It may be surmised that the curvilinear increase in RPE as a function of %VO2max in this study was a reflection of the effect of the lactate response, and/or that of ventilation, which responds in a similar fashion (Skinner and McClellan, 1980). Since no change was observed in the magnitude of the quadratic component following training, it would not be expected that these variables would exert a different degree of input into the effort sense at this time. The relationship between RPE and relative velocity was not curvilinear in nature, and greater reductions in rated effort were observed than when RPE was plotted against %VO2max. Therefore, although no direct evidence exists, it appears that decreasing strain experienced in the active muscles was the dominant local perceptual response to training. Since local factors appear to dominate central contributors to effort perception at exercise intensities below the AerT, the fact that decreases in RPE were greatest at moderate exercise intensities (55-85% Vmax) supports this conclusion. It also coincides with the finding that training may decrease the influence of local cues during maximal exercise at an elevated VO2max, without appreciable changes in plasma lactic acid concentration (Rejeski et al., 1982).

Slow-twitch muscle fibres appear to be more efficient than fast-twitch fibres (Davies, 1965; Gibbs and Gibson, 1972; Wendt and Gibbs, 1973) and provide a more sensitive measure of effort expenditure (Banister, 1979; Hore et al., 1976). In this case,
muscle fibre composition may mediate the perception of effort, as has been suggested elsewhere (Weiser and Stamper, 1977). Considerable evidence exists to support the notion that endurance training results in localized physiological adaptations (Gollnick et al., 1973; Magel et al., 1975; McArdle et al., 1978). While it is not clear whether fast-twitch fibres may be converted to slow-twitch fibres (Holloszy, 1973), reports of increased mechanical efficiency with training (Pandolf et al., 1975; Robinson and Harmon, 1941; Ekblom et al., 1978) subscribe to the concept that endurance training promotes the recruitment of exercise-specific motor units to more effectively meet the demands of a given task (Edgerton, 1976). On the basis of these findings, it is logical to conclude that neurological adaptations which accompany endurance training result in reductions in RPE at relative exercise velocities by increasing the efficiency of motor unit selection and improving the correspondence between effort evaluation and actual physiological demands. With respect to the current study, this might explain both the reductions in RPE at relative workloads based upon velocity, and the stability of RPE-AerT in the training group, as discussed previously. It would also help to confirm the results of Morgan and Pollock (1977), who found that highly-trained athletes interpret effort sensations more accurately than their less successful counterparts.

No explanation can be offered for the significant increase which was observed in maximum RPE. Possibly, by becoming more familiar with the test protocol, the subjects were able to judge
their capacity to continue running more accurately. Being more cognizant of approaching fatigue, they may have selected effort ratings which seemed more appropriate for the termination of exercise. Other investigators have not found differences in maximum RPE following training (Ekblom and Goldbarg, 1971, Lewis et al., 1980). An exception concerns the results of Rejeski et al. (1982), who observed a decrease in local ratings of RPE at a higher VO2max in trained subjects who wore toe-clips. Potentially, both maximum RPE and RPE at relative workloads could be lowered by habitual exercise, due to a modification of the perceptual processing of environmental and/or physiological stimuli. Many individuals either consistently reduce or augment the intensity of their perceptions (Petrie, 1967; Ryan and Foster, 1967; Sweeney, 1966), including their perception of effort (Robertson et al., 1977). The fact that high-intensity stimulation appears to develop the reduction response (Robertson et al., 1977) could apply to exercise. Reducers tend to display a low perceptual reactance to muscular effort, a high tolerance to pain (Petrie et al., 1960; Sweeney, 1966), and participate in athletics (Ryan and Foster, 1967). Pain and effort during exercise are temporally related, and often cannot be distinguished from each other (Caldwell and Smith, 1967). Since pain tolerance may be critical to successful participation in certain athletics (Tahu, 1981), perceptual reductions may contribute to increased exercise performance. In this respect, it is of interest to note that maximal exercise performance appears to be limited by a perceptual barrier (Banister, 1979;
Kilbom et al., 1983), which imposes restrictions on the full expression of physiological capacity. Analysis of the impact of reductions in effort perception upon the magnitude of this constraint to performance is worthy of consideration.
VI. SUMMARY AND CONCLUSIONS

The purpose of this investigation was to examine modifications in the perception of effort at relatively equivalent workloads following training, and compare the results obtained using different techniques of analysis. Thirteen subjects completed a progressive, 9-week endurance training program, which involved running at velocities above the ventilatory aerobic threshold (AerT). Changes in the perceptual and physiological responses of the training group (N=13) were compared to those observed in a control group (N=13). Improvements in VO2max, time to volitional fatigue and maximum ventilation were not found to be significant at the 0.05 probability level. Highly significant (p<0.01) improvements in AerT appeared to be the dominant physiological effect of training.

Aerobic threshold at a %VO2max (AerT-%VO2max) was not affected by training. In the control group, decreases in ratings of perceived exertion (RPE) at the AerT were paralleled by reductions in AerT-%VO2max. In the training group, RPE were 14% and 17% lower at a given VO2 and velocity, respectively, at the post-test. At equivalent relative workloads, decreases in RPE averaged 7.2% for VO2 and 12.8% for velocity. When modifications in RPE in the control group were considered, the changes in RPE in the training group were not significant (p<0.05). Despite the decrements in RPE in the control group, changes in RPE in the training group approached significance at fixed velocities (p<0.08) and relative velocities (p<0.06).
Maximum RPE were found to increase significantly in both the training and control groups.

Although RPE increased linearly with workload, a significant quadratic component was also identified in the relationship between RPE and given (p<0.001) or relatively equivalent (p<0.0001) VO2 levels. Changes in the magnitude of these components were not observed over time. No significant quadratic component was found in the relationship between RPE and either absolute or relative running velocity.

On the basis of the findings which have been presented, it is concluded that in a moderately fit sample:

1) Elevations in AerT can be achieved independent of changes in VO2max.

2) Changes in AerT as a percentage of VO2max are not a typical manifestation of training, but RPE appear to be related to AerT-%VO2max.

3) When training is evaluated in terms of improvements in running velocity rather than VO2, greater reductions in RPE are observed at moderate exercise intensities (55-75% maximum workload). Consequently, the changes in RPE which are observed following training are related to the method of analysis which is used.

4) Measured in terms of %VO2max, RPE are not significantly altered by endurance training. However, when equated in terms of % maximum velocity, reductions in RPE approach significance. In the present study, this change was probably due to a lowering of local effort cues, particularly those originating from
neuromuscular receptors which monitor physical strain. However, since RPE appear to be related to AerT-%VO2max, when this variable is affected by training, the mechanisms which are responsible for changes in RPE may be different. Therefore, the influence that training has upon RPE may be specific to the nature of underlying physiological adaptations. This effect should be studied further, under conditions in which subjects achieve greater improvements in physical conditioning, over prolonged periods.

5) Control groups are a necessity in studies which employ RPE as a dependent variable. When RPE are to be recorded during data collection, subjects should become well acquainted with test procedures and protocols prior to participation. It is recommended that repeated testing be performed at the outset of the study, until the effects of familiarization have been eliminated.
BIBLIOGRAPHY


13. Borg, G. and H. Linderholm. Perceived exertion and pulse rate during graded exercise in various age groups. *Acta*


175. Stamford, B.A., A. Weltman and E. Foulke. Information processing and perceived effort during bicycle ergometer


APPENDIX A - BORG 15-POINT SCALE FOR RATING PERCEIVED EXERTION

<table>
<thead>
<tr>
<th>Number</th>
<th>Description</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td></td>
<td>14</td>
</tr>
<tr>
<td>7</td>
<td>very, very light</td>
<td>15</td>
</tr>
<tr>
<td>8</td>
<td></td>
<td>16</td>
</tr>
<tr>
<td>9</td>
<td>very light</td>
<td>17</td>
</tr>
<tr>
<td>10</td>
<td></td>
<td>18</td>
</tr>
<tr>
<td>11</td>
<td>fairly light</td>
<td>19</td>
</tr>
<tr>
<td>12</td>
<td></td>
<td>20</td>
</tr>
<tr>
<td>13</td>
<td>somewhat hard</td>
<td></td>
</tr>
</tbody>
</table>

APPENDIX B - 9-POINT SCALE FOR RATING PERCEIVED EXERTION

1

2 Not at all stressful

3

4

5

6

7

8 Very, very stressful

9

APPENDIX C - BORG 10-POINT SCALE FOR RATING OF PERCEIVED EXERTION

0  Nothing at all

0.5 Very, very weak    (just noticeable)

1  Very weak

2  Weak    (weak)

3  Moderate

4  Somewhat strong

5  Strong    (heavy)

6

7  Very strong

8

9

10 Very, very strong    (almost max)

  Maximal