EFFECT OF EXERCISE INTENSITY ON DIFFERENTIATED AND UNDIFFERENTIATED RATINGS OF PERCEIVED EXERTION DURING CYCLE AND TREADMILL EXERCISE IN RECREATIONALLY ACTIVE AND TRAINED WOMEN

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EFFECT OF EXERCISE INTENSITY ON DIFFERENTIATED AND UNDIFFERENTIATED RATINGS OF PERCEIVED EXERTION DURING CYCLE AND TREADMILL EXERCISE IN RECREATIONALLY ACTIVE AND TRAINED WOMEN

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University of Pittsburgh, 2008

PURPOSE: To examine the effect of aerobic exercise intensity on components of the differentiated perceived exertion model in young women performing weight bearing and non-weight bearing aerobic exercise. METHODS: Subjects were 18-25 yr old women who were recreationally active (N = 19; VO_{2max} = 33.40 ml/kg/min) and trained (N = 22; VO_{2max} = 43.3 ml/kg/min). Subjects underwent two graded exercise tests (GXT) separated by 48 hours. The first GXT used a treadmill and employed a modified Bruce protocol to assess ratings of perceived exertion (RPE) and VO_{2max}. The second GXT used a cycle ergometer with a load incremented protocol to assess RPE and VO_{2peak}. RPE-Overall, -Legs, and –Chest, as well as oxygen uptake (VO_2) and heart rate were recorded each minute. Individual regression analyses were used to identify RPE-Overall,-Legs, and -Chest at 40, 60, 80% $VO_{2max/peak}$. Separate two factor (site (3) x intensity (3)) ANOVAs with repeated measures on site and intensity were computed for each training status. Furthermore, RPE responses were also examined with a one factor (site (3)) within subject ANOVA with repeated measure on site at the ventilatory breakpoint. RESULTS: For both the recreationally active and trained groups no significant differences were observed for RPE-Overall, -Legs, and –Chest during treadmill exercise. However, for cycling exercise results indicated that RPE-Legs was significantly greater at all exercise intensities than RPE-Overall and RPE-Chest for trained subjects while for recreationally active subjects RPE-Legs was only significantly higher at the highest exercise intensity. Responses at the ventilatory breakpoint during cycle exercise indicated that RPE-Legs was significantly greater than RPE-Chest and RPE-Overall for trained subjects but not for recreationally active subjects. Signal dominance was not observed at an intensity equivalent to the ventilatory breakpoint during treadmill exercise in either of the groups. CONCLUSION: In recreationally active and trained females signal dominance was demonstrated only during cycling exercise, but not during treadmill exercise. Signal integration could not be demonstrated during cycling and treadmill exercise at various intensities.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

PREFACE

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1.0 INTRODUCTION

This investigation examined the effect of exercise intensity on components of the differentiated perceived exertion model in young women performing weight bearing and non-weight bearing aerobic exercise.

The perception of physical exertion is defined as the subjective intensity of effort, strain, discomfort and/or fatigue that one feels during exercise (73). Ratings of perceived exertion (RPE) can be used to guide the time course of exercise testing (2, 4), and also to prescribe exercise intensity for training sessions (30). RPE can be measured as overall feelings of exertion (RPE-Overall), or differentiated feelings reflecting respiratory and metabolic functions arising from the chest (RPE-Chest) and alterations in energy producing and contractile properties of peripheral and skeletal muscle (RPE-Legs/RPE-arms). Previous research has examined differentiated RPE for different exercise modes. However, there are still many elements of the differentiated perceptual rating that are not well understood, especially with respect to the two component differentiated signal model, i.e. perceptual signal dominance and mode of signal integration. Specifically, the effect of aerobic exercise intensities (low, moderate, high) in people of various physical fitness levels (recreationally active vs. trained) during different exercise modes (cycle vs. treadmill) has not been extensively examined within the context of the differentiated RPE model. Hence, the purpose of this study was to examine the effect of exercise intensity on differentiated RPE for the legs and chest during treadmill and cycling exercise in recreationally active and trained females. Specific attention was given to the effect of these variables on (a) perceptual signal dominance and (b) mode of perceptual signal integration.

The differentiated RPE model holds that discrete perceptual signals are linked to specific underlying physiological events. These perceptual signals are often anatomically regionalized to the active limbs, as well as to the chest. Differentiated peripheral signals are mediated by changes in skeletal muscle environment. Movement of muscles and joints provide a localized peripheral perceptual signal that can be measured as differentiated ratings for the legs (RPE-Legs) or arms (RPE-Arms). As developed tension in the active muscle groups increases so does the intensity of the peripheral signal (3). Furthermore, higher exercise intensities increase anaerobic energy demands and hence the production of tissue lactate, which has been linked to the intensity of peripheral signals of muscular effort (3).

On the other hand, a rating for the chest/breathing (RPE-Chest) is a measure of respiratory/metabolic signals. These signals are linked to increased aerobic energy demands that occur with progressively greater exercise intensities. The strength of the respiratory-metabolic signal is linked to changes in oxygen uptake, pulmonary ventilation, and respiratory rate with somewhat less input from heart rate (10, 14, 24, 38).

While differentiated RPEs are linked to specific underlying physiological events this is not the case for the undifferentiated overall body RPE. The undifferentiated perceptual signal represents an integration of many differentiated perceptual signals and thus forms a rating for the overall body (58). This concept is termed perceptual signal integration. In addition, each differentiated signal is assumed to carry a specific intensity weighting with the most intense signal dominating the sensory integration process that forms the overall body RPE (73). This concept is termed perceptual signal dominance. Therefore, the principal components of the differentiated perceived exertion model are: (a) signal dominance and (b) signal integration.

Perceptual signal dominance has been demonstrated in adults performing cycle ergometer and treadmill exercise (58, 65, 69). These studies found that the differentiated RPE from the legs was consistently more intense than the respiratory/metabolic signals arising from the chest. When examining these studies collectively, the findings for adult samples generally indicate that perceptual signal dominance is present at comparatively lower exercise intensities during non-weight-bearing exercise modes but may be delayed in onset during weight-bearing exercise modes. The differentiation threshold, or the exercise intensity at which one of the differentiated signals becomes more intense than the other, appears to occur sooner during cycle ergometry than treadmill exercise. During cycle ergometry, the differentiated signal from the legs is typically more intense than that from either the chest or the overall signal, which becomes apparent at comparatively low intensities (58, 65, 69). However, for weight-bearing exercise, such as walking and running, the threshold appears at which the differentiated leg signal becomes dominant occurs much later and seems to be a function of body weight and walking/running speed (62). As an extension to these previous findings the present study determined if training status, exercise mode, and exercise intensity would play a role in the signal dominance/integration process. The model of signal integration predicts that RPE-Overall is a weighted average of RPE-Legs (or RPE-Arms) and RPE-Chest. This integration likely takes place in the sensory cortex.

Training status was defined by the aerobic fitness level of each subject and the amount of physical activity they performed on a weekly basis. Aerobic exercise intensity was categorized into three levels: low (40% VO_{2max}), moderate (60% VO_{2max}), and high (80% VO_{2max}). Exercise mode was defined as either weight bearing (i.e. treadmill) or non-weight bearing (i.e. cycle). In the context of this investigation exercise mode distinguished between weight bearing and non-weight bearing aerobic exercise and did not refer to the walk and run modes that were to be used during load incremented treadmill exercise.

1.1 RATIONALE

In 1996, the Surgeon General's Report on Physical Activity and Health established the importance of physical activity in the promotion of health and well being and the prevention of chronic diseases (76). The report linked sedentary behavior to chronic diseases such as osteoporosis, obesity and heart disease and identified physical activity as one of the most important health behaviors in the prevention and severity reduction of such diseases.

Yet, despite these acknowledged benefits of physical activity, surveys report that the majority of the adult population in the United States (60%) does not engage in regular physical activity. Furthermore, 31% are labeled as sedentary meaning that those adults do not engage in regular exercise at all (76). Moreover, the death rate in the United States from causes associated with physical inactivity is estimated to be more than 250,000 per year (33).

While the benefits of exercise have been widely advertised in the media, evidence still suggests that 50% of sedentary adults have no plan to start an exercise program (22). Moreover, among those who start an exercise program, adherence rates are low. Only 30% of older men and 15% of older women sustain regular activity (76). Evidence further indicates that the largest participant attrition, approximately 50%, occurs within 6 months of starting an exercise program (23).

It becomes clear from these statistics that although the benefits of exercise are well known to the public, most of the adult population still chooses to remain inactive. Hence, exercise scientist and public health officials ask the question “why”. Many studies have attempted to solve this problem by identifying psychological and environmental barriers to exercise, such as lack of time (7), and unsafe neighborhoods (18). Thus, “the problem of adherence and dropout is typically approached from the perspective of conceptual models originating in social psychology and general health behavior, none of which take the uniqueness of the physical activity stimulus into account (p. 652)” (26). Yet, the physical activity stimulus leads to physiological events that produce the sense of effort, strain and discomfort, which exercisers use to form their ratings of perceived exertion. Thus, perceived exertion could be a possible factor in determining exercise adoption, adherence, and preference as people usually tend to avoid actions that require too much effort or produce discomfort. Therefore, the role of the physical activity stimulus itself in experiencing the exertional perceptions during exercise warrants closer research attention.

An exercise prescription that not only targets improvements in cardiorespiratory fitness, but is also perceptually acceptable promotes program compliance and helps to establish a positive attitude towards physical activity (22). “The dominant RPE often can be used to select the exercise intensity that is perceptually preferable to the client and also does not exceed the client’s functional and clinical exercise tolerance (p. 31)” (61). For instance, while exercising on a stationary cycle the dominant perceptual cue comes from the legs and is expressed as RPE-Legs. During arm exercise the dominant signal arises from the arms and is measured as RPE-

Arms (73). The dominant RPE is determined by exercise type, anatomical origin of the differentiated feelings, and the performance environment. Since the dominant RPE varies with exercise type, it should be identified separately for exercises that vary in type, intensity, and the specific body regions involved. Also, since training status affects the intensity at which aerobic exercise is performed by individuals it likely will have an effect on undifferentiated and differentiated RPEs as well. To test the signal integration component of the perceived exertion model, this investigation did not only look at differentiated and undifferentiated RPEs, but also at the average of RPE-Legs and –Chest to determine how the two differentiated signals converged as a weighted average to form RPE-Overall. This observation was made for recreationally active and trained individuals performing treadmill and cycle exercise. Hence, by examining undifferentiated and differentiated RPE, within the context of exercise mode, training status and intensity of aerobic exercise it is maybe possible to determine whether recreationally active people experience the differentiated exertional perceptions differently than the trained individual.

As stated previously, one of the possible applications of the findings of the present investigation is to use differentiated RPE to prescribe mode specific aerobic exercise that is subjectively preferable depending on their activity level, i.e. recreationally active or trained. In this context it would be useful to quantify differentiated perceptual signal dominance and integration at intensities equivalent to the ventilatory breakpoint. Such information would provide a rationale for exercise prescriptions that employ differentiated target RPEs that span the ventilatory inflection point. The overload training zone for cardiorespiratory fitness contains the relative metabolic rates that typically define the lactate and ventilatory inflection points (50-80% VO_{2max}). Thus, producing an RPE that corresponds to these points by self-regulating exercise intensity ensures an appropriate overload stimulus to enhance functional aerobic power and therefore, qualifies as a physiologically valid prescription procedure. One possible application of the findings of this investigation would be the creation of subjectively preferred exercise that is based on differentiated RPE for both recreationally active and trained individuals performing weight bearing and non-weight bearing activities.

1.2 STATEMENT OF THE PROBLEM

1.2.1 Varying Exercise Intensities

This investigation determined if:

1. for recreationally active and trained subjects during cycle ergometer testing, exercise intensity influenced perceived exertion signal dominance and signal integration.
2. for recreationally active and trained subjects during treadmill testing, exercise intensity influenced perceived exertion signal dominance and signal integration.

1.2.2 Ventilatory Breakpoint

This investigation determined if:

1. during cycle ergometer exercise at an intensity equal to the ventilatory breakpoint, exercise intensity influenced perceived exertion signal

dominance and signal integration for recreationally active and trained subjects.

2. during treadmill exercise at an intensity equal to the ventilatory breakpoint, exercise intensity influenced perceived exertion signal dominance and signal integration for recreationally active and trained subjects.

1.3 HYPOTHESES

1.3.1 Signal Dominance and Integration for Recreationally Active and Trained Subjects at Varying Exercise Intensities

1.3.1.1 Cycle Ergometer

It was hypothesized that:

1. Recreationally active individuals would have a higher RPE-Chest than RPE-Legs or RPE-Overall during cycle ergometry at low, moderate and high exercise intensities.
2. Trained individuals would have a higher RPE-Legs than RPE-Chest or RPE-Overall during cycle ergometry at low, moderate and high exercise intensities.

1.3.1.2 Treadmill Exercise

It was hypothesized that:

1. Recreationally active individuals would have a higher RPE-Chest than RPE-Legs or RPE-Overall during treadmill exercise at low, moderate and high exercise intensities.
2. Trained individuals would have a higher RPE-Legs than RPE-Chest or RPE-Overall during treadmill exercise at low, moderate and high exercise intensities.

1.3.2 Signal Dominance and Integration for Recreationally Active and Trained Subjects at the Ventilatory Breakpoint

1.3.2.1 Cycle Ergometer Exercise

It was hypothesized that at an intensity equal to the ventilatory breakpoint:

1. Recreationally active individuals would report a greater RPE-Chest than RPE-Legs or RPE-Overall during cycling exercise.
2. Trained individuals would report a higher RPE-Legs than RPE-Chest or RPE-Overall during cycling exercise.

1.3.2.2 Treadmill Exercise

It was hypothesized that at an intensity equal to the ventilatory breakpoint:

1. Recreationally active individuals would have a higher RPE-Chest than RPE-Legs or RPE-Overall during treadmill exercise.
2. Trained individuals would have a higher RPE-Legs than RPE-Chest or RPE-Overall during treadmill exercise.

1.4 SIGNIFICANCE OF THE STUDY

It was anticipated that the findings of this study would add to the existing literature regarding differentiated perceived exertion responses during weight bearing and non-weight bearing exercise for recreationally active and trained females. Determining the influences exercise intensity on the differentiated perceived exertion model for recreationally active and trained subjects during non-weight bearing and weight bearing exercise may increase the precision of exercise prescriptions. The lack of studies that have focused on examining differentiated RPE in subjects of varying training levels and the absence of studies that examined differentiated RPE during different exercise modes, make this area appropriate for investigation.

2.0 REVIEW OF THE LITERATURE

The purpose of this study was to investigate the effect of exercise intensity on differentiated perceptual signal dominance and integration during treadmill and cycle ergometer exercise in recreationally active and trained women. This chapter reviews literature pertaining to (a) perceived exertion scaling methods, (b) the model of differentiated exertional perception, (c) the physiological and psychological mediators that contribute to the RPE response, and (d) exercise prescription.

2.1 OVERVIEW

The perception of physical exertion has been defined as the feelings of effort, strain, discomfort, and/or fatigue a person experiences during exercise (73). In the late 1950s and early 1960s Dr. Gunar Borg, an experimental psychologist at the University of Stockholm developed a category rating scale to measure perceived exertion. Since this initial research in scaling methods several perceived exertion metrics have been developed. Exercisers use these scales by selecting a numerical category that corresponds to the intensity of their physical exertion (61). This number is called the rating of perceived exertion (RPE). An RPE can be used by clinicians, exercise specialists, and exercisers to gauge the perceptual intensity of exertion associated with physical activity participation.

The theoretical rationale underlying the application of RPE in performance, clinical, and health fitness settings involves the functional interdependence of perceptual and physiological responses (61). This interdependence is presented in Borg's Effort Continuum Model. The model proposes that subjective responses to exercise involve three main effort continua: physiological, perceptual, and performance. As the intensity of exercise performance increases, corresponding and interdependent changes occur in the perceptual and physiological components of the model (61). "The functional links between the three effort continua indicate that a perceptual response provides much of the same information about exercise performance as a physiological response does (p.3)" (61). Hence, by using RPE to gauge exercise intensity, we essentially evaluate our physiological responses to exercise performance by relying on associated perceptual signals of exertion.

Factors that influence the perceptual intensity of exertion can be categorized into physiological and psychological mediators. The physiological mediators are sub-divided into peripheral, respiratory-metabolic, and nonspecific factors (61). Peripheral physiological mediators refer to factors such as metabolic acidosis, blood glucose, blood flow, muscle fiber type, free fatty acid concentration and muscle glycogen store. The peripheral mediators act individually or collectively to affect the intensity of exertional signals arising from the limbs and trunk. Respiratory-metabolic factors, such as pulmonary ventilation, oxygen uptake, carbon dioxide production, heart rate, and blood pressure affect the ventilatory drive during exercise giving rise to exertional signals from the chest and breathing (61). Nonspecific mediators include hormonal regulation, temperature regulation, pain, and possibly cerebral blood flow and oxygen saturation. These mediators are systemic events producing generalized exertional signals during exercise (61).

According to Robertson and Noble (73) these three categories of physiological mediators can act either individually or collectively to influence the intensity of perceptual signals of physical exertion. They do so in part by causing adjustments in the tension-producing properties of skeletal muscle during exercise. Copies of descending control commands from motor centers that regulate skeletal and respiratory muscle tension are sent to the sensory cortex when they are coded as exertional perceptions. The information received by the sensory cortex is in turn consciously expressed as an undifferentiated perception of physical exertion for the overall body or as a differentiated perception for the legs, arms, and/or chest.

The foregoing neurophysiological pathway employs combined feed-forward and feedback mechanism to signal perceived exertion (13). When exercise intensity is increased, motor unit recruitment and firing frequency of skeletal and respiratory muscles are also increased. This is achieved by increasing the number of central motor feed-forward signals descending from the motor cortex to skeletal muscles. At the same time copies of these afferent motor signals are sent to the sensory cortex. The greater the frequency and intensity of the corollary signals received by the sensory cortex the more intense the perception of physical exertion. In addition, activated muscles and joints send ascending signals back to the brain. These afferent signals modulate the intensity of the exertional signals arising from the sensory cortex. Hence, the final common neurophysiological pathway for perceived exertion depends on the integration of these feed-forward and feedback signals.

The perception of physical exertion also depends on psychological mediators, such as emotion or mood, cognitive function, perceptual processes, and social or situational factors (49).

Research has shown that these factors can account for interindividual differences in RPE, but more studies are needed to clarify both their independent and interactive effects with effort sense.

As exercise intensity increases the perception of physical exertion manifests itself as somatic symptoms such as aches, cramps, muscular and joint pain and heaviness, and dyspnea. It is proposed that the individual possesses a perceptual-cognitive reference filter that is comprised of one's perceptual style and contains sensory information and experiences from a wide range of psychosocial and cognitive processes (61). This filter modulates the intensity of perceived exertional signals as they travel from their physiological/neuromotor origins to conscious expression as an RPE. Hence, the sensory content of the reference filter can strongly influence an individual's RPE. In this context, although psychological constructs, such as emotion and mood, are not necessarily linked to underlying physiological substrata, they nevertheless systematically account for individual differences in perceived exertion during exercise.

The foregoing concepts are explored in greater detail in the following sections of this literature review.

2.2 METHODS FOR RATING PERCEIVED EXERTION

Perceived exertion is widely used in several fields such as exercise science, physiology, medicine, psychology and ergonomics (61). Probably the most widely used RPE metric is Borg's 15-category perceived exertion scale, developed and validated in the late 1950s and early 1960s. This initial scale has served as a reference for the development and validation of a number of RPE scales ranging in format and application. An example of such a new RPE scale is the OMNI picture system (68). In general, RPE scales have been validated by correlating RPE with the corresponding heart rate, oxygen consumption, pulmonary ventilation and blood/muscle lactic acid concentrations during cycle and treadmill exercise. In addition, RPE scale test-retest reliability has been established for short, long, and intermittent exercise protocols (73).

2.2.1 Selection of a Rating Scale

When selecting an RPE scale it is important to consider certain characteristics of the participant/client and the setting in which physical activity is to be performed. Category scales such as the Borg 15-category scale (6-20) and the OMNI picture system can be used for all types of exercise settings. Specifically, these scales are recommended for use during exercise that is either steady or intermittent, produces physiological responses that change linearly with changes in exercise intensity, and where perceptual, physiological, or clinical responses are collected to assess physical fitness, and to prescribe exercise and training programs (61). However, the selection of an RPE scale should be governed foremost by the fact that the scale has been validated and is reliable for the participant/client and type of exercise to be examined. Also, it is important that instructions are standardized with respect to scale use.

2.2.2 Correct Use of an RPE Scale

In order to use an RPE scale correctly the term perceived exertion should first be defined for the participant/client. The definition should be clear, concise and describe the exercise-related feelings that are to be rated as exertional perceptions. The participant/client should be presented the appropriate instructions and familiarized with scale anchoring procedures. The scale anchoring process should insure that instructions link the full exercise stimulus range with the full RPE response range (61). This can be accomplished by identifying the lowest verbal and numerical cue (and/or pictorial if present) and equating them with the feeling of exertion at the lowest exercise intensity. The highest verbal and numerical ratings should be equated with the feelings of exertion experienced during maximal exercise intensity. The client/participant should be informed that there are no right or wrong numbers (e.g. RPE) and that the rating should reflect feelings of exertion at the moment. Finally, the rating skills of the participant should be developed and tested to ensure correct use of the RPE scale. This can be achieved by asking a series of questions concerning the level of exertion experienced (a) “right now”, (b) “when they performed a favorite activity”, and (c) “when they engaged in the most exhausting exercise/activity they can recall”. Normally the RPE scale is in full view of the participant while the instructions are given.

2.2.3 Scale Anchoring

The anchors of the RPE scale define the lowest and highest sensory categories. According to Robertson (61) three anchoring methods can be used: exercise method, memory method, and the combined exercise and memory method. In the exercise method the anchors are established by having the participant exercise at a very low intensity and having them set their feelings at the lowest numerical rating of the scale. Next, the participant should perform at peak exercise intensity and be instructed to set their feelings as the highest numerical rating on the scale. Instruct the participant that in succeeding exercise sessions they should rate their perceptions of exertion relative to those established during the very low and maximal exercise intensities.

The memory anchoring procedure involves asking participants to recall their perception of exertion when they engaged in an activity that was very low intensity and then a very high or maximal intensity. The lowest and highest numerical rating on the scale should be assigned to those perceptions, respectively.

The exercise and memory anchoring procedure combines the above mentioned procedures by having the participant undergo exercise anchoring first and then reconfirming those scale anchors by memory procedures at a later point during an exercise program and/or as it becomes necessary.

2.3 THE OMNI PICTURE SYSTEM OF PERCEIVED EXERTION

The OMNI Picture System of Perceived Exertion was recently developed by Robertson (61). The term OMNI is a contraction of the word omnibus, "which in this context means that the perceived exertion scale is applicable for a wide range of clients and physical activity settings (p. 10)" (61).

The core format of the OMNI Scale uses a standard set of numerical categories and verbal descriptors. The scale's pictorial descriptors are interchangeable in order to be generally consistent with the type of exercise to be performed. The scale's numerical categories range from 0 to 10 and depict gradually increasing exercise intensity, such as encountered when going up a hill (see Appendix A). The OMNI Scale pictures show individuals participating in different types of physical exercise, yet the verbal cues and their corresponding numerical ratings are always the same. The correct OMNI pictorial for a particular exercise activity is selected by matching the exercise mode depicted on the scale with the type of physical activity to be performed.

2.3.1 Development of the OMNI Picture System

The development of the OMNI Picture System occurred in four steps. First, a series of pictures were drawn by an artist, depicting an individual at various levels of exertion while performing activities such as cycling, progressing from a walk to a run, stepping, and weightlifting. For each exercise mode a set of four pictures was drawn, featuring both female and male children and adults. To maximize generalization over normal variations in human skin tones, all pictorials were drawn in shades of gray on a white background.

The second step involved showing the picture sets for each exercise type to children and adults and having them describe the level of physical exertion depicted by the pictorials. Verbal responses to the pictorials were accepted if they met one of the following criteria: (a) described effort or exertion, (b) pertained to the intensity of exercise or work, and (c) described either body signs or symptoms of exercise discomfort or comfort.

In the third step, semantic differential analysis was used to select verbal descriptors from the initial pool of responses. Six verbal descriptors were chosen. Each conveyed a discrete level of exertional intensity. During the differential analysis a set of verbal cues was identified that shared common meanings among children and a separate set was selected that shared common meanings among adults. The key words that were included in the adult scale were *easy* and *hard*. The key word for the children's scale was tired.

During the fourth and final step, the six semantically discrete verbal cues were positioned at equal intervals along the 0 to 10 scale, as were the four pictorials. Thus, a general correspondence was achieved between the verbal and picture cues, each depicting a discrete level of perceived exertion. The scale was presented on an exertion format depicting a gradually increasing perceptual intensity gradient. This four step process was used to develop a series of OMNI scales for use by adults and children during weight-bearing (walk/run) and non-weight-bearing (cycling) exercise.

2.3.2 OMNI Scale Reliability and Validity

Evidence of OMNI Scale validity has been demonstrated by a positive linear relation between RPE and selected physiological variables (e.g. oxygen uptake, heart rate) during a load-incremented treadmill and cycle-ergometer test. Validity coefficients range from $r = 0.67$ to 0.88 ($p < 0.05$) for the walk/run format, and from $r = 0.81$ to 0.95 ($p < 0.05$) for the cycle format. Reliability coefficients for the OMNI Scale range from $r = 0.91$ to $r = 0.95$. Furthermore, measurement variability of the scale is small. The standard deviation for measures of RPE-Overall, -Legs, -Chest is approximately $\pm$ 0.6 for low, moderate and high intensity exercise (61).

2.3.3 Advantages of the OMNI Picture System

There are several advantages to the OMNI Scale in comparison to other perceived exertion metrics. Most importantly, the scale uses a single set of verbal cues for all the interchangeable sets of pictorials. Furthermore, owing to its interchangeable pictorials the scale can be used for exercise assessment of and program prescription for clients of various ages, fitness levels, clinical status and physical activity preferences. Another advantage of the scale is its narrow numerical rating range of 0 to 10. This range easily transfers and compares to many aspects of our lives that we evaluate on a 0 to 10 basis. Thus, the scale can be easily understood by most people. Also, the upper picture of the OMNI scale reinforces the client's maximal level of exertion. Last but not least, the small measurement variability of the OMNI Scale is advantageous when prescribing an exercise program that uses a narrowly defined RPE zone.

2.4 UNDIFFERENTIATED VS DIFFERENTIATED RPE

2.4.1 Is there a dominant rating?

Ratings of perceived exertion can be expressed as either undifferentiated or differentiated measurements. The undifferentiated RPE measures feelings of exertion of the overall body and is the most frequently employed perceptual response. The differentiated RPE measures exertion separately for the limbs (arms and legs) and chest/breathing. Typically the differentiated RPEs are measured within a relatively short time period. One of the differentiated ratings will usually be more intense than the others and is therefore considered the dominant RPE for the exercise mode and session. "The dominant RPE often can be used to select the exercise intensity that is perceptually preferable to the client and also does not exceed the client's functional and clinical exercise tolerance (p. 31)" (61). For instance, while cycling on a stationary bike the dominant perceptual cue comes from the legs and is expressed as RPE-Legs, whereas the RPE-Arms is dominant during arm exercise (73).

The dominant RPE is determined by exercise type, anatomical origin of the differentiated feelings, and the performance environment. Since the dominant RPE varies with exercise type, it should be identified separately for exercises that vary in type, intensity, and the specific body regions involved. In this context the present investigation determined if the dominant RPE not just depended on exercise intensity and exercise mode but also if it was different for people of differing training status (recreationally active vs. trained).

2.4.2 Experimental Model of Differentiated RPE

Weiser and Stamper (83) developed a psychophysical model that describes the sensory link between subjective symptoms and physiological mediators during dynamic exercise. This model employed physiological responses and exertional symptoms measured during cycle exercise. In the Weiser and Stamper model of exertional symptoms differentiated sensory events are linked to specific underlying physiological substrata and evolve to global exertional perceptions of the overall body. The model resembles a pyramid. The underlying physiological substrata form the base of the pyramid, indicating that they mediate the intensity of subjective symptoms of fatigue and exertional intolerance during cycling. The next level of the pyramid consists of discrete symptoms, such as shortness of breath and muscle aches. These symptoms have their origins in the underlying physiological substrata. The discrete symptoms are combined into fatigue subclusters including cardiopulmonary, leg, and general fatigue. It is in this subordinate level of sensory processing that differentiated exertional sub-clusters are linked to muscular exertion and cardiopulmonary exertion. The sub-clusters are combined at the ordinate level of sensory processing to form a primary symptom cluster termed bicycling fatigue. At the very top of the pyramid is the superordinate level of sensory processing, where the primary symptom clusters are integrated into a global report of fatigue for the overall body.

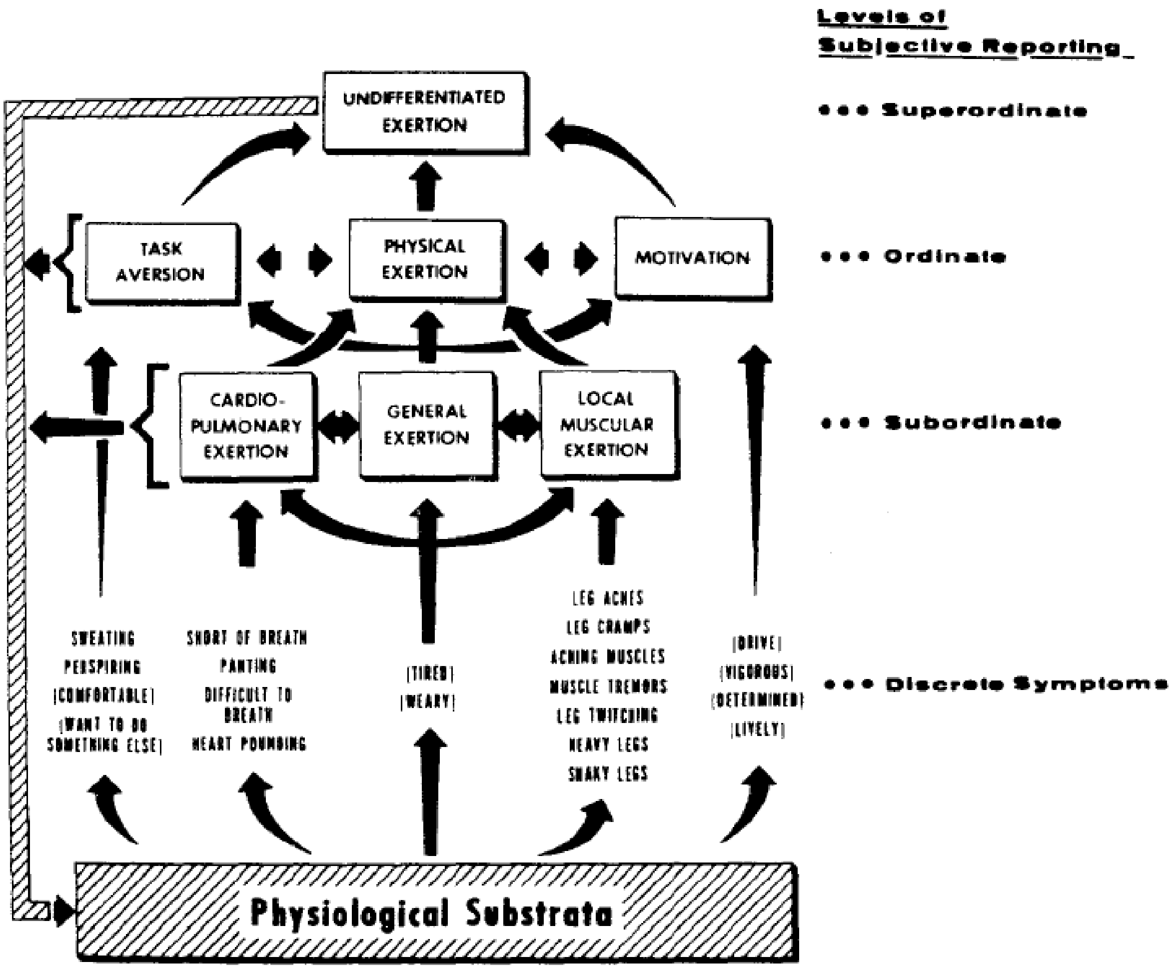

Figure 1. Experimental model, to describe the levels of subjective reporting applicable to different types of physical activity (83)

It is proposed that a more precise measure of the physiological and/or pathological processes that shape the "exertional context" during exercise is provided by perceptual signals that are differentiated to their specific physiological mediators (58, 65, 66). In his doctoral thesis, Borg (9) states that the concept of overall perceived exertion can be viewed as a “Gestalt” made up of perceptions from several important cues. In an extension of this concept, Ekblom and Goldbarg note that these physiological cues involve peripheral or “local” factors, arising from skin, muscles, and joints, and respiratory-metabolic or “central” factors, arising from cardiovascular and pulmonary organs (25). These cues can also be linked to psychological factors (83). Among the first to propose a model of perceptual responsiveness during exercise that assigns ratings of perceived exertion to either the undifferentiated or differentiated level of sensory processing were Kinsman and Weiser (41). Pandolf and colleagues (58) modified this initial model to indicate that the undifferentiated report represented a superordinate level of processing and was not directly linked to the underlying physiological substrata (Figure 1). On the other hand, differentiated or localized reports occurred at the subordinate level and reflected discrete symptoms arising from specific physiological events. Hence, two differentiated clusters, local muscular exertion and cardiopulmonary exertion, were added to the subordinate level of sensory processing. This allowed exertional symptoms to be differentiated according to physiological mediators that are specific to either the active muscles and joints or the cardiopulmonary and aerobic metabolic systems.

Besides the two differentiated clusters, several other nonspecific symptom clusters (e.g. task aversion, motivation) reflecting psychological traits are described in Kinsman and Weiser’s model. These nonspecific psychological symptom clusters are situated at the ordinate level of sensory processing and interact to form a “perceptual style”. A person’s perceptual style systematically influences their exertional perceptions at all levels of subjective reporting. Thus, these nonspecific psychological symptom clusters from a “perceptual-cognitive reference filter”, which contains an array of “sensory context” reflecting a broad range of psychological and cognitive processes. “Although these psychological constructs are not necessarily related to underlying physiological substrata, they nevertheless systematically account for individual differences in perceived exertion during exercise (p. 415)” (73). The filter modulates the intensity of sensory signals as they progress from physiological/neuromotor origins to conscious expressions of both differentiated and undifferentiated exertional perceptions.

2.5 PERCEPTUAL SIGNAL INTEGRATION AND DOMINANCE

The two frequently asked questions with regard to differentiated perceived exertion ratings are: (a) What is the mode of integration of the differentiated signals as their separate sensory intensities converge to form the undifferentiated rating of exertion? (b) Which differentiated perceptual signal is the most intense for a given exercise task and/or performance setting, thus, dominating the integration process?

Differentiated ratings are formed at the ordinate level of sensory processing and are closely linked to underlying physiological substrata (41). The undifferentiated rating for the overall body appears at the superordinate level and is the net integration of all the differentiated signals. Each differentiated rating of perceived exertion is thought to carry a specific intensity weighting. The differentiated perceptual signals arising from the body regions predominantly involved in the physical activity/exercise have the highest intensity weighting (65) and dominate the sensory integration process. This is true for example for cycling where leg muscles are predominantly active and where muscle mass per unit of work is comparatively small. In this sensory framework the differentiated signals from the legs dominate the undifferentiated report (58). In contrast, when pronounced regional feedback stems from two discrete sources such as during wheel-barrow pushing, the undifferentiated perception is higher than either dominant regional signal (28). For maximal treadmill running, the intensity of the undifferentiated rating is equal to or greater than the dominant signal, regardless of the number of pronounced regional perceptions (28). Thus the mode of integration must be identified separately for activities varying in type, intensity and number of involved regional signals.

The mode of integration of the differentiated perceptual signals seems to depend on: (a) exercise type, (b) anatomical origin of the differentiated signals, and (c) the performance/environmental medium. The functional link between signal integration and dominance is best demonstrated during cycle ergometer exercise, where muscle mass per unit of external work is standardized. During cycle ergometry the differentiated signal from the legs is usually more intense than the signal from the chest or the overall body (14). This was demonstrated in a study conducted by Robertson and colleagues (65) who employed a cycle ergometer paradigm with power output held constant (840 kgm/min) while pedal rate varied (40, 60, and 80 rpm). At each pedal rate, the legs ratings were more intense than the chest ratings. Furthermore, the undifferentiated rating for the overall body appeared as a weighted average of the differentiated legs and chest rating. These data suggest that peripheral signals from active limbs dominate the perceptual integration process during cycling. Signals from the chest reflecting cardiopulmonary and aerobic-metabolic functions are comparatively less pronounced.

Several other experiments have examined the mode of signal integration and sensory dominance during prolonged (60 – 180 min) submaximal cycle ergometer exercise (39) and arm plus leg ergometry (57) undertaken at 60-70% VO_{2peak}. During cycle-only exercise, the legs always produced a more intense rating than the chest and thus dominated the perceptual integration process. However, for combined arm and leg ergometry, the arms always produced the dominant perceptual signal. In each of these studies, the undifferentiated rating of perceived exertion for the overall body was a weighted average of the differentiated ratings. This means that the overall rating was close to but not exactly the same as the mean of the legs and chest/breathing rating. This is consistent with Weiser and Stamper's model which predicts that the undifferentiated perceptual signals reflect the separate input of both the dominant and the less intense differentiated signal.

Swank and Robertson (80) reported that during intermittent cycle ergometry the perceptual rating for the legs was more intense than the chest rating at high-intensity exercise (90% VO_{2peak}). For each intermittent exercise bout, the chest and overall body ratings were similar.

Also, a study conducted by Demura and Nagasawa (21) using incremental cycling exercise to exhaustion showed that RPE-Legs was perceived higher than RPE-Chest during both exercise and recovery. RPE-Legs and RPE-Overall reached peak at the point of exhaustion, but this was not observed for RPE-Chest. RPE-Chest increased linearly with increases in physical load, but was always less intense than RPE-Legs and overall RPE. Similarly Garcin, Vautier, Vandewalle, Wolff, and Monod (29) and Shephard, Vandewalle, Gil, Bouhlel, and Monod (77) reported that RPE from the legs was perceived as more intense than the respiratory signal arising from the chest during cycle ergometer exercise.

When comparing perceptual responses between intermittent and continuous cycling exercise at the same relative intensities, it was found that RPE for the legs and the overall body were similar throughout exercise (82). RPE-Chest was also similar between protocols throughout the exercise sessions. However, RPE-Chest increased significantly more at the end of exercise during the intermittent versus the continuous protocol. This increase in the chest/breathing signals can probably be attributed to the fact that during the intermittent protocol subjects were sporadically instructed to increase their power output thus increasing respiratory-metabolic requirements. The increased power output was accomplished by lifting off the seat and recruiting upper body musculature in or to accelerate the pedals against a greater load. During the continuous cycle protocol subjects did not perform this acceleration. As the RPE-Chest is linked to respiratory-metabolic demand it was significantly higher at the end of intermittent exercise. The authors concluded that further studies are needed in this area.

Robertson and colleagues (71) also found RPE-Legs to be the dominant perceptual signal at the ventilatory breakpoint during an incremental cycle session in average and above average fit children (8-12-year-olds). Furthermore, during 60 minutes of constant load cycling, it was reported that RPE-Overall and RPE-Legs were significantly greater at 30, 40, 50 and 60 minutes than at 20 minutes, whereas RPE-Chest only increased significantly after 40 minutes of cycling exercise (32). Thus, these findings also indicate that the differentiated perceptual rating from the legs acts as the dominant signal during cycle ergometer exercise.

However, when perceptual signals arise from two discrete sources, the intensity of the undifferentiated rating can be higher than that of either differentiated rating (28). During maximal treadmill running, the intensity of the undifferentiated rating is equal to or greater than the dominant differentiated rating, regardless of how many regional signals are involved (28, 37).

Furthermore, dominance of differentiated sensory signals also persists during the abatement of exertional responsiveness after maximal treadmill running (72). It was found that the rating of perceived exertion for the legs was more intense than the rating for the chest when examined over a 12 minute supine post-exercise period. The differentiated regional (i.e. legs and chest) ratings also formed a weighted average of the undifferentiated overall body rating during the recovery.

Moreover, an investigation by Robertson and colleagues (62) involving adults walking on a treadmill showed that the onset of a dominant perceptual signal is linked to a specific locomotor speed. Thus, a differentiation threshold (DT) for the ratings of perceived exertion was observed. This was indicated by the walking speed at which the intensities of the peripheral and respiratory-metabolic perceptual signals were first reported to be different from the overall signal of exertion. It was found that at speeds faster than the DT, the dominant signal arose from the legs and was more intense than in the overall body. The overall body signal was more intense than the exertion in the chest. In contrast, Pandolf and colleagues (58) reported that at treadmill speeds faster than the DT, the chest signal was the dominant exertional report. Furthermore, Rutkowski and colleagues (74) found no DT at slow to moderate walking speeds in children.

Thus, these results suggest that the mode of perceptual integration and the dominant sensory signal should be identified separately for physical activities that vary in type, metabolic intensities, and number of anatomical regions involved (73).

2.6 PHYSIOLOGICAL MEDIATORS OF EXERTIONAL PERCEPTION

Physiological responses to an exercise stimulus mediate the intensity of exertional perceptions by affecting tension producing properties of peripheral and respiratory skeletal muscle, either individually or collectively. The physiological mediators of perceptual signals of exertion are categorized as respiratory-metabolic, peripheral, and non-specific. Respiratory-metabolic mediators give rise to exertional signals from the chest and breathing, while peripheral mediators affect the intensity of exertional signals arising from the limbs and trunk. Non-specific mediators refer to systemic events and produce generalized exertional signals.

2.6.1 Respiratory-Metabolic Perceptual Signals

Respiratory-metabolic signals of perceived exertion are mediated by ventilatory drive (V_E), oxygen consumption (VO_2), carbon dioxide production, heart rate (HR), and blood pressure (54).

Simple and multiple regression analyses have established the sensory link between V_E and respiratory effort. Correlation coefficients between RPE and both V_E and respiratory rate (RR) range from r = 0.61 to 0.94 (59). Pulmonary ventilation and RR consistently accounted for the greatest amount of variation in a stepwise multiple regression model to predict RPE during treadmill and cycle ergometer exercise in neutral and hot environments (53). Furthermore, when V_E was experimentally manipulated to determine whether RPE demonstrated a corresponding change, RPE either increased or decreased in conjunction with experimentally induced increases or decreases in V_E drive (66). This finding strongly supports ventilatory drive as a physiological mediator of respiratory-metabolic exertional signals.

Other mediators for the respiratory-metabolic signal of exertion include oxygen consumption (VO_2) and carbon dioxide excretion (VCO_2). Correlation coefficients between VO_2 and RPE range from r = 0.76 to 0.99 for both intermittent and continuous arm and leg exercise (5, 27, 79). However, relative VO_2 (i.e. $\%VO_{2max}$) appears to play a more important role in mediating respiratory-metabolic perceptions of exertion than the absolute VO_2 (i.e. l/min and ml/kg/min) (5). In a study conducted by Robertson and Metz (70) it was found that RPE was lower under normoxic conditions than when subjects breathed a hypoxic gas mixture at a constant submaximal intensity. Under normoxic conditions the absolute VO_2 represents a lower relative aerobic metabolic rate than during hypoxia. The relative level of VO_2 therefore appeared to mediate the perceptual responses. When using $\%VO_{2max}$ as a reference, RPE was the same for normoxic and hypoxic conditions. Moreover, Okura and Tanaka (56) established an equation to indirectly assess VO_{2max} at the anaerobic threshold by using work rate and RPE during a submaximal graded cycle test. Their cross-validation results indicated high correlation coefficients between VO_{2max} and RPE ($r = 0.78$), as well as high measurement reliability ($r = 0.87$). Thus, they concluded that the RPE method for estimating cardiorespiratory fitness is a valid and useful tool in various settings of exercise prescription. This finding was also supported by a study conducted by Eston and colleagues (27), which suggested that even submaximal, perceptually-guided, graded exercise protocols can provide estimates of maximal aerobic power that are as valid and reliable as established methods based upon heart rate responses to externally prescribed exercise intensities.

A functional link has also been established between carbon dioxide excretion (VCO_2), and perceptual signals of exertion during dynamic exercise (16). Using a hypercapnic paradigm it was found that an increased demand for CO_2 excretion increases ventilatory drive. This response intensified respiratory-metabolic signals of perceived exertion producing a greater RPE.

The role of heart rate as a mediator for respiratory-metabolic signals of exertion is equivocal. Evidence that heart rate mediates the intensity of perceptual signals of exertion has mostly been derived from correlational data obtained when validating the Borg Scale. Correlations between HR and RPE responses for a variety of exercise modalities ranged from $r = 0.42$ to 0.94 (78). More recently, in a study conducted by Green and colleagues (32) a significant positive correlation between HR and RPE-Overall ($r = 0.43$) were found. Also, a significant moderate correlation (r = 0.63) was detected between HR and RPE-Overall during high-intensity interval cycling (31). The correspondence between RPE and HR should be viewed as coincidental and not causal (31). However, numerous investigations show a lack of a relation between HR and RPE when one of the variables has been experimentally manipulated during dynamic exercise. In a study conducted by Borg and Kaijser (8), HR was shown to be the variable contributing the most to RPE ratings. They also found that the postulated linear relation between RPE and HR can be manipulated, e.g. by the exercise modality or a special work-test protocol used (steady state exercise). During steady state exercise HR plateaus rather rapidly, while RPE increased throughout the entire exercise session. Others also suggest that there may be RPE (and mode) specific practice requirements to achieve a reliable heart rate response at a given RPE (40). Thus, when experimental evidence is examined as a whole, HR does not seem to function as an important physiological mediator for respiratory-metabolic signals of exertion.

2.6.2 Peripheral Perceptual Signals

Peripheral physiological mediators that influence the intensity of perceptual signals arising from the active muscles of the limbs, trunk and upper torso, include blood pH, blood lactic acid, muscle lactic acid and other selected physiological factors. Acidotic shifts in blood pH during high intensity dynamic exercise mediate peripheral perceptions of exertion in active limbs (63). This was demonstrated by Robertson and colleagues (63) when they manipulated blood pH via oral administration of either $NaHCO_3$ or $CaCO_3$ (placebo) during separate arm and leg trials. RPE-Arms was lower under alkalotic than under the more acidotic placebo condition at 80% VO_{2peak}. RPE-Arms was not affected by blood pH shifts during leg exercise. The reciprocal findings were true for leg exercise. Thus, shifts in blood pH during high-intensity exercise, such as 80% VO_{2peak}, would appear to mediate peripheral exertional perceptions arising from active muscles.

On the other hand, conflicting evidence has been found for blood lactic acid concentrations. Several psychophysiological investigations have demonstrated that experimental perturbation of blood lactic acid concentration does not produce corresponding changes in ratings of perceived exertion (72). Furthermore, in a study conducted by Green and colleagues (32) the correspondence between perceptual estimation of exertion and blood lactate during 60-min cycling sessions was investigated. A clear divergence was observed between lactate and perceived exertion (RPE-Overall), with lactate concentrations peaking at the 20 minute point and then declining. Whereas, RPE-Overall demonstrated a steady rise throughout the cycling session. Results indicated negligible influence of lactate on RPE-Overall. It was concluded that lactate did not serve as a strong RPE mediator during 60 minutes of constant workload cycling. Similar results were reported for the association between RPE with lactate during high-intensity interval cycling. In this trial, lactate did not appear to be the primary RPE mediator ($r = 0.43$) as dissimilar response times of the different measures to changing workloads accounted for a weak correspondence between RPE and lactate (31).

Another study examining the effects of repeated bouts of exercise on the blood lactate – RPE relation was conducted by Weltman et al. (84). They found that with repeated bouts of exercise administered on the same day, RPE-Overall increased, whereas blood lactate concentration decreased. However, the researchers pointed out that as the blood lactate – RPE relation was not causal, caution should be employed when using RPE to produce blood lactate concentrations during repeated exercise bouts on the same day.

On the other hand, numerous studies support blood lactic acid concentrations as a physiological mediator for ratings of perceived exertion (12, 20, 36, 51). However, such studies have often employed incremental exercise tests (12, 20, 36). Demello and colleagues (20) showed that RPE was not different in trained and untrained subjects when compared at the lactate threshold or at various percentages of VO_{2max}, indicating a strong link to the metabolic and gas exchange alterations initiated at the lactate threshold. Thus, it was concluded that the lactate threshold appears to be an important anchor point for perception of exertion during exercise that is not affected by state of training. Furthermore, no significant differences in RPE were found between exercise modalities during leg exercise (cycle and treadmill) (36). This finding also lead to the conclusion that a strong relation exists between RPE and blood lactate concentrations. Overall, it appears that blood lactic acid concentration is linked to the intensity of peripheral exertional perceptions by its relation with exercise intensity during progressively incremented test protocols. Both RPE and blood lactic acid are part of a more generalized psychophysiological response that represents the relative exercise intensity (52).

Evidence regarding muscle lactic acid as a peripheral mediator for exertional perceptual signals is limited and inconsistent. However, other select peripheral mediators are thought to mediate the intensity of exertional perception, such as fiber type. A higher RPE during cycle ergometry has been associated with a greater percentage of fast-twitch than slow-twitch fibers (51), but findings in this area have been inconsistent as well.

2.6.3 Nonspecific Mediators

Nonspecific physiological mediators of perceived exertion include processes related to hormonal and temperature regulation, and pain reactivity. Evidence supporting blood catecholamines and ß-endorphins as hormonal mediators of exertional perception is equivocal. While it seems suggestive that the morphine-like action of ß-endorphins could exert an analgesic effect and thus attenuate the intensity of exertional perception associated with localized muscle discomfort, research has produced inconclusive results in this area (73).

Furthermore, body core temperature and RPE during aerobic exercise show low non-significant correlations ($r = 0.14 – 0.20$) (81). Also, the relation between skin temperature and RPE has been found to be inconsistent. However, a strong correlation was shown between RPE and pain responsiveness ($r = 0.90$) (11). The intensity of differentiated exertional perceptions during swimming also seem to be mediated by local muscle soreness (55).

2.6.4 Neurophysiological Pathways for Exertional Perceptions

The neurophysiological pathway for both peripheral and respiratory-metabolic signals of exertional perceptions consists of a central feedforward and a combined feedforward-feedback mechanism (15). The feedforward mechanism is initiated through efferent commands from the central motor cortex. A copy of those commands is simultaneously transmitted to the sensory cortex for interpretation and conscious expression as exertional perceptions. The feedback mechanism sends signals from peripheral receptors in muscles, joints, tendons, and skin to the sensory cortex. A functional interaction exists between the two mechanisms, which provides for a precise adjustment of the sensory response according to the level of force production of active muscles.

Rspiratory metabolic signals are linked to alterations in respiratory muscle tension that support ventilatory drive and alveolar ventilation. Both feedforward and feedback mechanisms are involved in these alterations in respiratory muscle tension. The neurophysiological signal for respiratory effort is sent to the sensory cortex via corollary discharges that diverge from descending motor commands. Peripheral afferent feedback from muscle spindles, stretch receptors in lungs and joint receptors in the chest wall help to scale the central motor outflow response. These afferent signals are integrated centrally with information derived from efferent motor commands (45). Thus, the respiratory-metabolic and peripheral exertional signals share a final common neurological pathway.

2.7 PSYCHOLOGICAL MEDIATORS OF EXERTIONAL PERCEPTION

Psychological factors contribute to individual differences in perceived exertion (47). However, a consistent pattern of change in RPE in the presence of one or more psychosocial mediators has not been established. Psychological factors that appear to influence the intensity of exertional perception can be classified into the four categories (49): emotion (mood), cognitive function, perceptual process, social (situational).

2.7.1 Emotion or Mood

This category is composed of the following factors: anxiety, depression, extroversion, and neuroticism. A significant relation was found between extroversion and RPE (34). Morgan (48) reported that higher levels of neuroticism were correlated with lower RPE. However, both positive and negative, as well as no relations between these variables have been reported in the literature. Both anxiety and depression have been related to RPE regardless of clinical condition of the patient (6). In conclusion, results on the effects of emotion or mood on RPE are equivocal and hence this area is ripe for further investigation.

2.7.2 Cognitive Function

Cognitive function factors that may influence exertional perceptions are dissociation, self-efficacy, and Type-A personality. A consistent pattern of the effect of cognitive strategy on RPE has not been determined (44). Conflicting evidence exists on the relation between Type A personality and RPE. Nevertheless, an attractive hypothesis holds that Type A individuals rate their perceived exertion during exercise lower than Type B individuals (17). However, more research is needed to test this hypothesis.

2.7.3 Perceptual Process

Factors for perceptual process include: pain tolerance, sensory augmentation or reduction, and somatic perception. It has been shown that individuals who are sensory augmenters rated perceived exertion to be higher than sensory reducers during a cycle ergometer test (64).

Furthermore, evidence exists that muscle pain increases as a positively accelerating function of relative exercise intensity (19). However, pain ratings were shown to be distinct from RPE, meaning that those two sensory constructs are not isomorphic (19). Thus, it was concluded that muscle pain and RPE are distinct sensory constructs that present concurrently during many types of exercise.

2.7.4 Situational Factors

Situational variables that influence exertional perceptions are specific to a given time, physical activity setting, or exercise mode and include expected duration of exercise, anticipated performance outcome, self-presentation, and attentional focus (73). Overall, it should be noted that psychosocial mediators of exertional perceptions appear to be most salient at low and moderate exercise intensities whereas they are dampened at high intensities when physiological mediators become very potent (73).

2.8 PERCEPTUALLY BASED EXERCISE PRESCRIPTIONS

Both physiological (e.g. HR) and perceptual (e.g. RPE) responses to a graded exercise test (GXT) can be used to prescribe exercise training intensities for clinical, as well as competitive purposes. Since these test responses are functionally related, RPE can be used to prescribe and regulate exercise intensity (50). “A perceptually regulated exercise prescription assumes that a predetermined aerobic metabolic rate can be attained and maintained by using a target RPE in a manner analogous to that for a target HR (p. 432)” (73). During a GXT both RPE and VO_2 are determined at the end of each stage and also at the point of maximal exertion. Using test responses, the VO_2 equivalents to the training intensity (50-85%VO_{2max}) range are then calculated. Next, the target training range is determined by plotting the RPE responses as a function of corresponding VO_2 values. The target RPE range equivalent to the prescribed %VO_{2max} is identified from the plot. Exercise intensity is then titrated during training until the target RPEs are produced. Both the undifferentiated and differentiated RPE can be used in this prescription process. Applying and using perceptual self-regulation of exercise intensity ensures that the prescribed metabolic rate falls within the stimulus zone to improve cardiorespiratory fitness.

2.8.1 RPE at Lactate and Ventilatory Inflection Points

The lactate and ventilatory inflection points present physiological markers upon which a perceptually regulated exercise program can be developed (35). For arm, leg, and combined arm and leg exercise, RPE at the lactate and ventilatory inflection points ranges from 12 to 14 on the Borg scale (60). On the OMNI RPE Scale for children and adults, the ventilatory inflection point occurred at an RPE-Overall of 6, RPE-Legs of 7 and RPE-Chest of 4.5 during cycling exercise (Robertson et al, 2001). Ratings of perceived exertion that are anatomically differentiated, such as RPE-Legs and RPE-Chest are often used in limb-specific exercise prescriptions and in clinical assessment of exertional dyspnea. One of the possible applications of the findings of the present investigation is to use differentiated RPE to prescribe mode specific aerobic exercise that is subjectively preferable for recreationally active subjects. Thus, it is important to quantify differentiated perceptual signal dominance and integration at intensities equivalent to the ventilatory breakpoint. Such information will provide a rationale for exercise prescriptions that employ differentiated target RPEs that provide an overload training stimulus that spans the ventilatory inflection point.

RPE at the lactate and ventilatory inflection points is stable for men and women of varying age and training experience and persists from session to session (60). The training zone for cardiorespiratory fitness contains the relative metabolic rates that typically define the lactate and ventilatory inflection points (50-80% VO_{2max}). Thus, producing an RPE that corresponds to these points by self-regulating exercise intensity ensures an appropriate overload stimulus to enhance functional aerobic power resulting in a physiologically valid prescription procedure.

2.8.2 Cross-Modal Prescription Using RPE

The validity of a perceptually based cross-modal exercise prescription using a treadmill, stationary cycle, and hand-weighted bench stepping exercise was investigated by Robertson et al. (67). It was found that RPE for the overall body was the same between a treadmill reference test and both cycling and hand-weighted bench stepping tests when performed at an exercise intensity equivalent to 70% of mode-specific VO_{2peak}. Hence, a perceptually based cross-modal exercise prescription is valid when exercise intensity is set equal to the relative VO_2. A target RPE-Overall equivalent to the prescribed $\%VO_{2peak}$ can be obtained from the GXT and generalized to various exercise modes including leg-only exercise, arm-only exercise, and combined arm and leg exercise. Under most conditions the undifferentiated RPE is preferable to the differentiated RPE in prescribing cross-modal exercise training programs.

A perceptually based exercise prescription assumes that a target RPE from a GXT transfers to a constant-intensity submaximal training bout and also that it transfers from a load- or grade-incremented test protocol to prolonged steady-state exercise (73). Both of these assumptions are physiologically valid. Of course some special issues require attention when developing and implementing perceptually regulated exercise prescriptions, such as walk-run trading functions, anginal pain/discomfort, cardioactive medications, preferred training intensity, and intermittent versus concentric muscle contraction (73).

Both the undifferentiated and differentiated RPE can be used independently or in conjunction with HR responses to determine if and when it is necessary to adjust the intensity of a training program and to measure the magnitude of physiological adaptation to an aerobic training program involving healthy participants as well as cardiac and hypertensive patients. Positive training adaptations are reflected by a decrease in RPE and HR at a given training intensity as functional aerobic power increases.

2.8.3 Potential Role of Differentiated RPE in Exercise Prescription

The use of differentiated RPEs increases the application and specificity of an exercise prescription in that subjectively preferable exercise programs can be created that increase enjoyment of exercise for the less fit and might even increase fitness gains for the trained individual. Furthermore, RPE-Overall transfers between exercise modes. However, differentiated perceptions that contribute to the RPE-Overall might differ between modes and thus make one modality less appealing to certain individuals than others. Therefore, it was important to investigate how differentiated RPEs contribute to the overall exertional expressions during weight bearing and non-weight bearing exercise in both trained and recreationally active individuals. Such information will help to accommodate activity preference when prescribing exercise and target exercise preference in order to develop subjectively preferable exercise programs, such programs can lead to increase adoption and exercise adherence, especially among the inactive population.

In summary, this chapter discussed perceived exertion scaling methods, the model of differentiated exertional perceptions, the physiological and psychological mediators that contribute to the RPE response, and exercise prescription. The goal of the literature review was to increase our understanding of how these concepts help to explain differentiated perceptions of exertion in recreationally active and trained individuals.

3.0 METHODS

3.1 SUBJECTS

Inclusion criteria for this study were based on gender, training status and aerobic fitness. Subjects for this investigation were college age females (18-25 years old), who were recruited from the University of Pittsburgh physical activity classes, and/or who exercised at the University's fitness facilities. Participants were healthy, of normal body weight and either recreationally active or trained. Recreationally active was defined as participating less than or equal to twice a week in aerobic activity for a total of 80 minutes at moderate intensity (~5-6 METS) and having a VO_{2max} that is classified at or below the average for age (≤ 35.2 ml/kg/min) (1). Trained was defined as participating in aerobic activities at least five times a week for a minimum of 200 minutes at moderate (~5-6 METS) to high (~10-11 METS) intensity and a VO_{2max} above the superior classification for age (≥ 44.2 ml/kg/min) (1). Participants with a body mass index (BMI) of ≥ 30 kg/m^2 were excluded from the study. Also, participants with known cardiovascular or pulmonary disease were excluded.

Before the start of the study, the protocol was approved by the University of Pittsburgh Institutional Review Board and written informed consent to participate was obtained from all prospective subjects.

3.2 EXPERIMENTAL DESIGN

This investigation employed a within subject cross-sectional experimental design consisting of one load incremented treadmill exercise trial and one load-incremented cycle ergometer trial. Both load incremented trials were terminated at maximal/peak exercise intensity. The exercise trials were presented in counterbalanced order and separated by a minimum of 48h and maximum of 72h. All subjects were requested not to consume alcohol or participate in vigorous physical activity during the 24 h period preceding each trial. During the first exercise trial training status was determined by a questionnaire and body weight (kg) and height (cm) were measured. Each exercise trial began with an orientation phase, i.e. 15 minutes. The orientation included: (a) a definition of perceived exertion, (b) OMNI Scale anchoring procedures, and (c) OMNI Scale instructions. Each of these orientation procedures used the OMNI Scale format that is consistent with the mode to be used in the exercise trial for that day. That is, the OMNI Cycle Scale was used in the cycle test orientation and the OMNI Walk/Run Scale was used in the treadmill orientation. Also, at the beginning of the orientation for each trial participants completed the POMS Brief Form questionnaire.

3.3 RATINGS OF PERCEIVED EXERTION

Ratings of perceived exertion were measured during the treadmill protocol using the walk/run format of the Adult OMNI Scale and during the cycle protocol using the cycling format of the Adult OMNI Scale (Appendix A & B). Perceptual ratings were obtained from 40-60 seconds of each exercise minute during both protocols. An undifferentiated rating for the overall body

(RPE-Overall), and differentiated ratings for peripheral perceptions of exertion in the legs (RPE-Legs) and respiratory-metabolic perceptions for the chest/breathing (RPE-Chest) were obtained. A standard definition of perceived exertion and an instructional set for the mode specific OMNI Scale were read to subjects immediately before each exercise protocol. The walk/run and cycle format of the OMNI Scale were separately viewed by subjects when their respective instructional set was read. Both scales were anchored using a combination exercise and memory procedures as follows: Participants were asked to imagine themselves as the person on the left side of the scale who just started walking/cycling and whose exertion feels extremely easy. They were told that if they felt like this person during exercise they should point to a 0 on the scale. Then subjects were asked to imagine themselves as the person on the right side of the scale who is barely able to run/cycle to the top of the hill and whose exertion feels extremely hard. They were told that if they felt like this person during exercise they should point to a 10 on the scale. If their exertion felt somewhere between extremely easy (i.e. 0) and extremely hard (i.e.10), participants were told to point to a number between 0 and 10.

Participants were asked at the end of each minute (40-60 seconds) of the exercise protocol to give three ratings of perceived exertion by pointing to the appropriate numbers on the scale, i.e. a rating for their overall body, for their legs, and for their chest and breathing. A pointing procedure was used as the respiratory valve/mouthpiece prevented a verbal response. The OMNI Scale was placed in full view of the subjects during the entire exercise trial. To cognitively reinforce the low and high scale anchor points before the start of the protocol, participants were asked to select a number that indicates how their body felt at that moment when sitting. Next the participants were asked to select a number that indicated how their body felt when they had exercised as hard as they can remember. The same was done for differentiated ratings. Participants were asked how their legs and chest/breathing felt at the moment and how those parts of the body felt when the subjects had exercised as hard as they can remember. This RPE Scale reinforcement procedure was done to ensure participants understood the scale anchors and thus were able to rate their perceived exertions accurately during the exercise tests.

For both scales, perceived exertion was defined as the subjective intensity of effort, strain, discomfort, and/or fatigue that is felt during exercise (54). The instructions for the cycle format of the OMNI Scale were as follows:

We would like you to ride on a bicycle ergometer. Please use the numbers on this scale to tell us how your body feels when bicycling. Look at the person at the bottom of the hill who is just starting to ride a bicycle. If you feel like this person when you are riding, the exertion will be EXTREMELY EASY. In this case, your rating should be a number zero. Now look at the person who is barely able to ride a bicycle to the top of the hill. If you feel like this person when riding, the exertion will be EXTREMELY HARD. In this case, your rating should be a number 10. If you feel somewhere between Extremely Easy (0) and Extremely Hard (10) then give a number between 0 and 10.

For the walk/run format of the OMNI Scale the following instructions were read:

We would like you to walk and then run on a treadmill. Please use the numbers on this scale to tell us how your body feels when walking or running. Look at the person at the bottom of the hill who is just starting to walk. If you feel like this person when you are walking, the exertion will be EXTREMELY EASY. In this case, your rating should be a number zero. Now look at the person who is exhausted after reaching the top of the hill. If you feel like this person when walking/running, the exertion will be EXTREMELY HARD. In this case, your rating should *be a number 10. If you feel somewhere between Extremely Easy (0) and Extremely Hard (10) then give a number between 0 and 10.*

For both formats of the OMNI scale the following instructions were the same:

We will ask you to point to a number that tells how your whole body feels then how your legs and chest/breathing feel. Remember, there are no wrong numbers. Use both the pictures and words to help you select a number. Use any of the numbers to tell how you feel when cycling/walking/ running.

3.4 EXERCISE TRIALS

3.4.1 Anthropometric measures

Body mass (kg) and height (cm) were determined at the beginning of the first trial using a Detecto-Medic Scale and attached stadiometer (Detecto Scales Inc., Brooklyn, NY) and were also used to obtain BMI. Percent body fat was determined by bioelectrical impedance analysis (BIA) (TBF-300A, Tanita, Arlington Heights, IL) using the standard mode. These data were used to describe the subject cohort.

3.4.2 Profile of Mood States (POMS)

The POMS Brief Form (46) was used to measure mood before the start of each exercise trial. The POMS Brief Form consists of 30 items that assess six mood states: Tension-Anxiety, Depression-Dejection, Anger-Hostility, Vigor-Activity, Fatigue-Inertia, and Confusion-

Bewilderment. The subjects rated their feelings on a 5-point (0–4) Likert scale. The response set "How are you feeling right now?" was chosen in this study. As a global measure of affective state, a Total Mood Disturbance score was calculated by summing the five negative scale scores and subtracting the positive mood (i.e. vigor) score. The POMS is one of the most frequently used mood measures in sport and exercise psychology and has been shown to be a valid and reliable mood measurement tool (42).

3.4.3 Cardiorespiratory and aerobic metabolic measures

Oxygen uptake (VO_2, L/min and ml/kg/min), carbon dioxide production (VCO_2 L/min, ml/kg/min) and pulmonary ventilation (V_E L/min) during each trial were measured using an open-circuit respiratory metabolic system (TrueMax 2400, Parvo Medics, Salt Lake City, UT). Measures were determined every 15 seconds and expressed as STPD. System calibration was undertaken before each trial. A standard respiratory valve (Model 2700; Hans Rudolph, Kansas City, MO) and mouthpiece were used for all respiratory-metabolic measurements. Heart rate (HR) was measured using a Polar Monitor System (Polar Electro Inc., Woodbury, NY). Maximal/peak oxygen uptake was taken as the highest value recorded during the final stage of the exercise protocols when:

1. There was a change of $\leq$ 2.1 ml/kg/min or $\leq$ 150 ml/min in VO_2 between contiguous stages at maximal exercise intensity.
2. Attainment of ± 5 beats/min of the age-predicted maximal/peak heart rate.
3. Respiratory exchange ratio (RER) $\geq$ 1.1.

Any one or combination of the above criteria was accepted as confirmation of attainment of $VO_{2max/peak}$.

The ventilatory breakpoint (V_{pt}) was determined for both the treadmill and cycle ergometer exercise tests using respiratory-gas exchange measurements obtained every 15 seconds. The ventilatory equivalents for oxygen (V_E:VO_2) and carbon dioxide (V_E:VCO_2) were plotted as a function of VO_2. Using the V-slope measurement criterion, the V_{pt} was taken as the VO_2 at which V_E:VCO_2 increased without a simultaneous increase in V_E:VO_2 (43). The V_{pt} was determined from individual plots for each subject and was expressed in both absolute (L/min and ml/kg/min) and relative (%VO_{2max}) units. Three investigators independently examined the plots to identify the V_{pt}. Agreement within 150 ml between two of the three investigators was required to establish the V_{pt}. The average of the two agreeing determinations was taken to be the V_{pt}.

3.4.4 Treadmill protocol

At the start of this session subjects first completed the POMS Brief Form questionnaire. Next, an orientation to the OMNI RPE Scale and testing procedures was presented prior to the load-incremented treadmill protocol. Immediately prior to the treadmill test the investigator read a standard set of scaling instructions to the subject. These included the definition of perceived exertion, scale anchors and procedures to use the OMNI RPE Scale (walk/run format). The exercise test was performed on a Trackmaster treadmill, model TMX 425C (FullVision Inc, Newton, KS). A modified Bruce protocol (Appendix C), with 3 minute exercise stages was employed. The treadmill speed/grade control system were preprogrammed for the modified Bruce protocol, and interfaced with the respiratory-metabolic unit for automatic stage-by-stage adjustments. Measurement order for RPE-Overall, RPE-Legs, and RPE-Chest was established by a counterbalance sequence. A restricted randomized procedure was used to assign subjects to the counterbalanced sequence. For a given subject the same measurement order was used for each exercise minute. Subjects followed a different counterbalance sequence in the alternate mode. RPE-Overall, RPE-Legs, and RPE-Chest were measured during the last 20 seconds of each exercise minute. VO_2, VCO_2, and V_E were measured in 15 second intervals during each exercise minute. HR was measured during the last 15 seconds of each exercise minute. The $\%VO_{2max}$ was calculated for each minute using the average VO_2 for the last 30 seconds of each minute. The highest recorded HR was taken as the maximal HR. The test was terminated when the subject volitionally stopped exercise owing to fatigue. V_{pt} was calculated at the completion of the trial. Standardized verbal encouragement (good job, keep it up) was given each minute throughout the trial by the investigator to maximize performance.

3.4.5 Load-incremented cycle protocol

At the start of this session subjects first completed the POMS Brief Form questionnaire. Next, an orientation to the OMNI RPE Scale and testing procedures was presented prior to the load-incremented cycle ergometer protocol. Immediately prior to the cycle ergometer exercise test the investigator read a standard set of scaling instructions to the subject. These included the definition of perceived exertion, scale anchors and procedures to use the OMNI Cycle Scale. The test was administered using a Monark cycle ergometer (Model 864, Sweden) equipped with toe clips and a plate-loading system to apply break force. Seat height was determined before the start of the trial by adjusting the seat so that the subject had 5° knee flexion when sitting on the cycle with the foot in its lowest position. The load-incremented cycle protocol (Appendix D) consisted of 3 minute exercise stages, with an initial resistance of 150 kgm/min. Resistance was incremented 150kgm/min every 3 minutes. Subjects were instructed to maintain a constant cadence of 50 rev/min signaled by an electronic metronome. The resistance was set by the investigator at the beginning of each stage, the absolute value not known to the subject. The test was terminated when the subject volitionally stopped owing to fatigue, or the investigator determined that the subject could not maintain the designated pedal rate for 10 consecutive seconds.

Measurement order for RPE-Overall, RPE-Legs, and RPE-Chest was established by a counterbalance sequence. A restricted randomized procedure was used to assign subjects to the counterbalance sequence. For a given subject the same measurement order was used for each exercise minute. Subjects followed a different counterbalance sequence in the alternate mode. RPE-Overall, RPE-Legs, and RPE-Chest were measured during the last 20 seconds of each exercise minute. VO_2, VCO_2, and V_E were measured in 15 second intervals during each minute. HR was measured during the last 15 seconds of each exercise minute. The $\%VO_{2peak}$ was calculated for each minute using the average VO_2 for the last 30 seconds of each minute. The highest measured HR was accepted as the maximal HR. V_{pt} was calculated at the completion of the trial. Verbal encouragement (good job, keep it up) was given each minute throughout the trial by the investigator to maximize performance.

3.5 DATA ANALYSIS

Sample size was determined by power analysis. Power calculation was based on the two-way site x intensity interaction. The analysis assumed an effect size of 0.4 for ANOVA (equivalent to 0.8 for t-test), an alpha of 0.05, an inter-class correlation of 0.2, and a desired power of 80%. The actual inter-class correlation is expected to be higher than 0.2, but this value was chosen to be most conservative. Thus, it was determined that a minimum of 16 recreationally active females and 16 trained females were required to test both the main and interaction effects.

Descriptive data for perceptual and physiological variables were calculated as mean ± standard deviation. Total mood disturbance scores from the POMS were compared between the recreationally active and trained groups with an independent samples t-test. Separate t-tests were done for each exercise mode.

A regression analysis was used to identify RPE-Overall, -Legs, and –Chest equivalent to 40, 60, and 80% $VO_{2max/peak}$. Separate regression analyses were calculated for individual subjects. For the first research purpose separate calculations were performed for cycling and treadmill exercise. The derived RPE data (Overall, Legs, Chest) were examined with a two factor (site (3) x intensity (3)) ANOVA with repeated measures on site and intensity. Separate ANOVAs were calculated for each training status. Level of significance was set at $p < 0.05$. Significant interactions were plotted and any significant main effects were examined with a Bonferroni *post-hoc* analysis.

For the second research purpose, separate calculations were performed for cycling and treadmill exercise. RPE (Overall, Legs, Chest) measured at the ventilatory breakpoint were examined with a one factor (site (3)) within subject ANOVA with repeated measure on site.

Separate analyses were conducted for each mode. Level of significance was set at $p < 0.05$. Significant main effects were examined with a Bonferroni *post-hoc* analysis.

4.0 RESULTS

The purpose of this study was to examine the effect of exercise intensity on components of the differentiated perceived exertion model in young recreationally active and trained women performing weight bearing and non-weight bearing aerobic exercise. Subjects underwent two maximal graded exercise tests, the first on a treadmill and the second on a stationary cycle ergometer. The two exercise tests were separated by a minimum of 48 hours and a maximum of 72 hours. RPE, oxygen consumption, ventilation, and heart rate were measured every minute of both exercise tests.

4.1 DESCRIPTIVE INFORMATION

Subjects for this investigation were aerobically trained (n = 22) and recreationally active (n = 19) 18 – 25 year-old females. Descriptive data for the subjects are presented in Table 1.

Table 1. Descriptive characteristics of subjects

	Trained Females	Recreationally Active Females	p values
Age (yr)	21.9 ± 1.4	21.6 ± 1.4	0.592
Height (m)	1.64 ± 0.07	1.65 ± 0.06	0.677
Weight (kg)	58.0 ± 6.1	59.1 ± 8.0	0.607
BMI (kg/m^2)	21.5 ± 1.8	21.8 ± 2.5	0.701
POMS TMD Score Cycle Ergometer	-0.33 ± 7.49	1.00 ± 4.85	0.513
POMS TMD Score Treadmill	-1.41 ± 8.82	-1.05 ± 5.37	0.879
Body Fat (%)	20.8 ± 3.3	23.0 ± 5.0	0.095
VO_{2max} (ml/kg/min)	43.3 ± 3.1	33.4 ± 2.4	< 0.0005

Values are means ± SD. VO_{2max} = Maximal Oxygen Consumption.
BMI = Body Mass Index.

There was no significant difference between groups regarding age, height, weight and BMI and percent body fat. VO_{2max} was lower ($p < 0.05$) for the recreationally active as compared to the trained group. Furthermore, there was no significant difference between groups for total mood disturbance scores before the treadmill and cycle ergometer trial. The ventilatory breakpoint during treadmill exercise for recreationally active subjects occurred at 61.5%VO_{2max} and for trained subjects at 69.5%VO_{2max}. During cycling exercise the ventilatory breakpoint for recreationally active subjects occurred at 62.0%VO_{2peak} and for trained subjects at 69.4%VO_{2peak}.

4.2 RPE RESPONSES

4.2.1 Cycle Ergometer: Intensity Effects on differentiated and undifferentiated RPE

Separate regression analyses were performed for individual subject data to identify RPE-Overall, -Legs, and –Chest equivalent to 40, 60, and 80% VO_{2peak} during cycle exercise. Two-factor (site (3) x intensity (3)) ANOVAs with repeated measures on site and intensity were then computed for the RPE-Overall, -Legs, and –Chest responses. A separate analysis was computed for the recreationally active group and the trained group.

Presented in Table 2 are the mean ± SD for RPE responses of recreationally active subjects. The results of the ANOVA of the RPE data for recreationally active subjects are presented in Table 3. Since the assumption of sphericity was not met the results of the ANOVA were reported using the Greenhouse-Geisser statistic.

Table 2. RPE responses for recreationally active subjects during cycling exercise

$\%VO_{2peak}$	RPE-Overall	RPE-Legs	RPE-Chest
40	1.59 ± 1.41	1.47 ± 1.30	1.97 ± 1.59
60	4.42 ± 1.87	4.75 ± 1.68	4.54 ± 1.94
80	7.38 ± 2.06	8.11 ± 1.58	7.33 ± 2.29

Data are means ± standard deviation.

Table 3. Results of the analysis of variance for recreationally active subjects during cycling exercise

	df	***F***	***p***	η^2
Main Effects				
Site	1.209	1.969	0.174	0.099
Error	21.760			
Intensity	1.230	522.244	< 0.0005	0.967
Error	22.132			
Interaction Effects				
Site x Intensity	1.543	10.561	0.001	0.370
Error	27.765			

The interaction effect for site x intensity was significant ($p = 0.001$). This significant interaction is plotted in Figure 2. Simple effects post-hoc analysis indicated that for recreationally active subjects, RPE-Legs was significantly higher than RPE-Overall and RPE-Chest at 80% of VO_{2peak}, while RPE-Overall and RPE-Chest were similar to each other (Figure 2). On the other hand there was no difference between RPE-Overall, -Legs, and -Chest for recreationally active subjects at 40 and 60% of VO_{2peak} during cycling exercise. This indicates that recreationally active subjects did not report a dominant RPE at the lower intensities but RPE-Legs became the dominant signal at the high exercise intensity (80% VO_{2peak}) during cycling exercise.

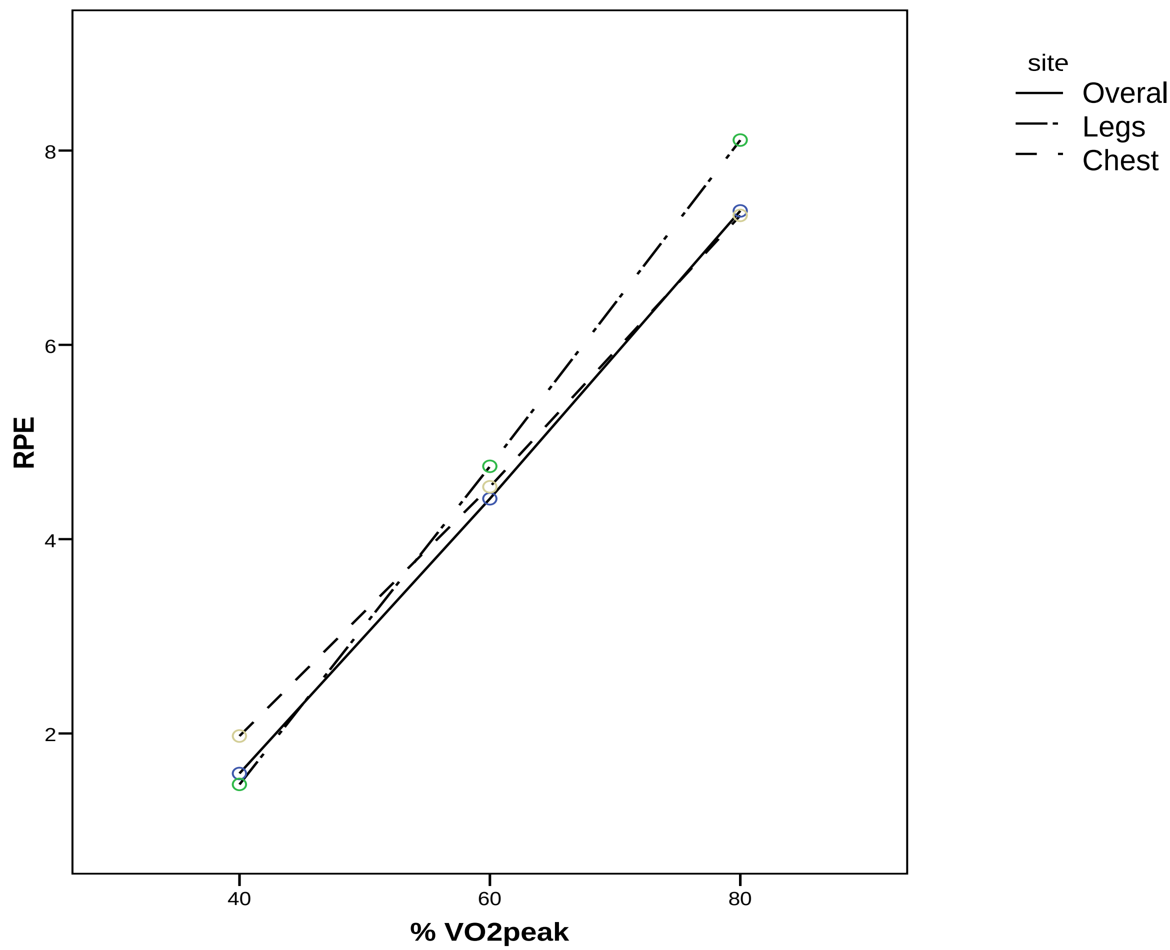

Figure 2. Mean differentiated and undifferentiated RPEs for recreationally active subjects during cycling exercise. RPE: ratings of perceived exertion. $\%VO_{2peak}$: percent of peak oxygen consumption.

There was also a main effect of intensity ($p < 0.0005$) on RPE for recreationally active subjects during cylcing. Because the interaction was ordinal the main effect for intensity can also be interpreted. The main effect for intensity indicated that when averaged over site, RPE increased from 40% **(**RPE = 1.67) to 60% (RPE = 4.57) to 80% (RPE = 7.61) VO_{2peak}, meaning that subjects reported higher RPEs as intensity increased.

Presented in Table 4 are the mean ± SD for RPE responses of trained subjects performing cycle exercise. One trained subject did not complete the cycle exercise test. Thus an N = 21 was used for analysis. The results of the ANOVA of the RPE data for trained subjects are presented in Table 5. Since the assumption of sphericity was not met the results of the ANOVA are reported using the Greenhouse-Geisser statistic.

Table 4. RPE responses for trained subjects during cycling exercise

$\%VO_{2peak}$	RPE-Overall	RPE-Legs	RPE-Chest
40	1.53 ± 1.20	1.72 ± 1.36	1.59 ± 1.17
60	4.34 ± 1.42	4.65 ± 1.61	4.34 ± 1.43
80	7.33 ± 1.37	7.77 ± 1.57	7.29 ± 1.40

Data are means ± standard deviation.

Table 5. Results of the analysis of variance for trained subjects during cycling exercise

	df	*F*	*p*	η^2
Main Effects				
Site	1.454	9.851	0.001	0.330
Error	29.076			
Intensity	1.507	1008.984	< 0.0005	0.981
Error	30.149			
Interaction Effects				
Site x Intensity	2.191	11.652	< 0.0005	0.368
Error	43.829			

The interaction effect for site x intensity was significant ($p < 0.0005$). This significant interaction is plotted in Figure 3. Simple effects post-hoc analysis indicated that for trained subjects, RPE-Legs was significantly higher than RPE-Overall and RPE-Chest, while RPE-Overall and -Chest were similar to each other at all three intensities (Figure 3).

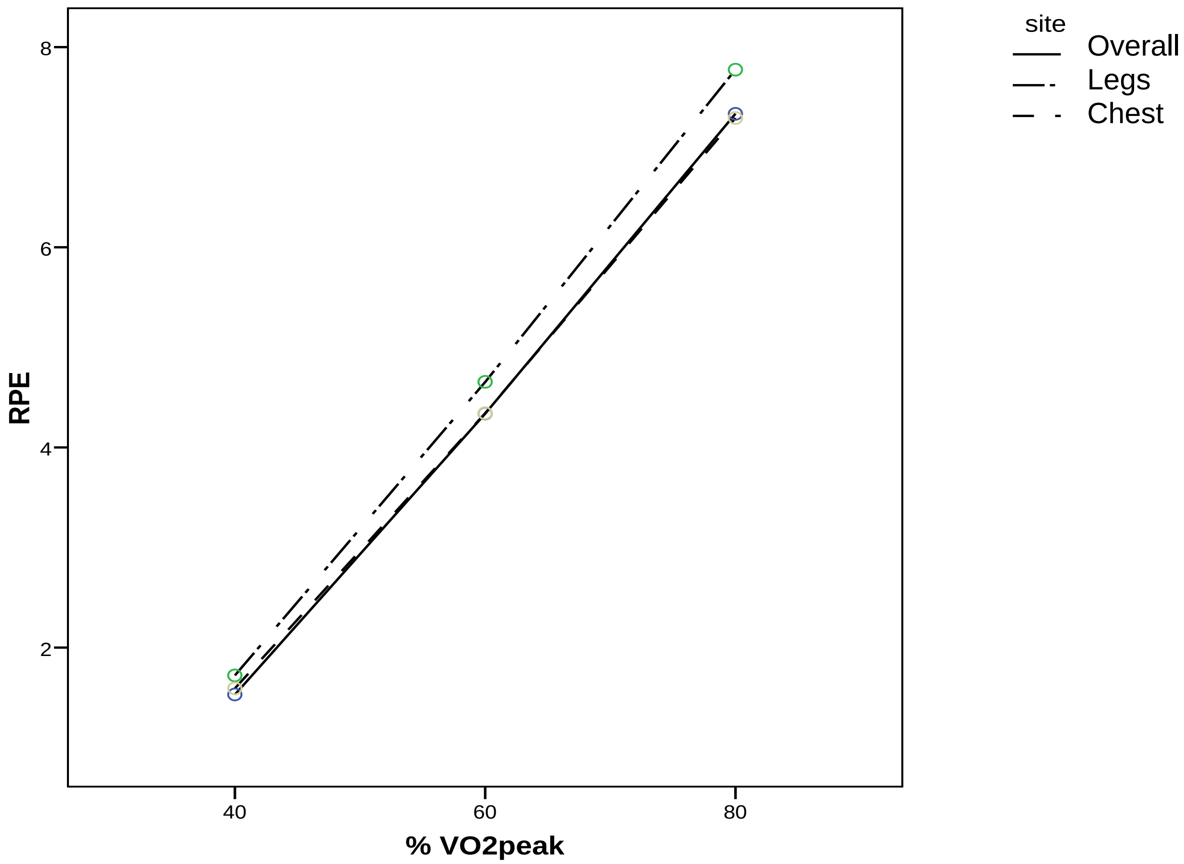

Figure 3. Mean differentiated and undifferentiated RPEs for trained subjects during cycling exercise. RPE: ratings of perceived exertion. %VO2peak: percent of peak oxygen consumption.

There was also a signifcant main effect of site and intensity on RPE ($p < 0.0005$) for trained subjects. Because the interaction was ordinal the main effect for site and intensity can also be interpreted using Figure 3. Post-hoc comparisons for intensity indicated that when averaged over site, RPE increased from 40% (RPE = 1.61) to 60% (RPE = 4.44) to 80% (RPE = 7.46) VO_{2peak}. This indicates that subjects reported higher RPEs for all sites as intensity increased. The main effect for site indicated that RPE-Legs was significantly higher than RPE-Overall and RPE-Chest for all intensities in trained subjects during cycling exercise. Thus it appears that trained subjects experienced a dominant RPE signal in the legs throughout varying intensities.

4.2.2 Treadmill Exercise: Intensity Effects on differentiated and undifferentiated RPE

Separate regression analyses were performed for individual subject data to identify RPE-Overall, -Legs, and –Chest equivalent to 40, 60, and 80% VO_{2maz} during treadmill exercise. Two-factor (site (3) x intensity (3)) ANOVAs with repeated measures on site and intensity were then computed for the derived RPE-Overall, -Legs, and –Chest responses. A separate analysis was computed for the recreationally active group and the trained group.

Presented in Table 6 are the means ± SD for RPE responses of recreationally active subjects. The results of the ANOVA of the RPE data for recreationally active subjects during treadmill exercise are presented in Table 7. Since the assumption of sphericity was not met the results of the ANOVA are reported using the Greenhouse-Geisser statistic.

Table 6. RPE responses for recreationally active subjects during treadmill exercise

$\%VO_{2max}$	RPE-Overall	RPE-Legs	RPE-Chest
40	1.61 ± 1.43	1.42 ± 1.42	1.72 ± 1.68
60	3.97 ± 1.37	3.72 ± 1.50	4.08 ± 1.44
80	6.60 ± 1.27	6.46 ± 1.37	6.65 ± 1.37

Data are means ± standard deviation.

Table 7. Results of the analysis of variance for recreationally active subjects during treadmill exercise

	df	*F*	*p*	η^2
Main Effects				
Site	1.196	1.204	0.295	0063
Error	21.535			
Intensity	1.104	280.603	< 0.0005	0.940
Error	19.873			
Interaction Effects				
Site x Intensity	1.928	0.601	0.548	0.032
Error	34.699			

No site x intensity interaction effect on RPE was found for recreationally active subjects during treadmill exercise. The main effect for measurement site was not significant while the main effect for intensity was significant ($p < 0.0005$). Post-hoc comparisons for intensity indicated that when averaged over site (i.e. Overall, Legs, Chest), RPE increased from 40% (RPE = 1.58) to 60% (RPE = 3.92) to 80% (RPE = 6.57) VO_{2max}.

Presented in Table 8 are the means ± SD for RPE responses of trained subjects performing treadmill exercise. The results of the ANOVA of the RPE data for trained subjects during treadmill exercise are presented in Table 11. Since the assumption of sphericity was not met the results of the ANOVA are reported using the Greenhouse-Geisser statistic.

Table 8. RPE responses for trained subjects during treadmill exercise

$\%VO_{2max}$	RPE-Overall	RPE-Legs	RPE-Chest
40	1.16 ± 1.32	1.14 ± 1.26	1.34 ± 1.23
60	3.80 ± 1.35	3.78 ± 1.43	3.97 ± 1.21
80	6.66 ± 1.15	6.73 ± 1.45	6.82 ± 1.12

Data are mean ± standard deviation.

Table 9. Results of the analysis of variance for trained subjects during treadmill exercise

	df	*F*	*p*	η^2
Main Effects				
Site	1.371	1.553	0.228	0.069
Error	28.782			
Intensity	1.304	440.865	< 0.0005	0.955
Error	27.386			
Interaction Effects				
Site x Intensity	2.007	0.431	0.653	0.020
Error	42.145			

No site x intensity interaction effect on RPE was found for trained subjects during treadmill exercise. The main effect for measurement site was not significant while the main effect for intensity was significant ($p < 0.0005$**).** Post-hoc comparisons for intensity indicated that when averaged over site (i.e. Overall, Legs, Chest), RPE increased from 40% (RPE = 1.21) to 60% (RPE = 3.85) to 80% (RPE = 6.74) VO_{2max}.

4.3 MEAN RPE RESPONSES AT THE VENTILATORY BREAKPOINT

4.3.1 Cycle Ergometer

Perceptual signal dominance and integration were also examined at an exercise intensity equivalent to the individually determined ventilatory breakpoint (V_{pt}) for the recreationally active and trained subjects. A one factor (site (3)) within subject ANOVA was calculated separately for cycle ergometer and treadmill exercise and also separately for each activity group.

Presented in Table 10 are the means ± SD for RPE responses at V_{pt} of recreationally active and trained subjects. The results of both ANOVAs for cycle ergometer data are presented in Table 11. Since the assumption of sphericity was not met the results of the ANOVA are reported using the Greenhouse-Geisser statistic.

Table 10. RPE at the ventilatory breakpoint during cycle exercise for recreationally active and trained subjects

	RPE-Overall	RPE-Legs	RPE-Chest
Recreationally Active	4.93 ± 2.73	5.52 ± 2.72	5.13 ± 2.74
Trained	5.13 ± 2.42	5.51 ± 2.60	5.15 ± 2.41

Data are mean ± standard deviation.

Table 11. Results of the analysis of variance for recreationally active and trained subjects during cycling exercise at the ventilatory breakpoint

	df	***F***	***p***	$\boldsymbol{\eta^2}$
Main Effect (recreationally active)				
Site	1.229	3.475	0.068	0.162
Error	22.129			
Main Effect (trained)				
Site	1.568	12.134	< 0.0005	0.378
Error	31.351			

The main effect for site was not significant for the recreationally active subjects. This finding indicates that at a cycle intensity equivalent to the ventilatory breakpoint recreationally active subjects did not experience a dominant RPE.

However, a significant main effect for site was reported for the trained subjects. Post-hoc comparisons indicated that at the ventilatory breakpoint trained subjects reported a significantly higher RPE-Legs than RPE-Overall and RPE-Chest. This finding is also depicted in Figure 4.

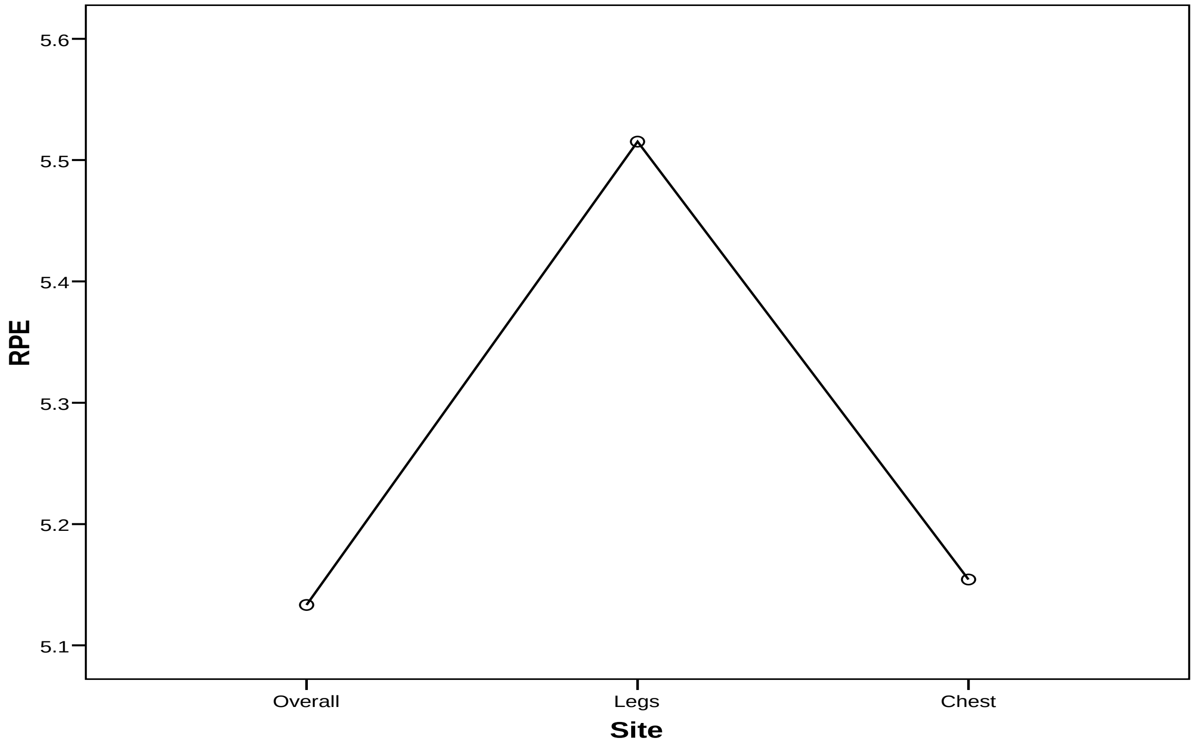

Figure 4. Mean undifferentiated and differentiated RPE at the ventilatory breakpoint during cycling exercise for trained subjects. RPE: ratings of perceived exertion. Site: RPE for the overall body, legs, and chest.

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4.3.2 Treadmill Exercise

Perceptual signal dominance and integration were also examined at an exercise intensity equivalent to the individually determined ventilatory breakpoint (V_{pt}) during treadmill exercise for the recreationally active and trained subjects. A one factor (site (3)) within subject ANOVA was calculated separately for cycle ergometer and treadmill exercise and also separately for each activity group.

Presented in Table 12 are the mean ± SD for RPE responses at V_{pt} of recreationally active and trained subjects. The results of both ANOVAs for treadmill data are presented in Table 13. Since the assumption of sphericity was not met the results of the ANOVAs were reported using the Greenhouse-Geisser statistic.

Table 12. RPE at the ventilatory breakpoint during treadmill exercise for recreationally active and trained subjects

	RPE-Overall	RPE-Legs	RPE-Chest
Recreationally Active	4.68 ± 1.52	4.46 ± 1.62	4.78 ± 1.56
Trained	4.51 ± 1.78	4.50 ± 1.89	4.71 ± 1.66

Data are mean ± standard deviation.

Table 13. Results of the analysis of variance for recreationally active and trained subjects during treadmill exercise at the ventilatory breakpoint

	df	*F*	*p*	η^2
Main Effect (recreationally active)				
Site	1.234	1.549	0.231	0.079
Error	22.203			
Main Effect (trained)				
Site	1.310	1.340	0.268	0.060
Error	27.506			

There was no main effect of site for either activity group meaning that neither recreationally active nor trained subjects experienced a dominant signal at the ventilatory breakpoint during treadmill exercise.

5.0 DISCUSSION, CONCLUSION, AND RECOMMENDATIONS

The purpose of this investigation was to determine the effect of exercise intensity on components of the differentiated perceived exertion model in young women performing weight bearing and non-weight bearing aerobic exercise. Ratings of perceived exertion can be expressed as either undifferentiated or differentiated measurements. The undifferentiated RPE measures the feelings of exertion for the overall body while the differentiated RPE measures exertion separately for the limbs (arms or legs) and chest/breathing. Usually one of the differentiated ratings will be more intense than the other and is therefore, considered the dominant RPE for the exercise mode and session (58). This concept is termed signal dominance. On the other hand, the undifferentiated perceptual signal represents an integration of many differentiated perceptual signals and thus forms a rating for the overall body (73). This concept is termed signal integration. The present findings indicated that there were significant differences between differentiated RPEs and undifferentiated RPEs at the high exercise intensity for recreationally active subjects during cycling exercise. Recreationally active subjects reported a higher RPE-Legs than RPE-Chest and RPE-Overall at high intensity cycling exercise. Also, significant differences were found between differentiated RPEs and undifferentiated RPEs at low, moderate, and high exercise intensities for trained subjects during cycling exercise. Trained subjects reported a higher RPE-Legs than RPE-Chest and RPE-Overall at each intensity during cycling exercise. However, no significant differences were found between differentiated RPEs and undifferentiated RPEs at any exercise intensity in either of the two groups for treadmill exercise. The findings suggested that during cycling exercise in trained individuals the legs provided the dominant signal at all intensities, while in recreationally active individuals dominance of the legs signal was only experienced at high intensity exercise. Perceptual signal dominance was not present in either recreationally active or trained individuals during treadmill exercise at any intensity. On first consideration, these responses suggest that the overall body exertional experience is formed by a sensory integration of the activated differentiated signals from the legs and chest. For the most part RPE-Overall did not differ significantly from RPE-Legs and RPE-Chest especially during treadmill exercise. Therefore, the RPE-Legs and RPE-Chest signal are likely contributing equally to the formation of the RPE-Overall.

5.1 SIGNAL DOMINANCE AND INTEGRATION FOR RECREATIONALLY ACTIVE AND TRAINED WOMEN AT VARYING EXERCISE INTENSITIES

5.1.1 Cycle Ergometer

5.1.1.1 Perceptual Signal Dominance

During aerobic exercise one differentiated perceptual rating will usually be more intense than the other and is therefore, considered the dominant RPE for that exercise mode and session (58). The differentiated perceptual signals arising from the body regions predominantely involved in the physical activity/exercise task usually have the highest intensity and dominate the sensory integration process (65). This means that the undifferentiated RPE for the overall body is primarily influenced by the intensity of the dominant differentiated signal. In the present study it was hypothesized that recreationally active subjects would have a higher RPE-Chest than RPE-Legs or RPE-Overall during cycle ergometry at low, moderate and high exercise intensities. In contrast, trained subjects were expected to report a higher RPE-Legs than RPE-Chest or RPE-Overall during cycling at these intensities. These hypotheses were based on previous research findings (58, 66, 69).

Perceptual signal dominance has been demonstrated in adults performing cycle ergometer exercise (58, 61, 65, 69). These studies found that the differentiated RPE for the legs was consistently more intense than the respiratory/metabolic signals arising from the chest. More specifically, it was found that for load incremented cycling to exhaustion, RPE-Legs was higher than RPE-Chest during both exercise and recovery (21). Peak RPEs for legs and overall body were reached at the point of exhaustion.

The results of the present study are for the most part consistent with previous findings regarding perceptual signal dominance during cycle exercise. That is, in trained subjects RPE-Legs was the dominant signal at low, moderate and high intensity exercise. RPE-Legs was significantly higher than RPE-Overall and RPE-Chest at all three exercise intensities, while RPE-Overall and –Chest were similar. However, this was not the case for the recreationally active group. In these subjects RPE-Legs only became the dominant signal at high intensity exercise (80% VO_{2peak}). At the high intensity RPE-Legs was significantly greater than RPE-Overall and RPE-Chest. At low (40% VO_{2peak}) and moderate (60% VO_{2peak}) exercise intensities recreationally active subjects did not evidence a dominant rating.

Therefore, the hypothesis that recreationally active individuals would have a higher RPE-Chest than RPE-Legs or RPE-Overall during cycle ergometry at low, moderate and high exercise intensities was not supported. However, the hypothesis that trained individuals would have a higher RPE-Legs than RPE-Chest or RPE-Overall during cycle ergometry at low, moderate and high exercise intensities was supported. During cycling, the expected dominance of the chest perceptual signal was not established for the recreationally active group but dominance of the legs signal was established for the trained group.

The present responses were unexpected as previous research findings have reported that RPE for the legs was more intense than the respiratory signal arising from the chest during cycle ergometer exercise (21, 29, 77). The present study demonstrated a dominant legs signal for the trained group. In contrast, the recreationally active group evidenced a dominant legs signal only at the highest exercise intensity. These findings might have occurred for a number of reasons. The intensity of perceived exertion can be influenced by peripheral, respiratory-metabolic and non-specific physiological mediators. The neurophysiological pathway for the undifferentiated and differentiated RPE employs a feed-forward and feedback sensory mechanism (14). When exercise intensity is increased, motor unit recruitment and firing frequency of skeletal and respiratory muscles also increase. These signals are sent to the sensory cortex. The greater the intensity and frequency of the signals, the more intense is the perception of physical exertion. The present subjects underwent a graded cycle ergometer test, where the protocol gradually increased in intensity. Thus, motor unit recruitment and firing frequency increased in both the leg muscles and respiratory muscles to meet the increased exercise intensity. As exercise intensity increased, fast-twitch muscle fibers were recruited which relied on anaerobic glycolysis and thus produced lactic acid. The increased blood lactic acid concentration was buffered via respiratory compensation. This occurred because lactic acid dissociated into lactate, releasing a hydrogen ion that was buffered by bicarbonate to form carbonic acid. Carbonic acid dissociated into carbon dioxide and water, increasing respiratory excretment of carbon dioxide. This resulting increase in metabolic acidosis and associated respiratory alkalosis increased RPE-Overall, -Legs, and -Chest with increasing exercise intensity as was expected.

The present findings did not demonstrate a dominant RPE-Chest for recreationally active subjects at any intensity. It was hypothesized that RPE-Chest would present as the dominant signal in the recreationally active subject group. The rationale underlying this expectation was that the recreationally active subjects would be unaccustomed to the elevated ventilatory drive that was linked to an increased aerobic-metabolic demand with load incremented exercise. In contrast, it was expected that the energy and contractile demands placed upon leg muscles would produce exertion sensations that were familiar to the recreationally active subjects. On the other hand, for trained subjects it was thought that because of their comparatively high level of aerobic training the perceptual responses involved with meeting the aerobic-metabolic demand would be comparatively lower. In this case exertional signals arising from the legs were expected to be more intense. However, it is possible that for the recreationally active subjects motor unit recruitment and firing frequency increased in both leg and respiratory muscles using the same activation pattern during low and moderate exercise intensity. Therefore, it was found that RPE-Overall, -Legs, and –Chest increased with increasing exercise intensity. However, no single regional signal was found to be perceptually dominant at the lower intensities for the recreationally active subjects. At the high intensity the legs signal evidenced perceptual dominance. This was likely due to increased motor unit recruitment and firing frequency of leg muscles as exercise intensity and local metabolic rate increased in leg muscles. In addition, at high intensity exercise muscle fatigue could have induced increased lactic acid levels which would have lowered blood pH contributing to the comparatively more intense perceptual signal from the legs. In contrast, trained individuals appear to experience greater motor unit recruitment and firing frequency in leg muscles as compared to respiratory muscles at lower intensity exercise. This finding in the trained group can also be explained by a higher aerobic fitness level. Having higher aerobic fitness would place less metabolic demand on respiratory muscles leading to a lower RPE-Chest than RPE-Legs and RPE-Overall. As a result the legs signal became dominant at the low exercise intensity in this group.

It should be noted that perceptual signal dominance was examined in both groups at the same relative exercise intensities (e.g. 40, 60, and 80% VO_{2peak}). These intensities were chosen to span a large portion of the aerobic-metabolic range. It was thought that recreationally active subjects would have a comparatively lower maximal aerobic power, e.g. lower maximal stroke volume and cardiac output which would result in lower oxygen delivery. The respiratory-metabolic exertional signal represented by RPE-Chest would in turn be more pronounced. In contrast, it was assumed that trained subjects would have a comparatively higher functioning cardiorespiratory system. Therefore, ventilatory drive would not be as pronounced and the exertion experienced by the leg muscles would provide the dominant perceptual signal. To test this hypothesis both groups exercised at relative metabolic intensities (e.g. % $VO_{2max/peak}$) rather than absolute intensities (e.g. l/min). It seems that the perceptual responses were mediated by the relative level of oxygen uptake/delivery in both recreationally active individuals and trained individuals throughout a wide aerobic-metabolic range. This finding is consistent with Robertson and colleagues who reported that during aerobic exercise RPE disributed as a strong positive function of $\%VO_{2max}$ (62). Thus, in the present study it appears that the potential influence of exercise intensity on perceptual signal dominance might be due to the relative level of oxygen uptake/delivery in recreationally active and trained subjects. Since all subjects' responses were examined at the same relative metabolic rate, the design eliminated mediating influence of differences in VO_{2max} between recreationally active and trained subjects. It was concluded that the similarity between RPE-Legs and –Chest during cycling exercise for recreationally active subjects held over the lower and middle portions of the metabolic range. At higher relative intensities the legs signal became dominant. For the trained subjects it was concluded that RPE-Legs became the dominant signal at comparatively lower relative intensities and remained so throughout a wide metabolic range.

Thus, the present findings do support previous reports that RPE is a valid psychophysiological tool to track relative intensity of aerobic exercise. The differentiated as well as undifferentiated RPEs increased as a function of the load incremented cycle ergometer exercise protocol. Both differentiated and undifferentiated RPE can be used to track changes is cycle ergometer exercise intensity regardless of the training status of young adult women. However, it might be advantageous especially for trained individuals to gauge exercise intensity by the differentiated RPE-Legs signal during cycling exercise as it was the dominant exertion signal throughout that exercise test.

5.1.1.2 Signal Integration

The expectation that the overall body perceptual report would at least in part be formed as an integration of separate signals from active limbs and the chest during aerobic exercise was used as the rationale to examine the signal integration component of the differentiated model.

In previous studies involving cycle ergometer exercise signal integration was evidenced as an undifferentiated rating for the overall body that appeared as an average of the differentiated legs and chest rating (65). In these studies the overall rating was close to but not exactly the same as the mean of the legs and chest/breathing rating. This mode of signal integration follows

Weiser and Stamper's model which predicts that the undifferentiated perceptual signals reflect the separate input of both the dominant and the less intense differentiated signals (83). In the present study, RPE-Overall appeared to be an average of the separate RPE-Legs and –Chest. Therefore, the RPE-Legs and –Chest signals contributed equally to the formation of RPE-Overall.

Overall, exercise intensity influenced signal dominance and integration in young recreationally active and trained women during cycling exercise. Since previous literature indicates differences in signal dominance and integration based on exercise mode, the present study examined non-weight-bearing and weight-bearing activities. Previous reports found that during non-weight-bearing exercise, the onset of signal dominance occurred at comparatively lower exercise intensities as compared to weight-bearing exercise (i.e. treadmill) modes (58, 66, 69). This finding was supported by the present investigation whereby trained subjects evidenced a dominant perceptual signal at low cycle exercise intensity. However, the same could not be said for recreationally active subjects as signal dominance was only present at the high cycle intensity exercise.

5.1.2 Treadmill Exercise

5.1.2.1 Perceptual Signal Dominance

Perceptual signal dominance was also examined during treadmill exercise for separate groups of trained and recreationally active female subjects. It was hypothesized that recreationally active individuals would have a higher RPE-Chest than RPE-Legs or RPE-Overall at low, moderate and high intensity treadmill exercise and that trained individuals would have a higher RPE-Legs than RPE-Chest or RPE-Overall at low, moderate, and high treadmill exercise intensities. In previous studies involving treadmill exercise the intensity of the undifferentiated rating was equal to or greater than the dominant differentiated rating, regardless of the number of pronounced regional perceptual signals evoked by the exercise task (28, 37). Furthermore, Robertson and colleagues (62) found that for adults walking on a treadmill the onset of a dominant perceptual signal was linked to a specific locomotor speed. The walking speed at which the intensities of the peripheral and respiratory-metabolic perceptual signals were first reported to be different from the overall signal of exertion was termed the differentiation threshold (DT). Results demonstrated that at speeds faster than the DT, the dominant signal arose from the legs and was more intense than in the overall body. The overall body signal was more intense than the exertion in the chest. A divergence in intensity of differentiated perceptual responses was only found at walking speeds greater than 4 $mi \cdot h^{-1}$. At walking speeds less than 4 $mi \cdot h^{-1}$ a dominant perceptual signal was not observed. On the other hand, Pandolf and colleagues (58) reported that at treadmill speeds faster than the DT, the chest signal was the dominant exertional report. Moreover, Rutkowski and colleagues (74) did not find a DT at slow to moderate walking speeds in children. The present results generally support Rutkowski and colleagues' findings as no significant difference was found between RPE-Legs, -Chest, and –Overall at low, moderate, and high exercise intensities in either recreationally active or trained subjects. Thus, neither regional signal was dominant at any of the exercise intensities in either of the two groups.

It is possible that the absence of a dominant perceptual signal across the exercise intensities in the present investigation occurred because the walking speeds were too slow to attain the DT. All subjects walked slower than 4 $mi \cdot h^{-1}$ during the graded exercise test while changes in intensity were primarily accomplished by incrementing treadmill grade. As Robertson and colleagues (62) demonstrated, the onset of a dominant perceptual signal or the DT is linked to a specific walking speed. As such, the locomotor speed may be more of a factor than the aerobic-metabolic demand in setting perceptual signal dominance at a given point during load-incremented treadmill exercise. In the present study it was possible that a DT was not reached because subjects were not allowed to progress to comparatively faster treadmill speeds. As such, they did not reach the specific locomotor speed where a DT occurred. Therefore, the hypotheses that recreationally active individuals would have a higher RPE-Chest than RPE-Legs or RPE-Overall during treadmill exercise at low, moderate, and high exercise intensities, as well as that trained individuals would have a higher RPE-Legs than RPE-Chest or RPE-Overall during treadmill exercise at low, moderate and high exercise intensities could not be adequately supported owing to design constraints involving the test protocol.

However, the findings do support previous research indicating that RPE is a valid tool to track relative exercise intensity as differentiated as well as undifferentiated RPEs increased as a function of an increase in $\%VO_{2max}$. Thus, differentiated or undifferentiated RPE can be used to track exercise intensity regardless of training status during treadmill exercise in young adult women.

5.1.2.2 Signal Integration

To test the signal integration component of the differentiated perceived exertion model, the present investigation examined whether the RPE-Overall appeared as an average of the two differentiated signals. Results indicated that RPE-Overall, -Legs, and –Chest were not different from each other for all exercise intensities in either of the two groups (Table 6 and 8). Thus, RPE-Legs and RPE-Chest likely contributed equally to the formation of RPE-Overall.

Overall, findings are inconclusive regarding the influence of exercise intensity on perceptual signal dominance and integration in young recreationally active and trained women during treadmill exercise. However, it appears that exercise mode plays a role in signal dominance and integration for these population sub-sets as a dominant differentiated RPE was found during cycle ergometry exercise but not for treadmill exercise.

5.2 SIGNAL DOMINANCE AND INTEGRATION FOR RECREATIONALLY ACTIVE AND TRAINED SUBJECTS AT THE VENTILATORY BREAKPOINT

5.2.1 Cycle Ergometer

Robertson and colleagues (71) observed that the perceptual signal arising from the legs was dominant when measured at the ventilatory breakpoint during an incremental cycle session in average and above average aerobically fit children. Also, Mahon and colleagues (43) observed that RPE-Legs and RPE-Overall were significantly greater than RPE-Chest when measured at the ventilatory breakpoint during cycling. Some studies have shown that blood lactic acid concentrations did not serve as a strong RPE mediator during cycle ergometer exercise (31, 32). However, Demello and colleagues (20) reported that RPE was not different between trained and untrained subjects when compared at the lactate threshold or at various percentages of VO_{2max}. This indicated a strong link between the metabolic and gas exchange alterations initiated at the lactate threshold and the intensity of the perceptual signal. These previous investigations concluded that the lactate threshold or its ventilatory breakpoint surrogate appears to be an important reference point for perception of exertion during exercise and that this psychophysiological link is not affected by state of aerobic training.

The lactate threshold is physiologically coupled to the ventilatory breakpoint due to the metabolic and respiratory gas alterations that take place in the presence of a lower of regional oxygen supply than demand. The present study assessed differentiated and undifferentiated RPE responses at the ventilatory breakpoint and found no difference among RPE-Legs, -Chest, and –Overall in recreationally active and trained subjects during cycle ergometry. The findings indicated that at the exercise intensity equal to the ventilatory breakpoint, perceptual signal dominance could not be established.

In the present investigation it was hypothesized that RPE-Chest would be higher than RPE-Legs when measured at the ventilatory breakpoint in recreationally active subjects. The rationale for this hypothesis was based on the assumed unfamiliarity of recreationally active individuals with this exercise mode at intensities equivalent to or greater than the ventilatory breakpoint. The increased carbondioxide production resulting from respiratory compensation of an increased lactic acid load results in an increased ventilatory drive for a given VO_2. It was expected that this increase in ventilatory drive would be reflected in an increased RPE-Chest. This was the case as RPE-Chest increased throughout the cycle ergoemter protocol. However, the recreationally active subjects did not perceive this added work of breathing as requiring greater exertion compared to the exertion felt in their leg muscles in response to an increased muscle force production. This finding is also consistent with the findings for cycling exercise at various exercise intensities as in the recreationally active group. For the present subjects signal dominance could not be established at 60% of VO_{2peak}, which is usually an intensity above the ventilatory breakpoint for this group. For individuals of lower aerobic fitness, the ventilatory breakpoint has been reported to occur at approximately 50% VO_{2max} . This may also have been the case for the recreationally active subjects employed in this study. Thus, if signal dominance was not detected at 60% of VO_{2peak}, none would be expected to occur at a lower exercise intensity either. Hence, the lack of signal dominance at the ventilatory breakpoint for this group is in line with the findings for recreationally active subjects as no signal dominance was detected at 60%VO_{2peak} during cycling exercise.

On the other hand, because it was thought that the trained subjects would be more familiar with the comparatively "higher" cycling exercise intensities it was hypothesized that they would report a higher RPE-Legs than RPE-Chest or RPE-Overall during cycle ergometer exercise. This was the case for perceptual responses measured at the ventilatory breakpoint as a higher RPE-Legs than RPE-Chest or RPE-Overall was found for trained subjects. These findings indicate that trained subjects perceived the exertion arising from their legs to be stronger than the exertion associated with the work of breathing. Thus, perceptual signal dominance was demonstrated in trained subjects when examined at the ventilatory breakpoint. The present study confirmed findings of previous work that during cycling, RPE-Legs was significantly greater than RPE-Overall and RPE-Chest (43).

To examine the mode of perceptual signal integration at the ventilatory breakpoint, RPE-Legs and -Chest were compared to RPE-Overall. It was found that RPE-Overall did not differ from the RPE-Legs and -Chest for the recreationally active subjects. In contrast, for the trained subjects the legs signal was dominant at the ventilatory breakpoint. However, while the difference in RPE was statistically significant the absolute value of the difference was small. Thus, the hypothesis that for both recreationally active and trained individuals, RPE-Overall represented an integration of various dominant and less intense differentiated signals was accepted. The RPE-Legs and –Chest signals likely contributed equally to the formation of the RPE-Overall response.

5.2.2 Treadmill Exercise

The present study assessed differentiated and undifferentiated RPE responses at the ventilatory breakpoint during treadmill exercise. Abundant research has demonstrated that the ventilatory breakpoint is representative of the same anaerobic metabolic dynamics as the lactate threshold. As such, it was possible to examine RPE responses between studies that used either the ventilatory breakpoint or lactate threshold as a metabolic reference point. Previous investigations reported that RPE-Legs was significantly greater than RPE-Chest at the lactate threshold during treadmill exercise (36). However, Seip and colleagues (75) found no significant differences between overall and differentiated RPE at the lactate threshold. The present results support these latter findings as no difference was found among RPE-Legs, -Chest, and –Overall when measured at the ventilatory breakpoint for the recreationally active and trained subjects. Thus, at the exercise intensity equivalent to the ventilatory breakpoint perceptual signal dominance could not be established. The hypotheses that recreationally active individuals would have a higher RPE-Chest than RPE-Legs or RPE-Overall, as well as that trained individuals would have a higher RPE-Legs than RPE-Chest or RPE-Overall during treadmill exercise at an intensity equivalent to the ventilatory breakpoint could not be supported. Again, the lack of signal dominance in both groups during treadmill exercise could be due to the fact that subjects did not reach their DT prior to demonstrating a ventilatory breakpoint. This occurred because treadmill speeds did not exceed 4 $mi \cdot h^{-1}$. The results do demonstrate that the sensory processes governing the formation of a perceptual signal seem to be generalizable across individuals but perceptual signal dominance was not influenced by exercise intensity for weight-bearing exercise in recreationally active and trained subjects.

To examine signal integration at the ventilatory breakpoint, RPE-Legs and -Chest were compared to RPE-Overall. Once again no significant difference emerged between these variables indicating that RPE-Overall did not differ from the RPE-Legs and -Chest for both recreationally active and trained subjects (Table 12). In addition, because the two differentiated RPEs equivalent to the V_{pt} did not differ, it appears that RPE-Legs and –Chest contributed equally to the formation of RPE-Overall.

5.3 SUMMARY

Overall, this investigation demonstrated that exercise intensity had an effect on perceived exertion signal dominance and mode of integration during cycling exercise in recreationally active and trained women. During cycle exercise a dominant perceptual signal was evident for recreationally active women at a high relative exercise intensity, while trained women experienced a dominant perceptual signal at low through high relative exercise intensities. However, during cycle exercise it was not possible to determine if RPE-Overall appeared to be an average of the differentiated signals arising from the legs and chest. RPE-Legs significantly differed for trained subjects at all cycle exercise intensities. However, this was only the case for recreationally active subjects during high exercise intensity. In general, both the differentiated and undifferentiated RPEs were very similar. Thus, while the difference in RPE was statistically significant at all cycle exercise intensities for trained subjects and the high exercise intensity for the recreationally active subjects, the absolute value of the difference was very small. As such, it appears that RPE-Legs and –Chest contributed equally to the formation of RPE-Overall during cycling exercise in recreationally active and trained women.

In contrast, perceptual signal dominance could not be established during treadmill exercise for recreationally active and trained women. At any exercise intensity, RPE-Overall, -Legs and –Chest did not differ significantly. Furthermore, it was not possible to determine if RPE-Overall appeared to be an average of the differentiated signals arising from the legs and chest. Since the differentiated ratings did not differ from the undifferentiated rating for recreationally active and trained subjects at any of the exercise intensities it appeared that RPE-Legs and –Chest contributed equally to the formation of RPE-Overall.

Thus, the findings of the present study for cycling exercise, support previous reports that examined the two components of the differentiated perceived exertion model (e.g. signal dominance and mode of integration). These previous studies concluded that the peripheral signal likely dominates the whole body sensory integration process during aerobic exercise on a cycle ergometer. However, since in the present study both differentiated signals were similar they may have had equal input into the sensory integration process during cycle exercise.

For treadmill exercise at low, moderate, and high intensity the present results showed no difference between differentiated and undifferentiated RPE for recreationally active as well as trained subjects. This finding is in agreement with results previously reported by Seip and colleagues (75) as well as Rutkowski and colleagues (74). On the other hand, they are somewhat in contrast to findings observed by Robertson and colleagues (62) who demonstrated that the onset of a dominant perceptual signal is keyed to a specific locomotor speed. However, even in Robertson's et al. (62) study, subjects did not evidence a dominant perceptual signal at speeds less than 4 $mi \cdot h^{-1}$. Since none of the subjects reached walking speeds above 4 $mi \cdot h^{-1}$ the present findings are at least partially in agreement with Robertson and colleagues study. Because the differentiated RPE for the legs and chest did not differ it appeared that RPE-Legs and –Chest contributed equally to the formation of RPE-Overall and thus the whole-body sensory integration process.

Similar responses to those noted above were found for perceptual signal dominance and mode of integration at the ventilatory breakpoint during cycle ergometer and treadmill exercise. Neither respiratory-metabolic nor peripheral ratings of perceived exertion appeared to dominate the overall body sensory integration process at exercise intensities equivalent to the ventilatory breakpoint for recreationally active and trained subjects during treadmill exercise. Only the trained subjects experienced legs signal dominance during cycle ergometry at an intensity equivalent to the ventilatory breakpoint. This response provided evidence for perceptual signal integration at an intensity equivalent to the ventilatory breakpoint. Since a difference between the differentiated and undifferentiated ratings was not observed, RPE-Legs and –Chest contributed equally to the formation of RPE-Overall. The literature shows equivocal findings regarding perceptual signal dominance and integration at the ventilatory breakpoint and thus more research in this area is needed.

Non-weight-bearing and weight-bearing exercise modes were examined to explore the possibility that the differentiated perceived exertion model would be expressed differently depending on the weight bearing properties of the exercise testing mode. It was anticipated that the different modes might require different skeletal muscle recruitment patterns, producing mode specific dominant RPE signals. It can be concluded from the present findings that the weight-bearing properties of exercise mode did not have an effect on signal dominance and integration at relative exercise intensities ranging from 40 to 80% VO_{2max} in recreationally active and trained individuals. Although, it was thought that non-weight-bearing and weight-bearing exercise would elicit muscle specific physiological events leading to differences between the differentiated RPEs this only seemed to be the case for cycling exercise in this study. Thus, the expectation that perceptual signal dominance would be present at comparatively lower exercise intensities during non-weight-bearing exercise, such as cycling, and have a delayed onset during weight-bearing exercise (58, 66, 69) was only partially supported.

5.4 RECOMMENDATIONS

In light of current findings, future investigations regarding perceptual signal dominance and integration should focus on the following research questions:

1. The present investigation used college-age female subjects that were classified as either trained or recreationally active. It would be of interest to study college-age males to determine signal dominance and integration.
2. The current study did not examine signal dominance and integration in an adolescent or elderly population. Thus, it would be of interest to investigate how signal dominance and integration develop and possibly change as a function of aging.
3. The present investigation employed a walking protocol for treadmill exercise and results indicated that no signal dominance was detected at various walking speeds. Therefore, it would add to the literature if

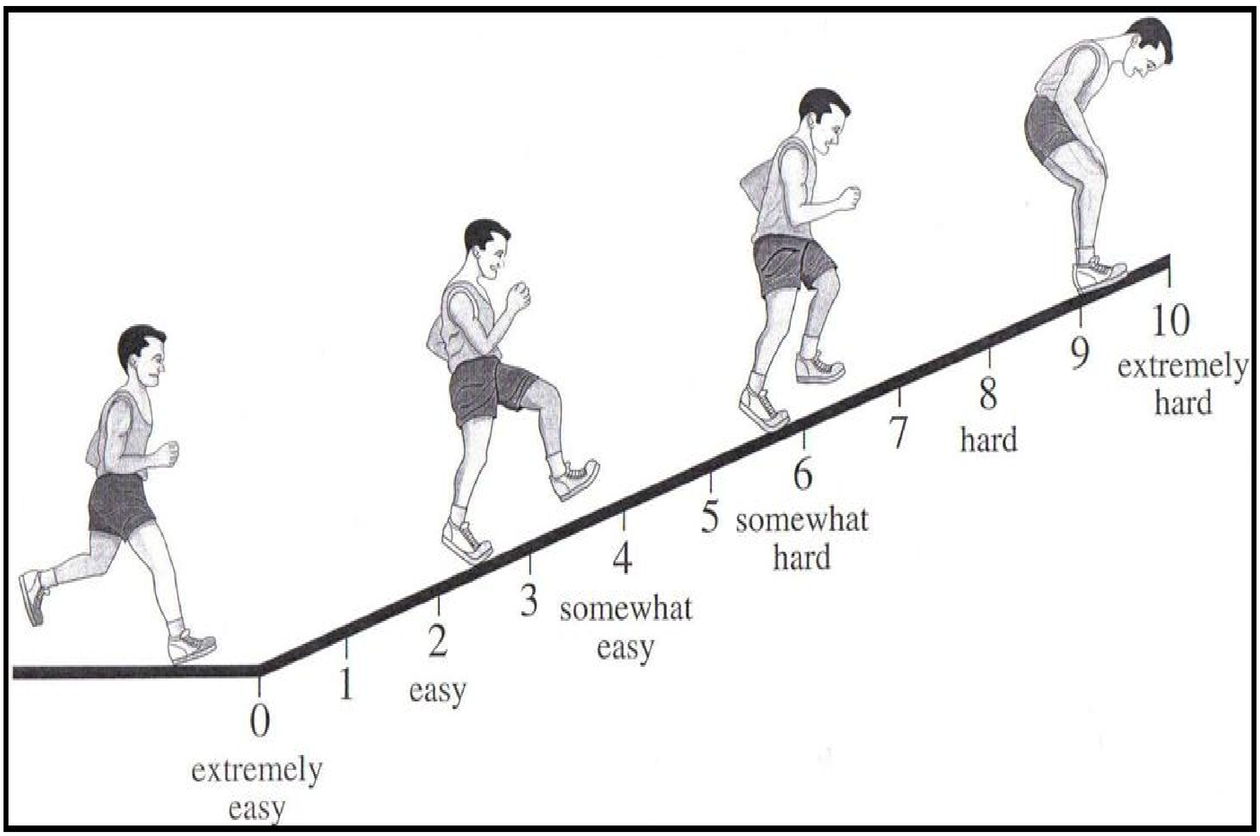
future studies further examined signal dominance and integration over a range of running speeds as findings in the literature are equivocal.

4. Future investigations should examine possible differences in signal dominance and integration in the same individual performing non-weight-bearing, partial weight-bearing, and weight-bearing exercise modes.

5. In the present investigation a graded exercise test was employed during both exercise trials to measure the perceptual responses and determine maximal oxygen uptake. It would be of interest to examine the impact of other exercise test protocols involving constant load, continuous and intermittent exercise on perceptual signal dominance and integration.

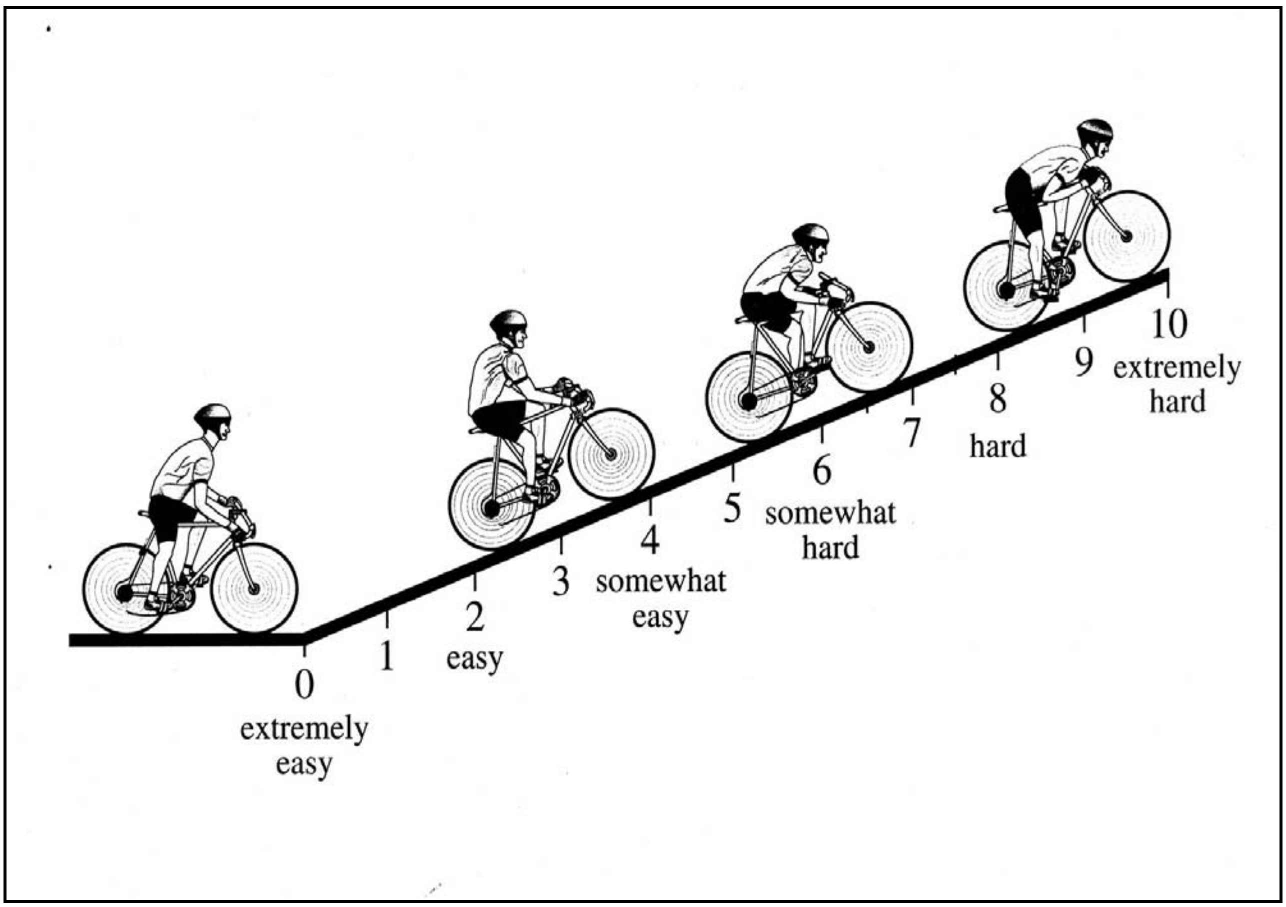
APPENDIX A

OMNI WALK/RUN SCALE



APPENDIX B

OMNI CYCLE SCALE



APPENDIX C

MODIFIED BRUCE PROTOCOL

3 Min Stages		
MPH	**% Grade**	**METS***
1.7	10	4.64
2.5	12	7.05
3.4	14	10.16
3.4	21	13.48
3.4	25	15.32
4.2**	25	18.69

***METS = VO_2/ 3.5ml/kg/min**

VO_2 = 0.1 S + 1.8 G x S + 3.5 (Walking equation - ACSM Guidelines)
VO_2 in ml/kg/min
S is speed in m/min; 1mph = 26.8 m/min
G is grade entered as a fraction; 10% = 0.10

**** Last stage will only be used if necessary for individuals to reach VO_{2max}**

APPENDIX D

BICYCLE ERGOMETER PROTOCOL

3 Min Stages
Kgm/min (Watts)
150 (25)
300 (50)
450 (75)
600 (100)
750 (125)
900 (150)
1050 (175)
1200 (200)
1350 (225)
1500 (250)

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