PHYSIOLOGICAL RESPONSES AT THE RATING OF PERCEIVED EXERTION AT AND ABOVE THE GAS EXCHANGE THRESHOLD DURING TREADMILL RUNNING

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The purposes of this study were to examine: 1) the metabolic, cardiovascular, respiratory, neuromuscular, and velocity responses during continuous, constant rating of .perceived exertion (RPE) runs at the RPE corresponding to the velocity at the gas exchange threshold (RPE_{GET}) and 15% above GET ($RPE_{GET+15\%}$); and 2) the metabolic efficiency changes during continuous, constant RPE runs at RPE_{GET} and $RPE_{GET+15\%}$. Eleven moderately trained runners performed an incremental treadmill test to exhaustion. GET and GET+15% were determined from the incremental test to exhaustion, and the velocity at GET and GET+15% were used to estimate the RPE_{GET} and $RPE_{GET+15\%}$ using linear regression. On separate days, subjects performed 60 min runs at RPE_{GET} and $RPE_{GET+15\%}$, and physiological, neuromuscular, and perceptual responses were recorded. Polynomial regression analyses were used to examine the patterns of responses for all of the variables and paired-samples *t*-tests were used to determine changes in metabolic efficiency at RPE_{GET} and $RPE_{GET+15\%}$. The results of the polynomial regression analyses indicated that there were negative, quadratic relationships ($R^2 = 0.96 – 0.99$) for $\dot{V}O_2$, RER, $\dot{V}_E$, and velocity vs. time at RPE_{GET} and $RPE_{GET+15\%}$; positive, quadratic relationships ($R^2 = 0.87$ and 0.74) for $\mathcal{F}_b$ vs. time at RPE_{GET} and $RPE_{GET+15\%}$; and positive, linear ($r^2 = 0.73$), and no significant ($r^2 = 0.0$) relationships for HR vs. time at

RPE_{GET} and $RPE_{GET+15\%}$, respectively. There were negative, linear relationships ($r^2 = 0.96$ and 0.63) for VL and VM EMG RMS vs. time, and positive, linear relationships ($r^2 = 0.72$ and 0.40) for VL and VM EMG MPF vs. time at RPE_{GET}. In addition, there was a negative, linear relationship ($r^2 = 0.16$) for VL EMG RMS vs. time, a positive, quadratic relationship ($R^2 = 0.74$) for VM EMG RMS vs. time, and positive, quadratic relationships ($R^2 = 0.73$ and 0.96) for VL and VM EMG MPF vs. time at $RPE_{GET+15\%}$. There were decreases in metabolic efficiency at RPE_{GET} and $RPE_{GET+15\%}$. These findings indicated that the only variable that tracked RPE was the normalized, composite HR vs. time response at $RPE_{GET+15\%}$, and that treadmill running at RPE_{GET} and $RPE_{GET+15\%}$ was sustainable for up to 60 min.

DEDICATION

I would like to dedicate this project to my parents, Bill and Susie Cochrane, who have supported my academic endeavors for my entire life and who never hesitated to support my desire to pursue my doctorate degree and a career in higher education. They have always provided the encouragement I needed throughout all of the migraine days and stress, without which I would not be where I am today. I would also like to dedicate this project to my husband, Andrei. Through his endless encouragement, love, and support I was able to keep my eye on the prize and do what was necessary to be successful. He is the most caring and selfless person I know.

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CHAPTER I

INTRODUCTION

Mielke et al. (76) proposed a fatigue threshold that was based on the perception of effort, known as the physical working capacity at the rating of perceived exertion threshold (PWC_{RPE}), using either the Borg 6-20 (PWC_{Borg}) or OMNI 0-10 (PWC_{OMNI}) scale (26,76). In theory, the PWC_{RPE} estimates the maximal power output during cycle ergometry that can be maintained during continuous exercise without an increase in the perception of effort (76). The mathematical model used to estimate the PWC_{RPE} was based on the electromyographic (EMG) fatigue threshold (EMG_{FT}) test of deVries et al. (36) and involves determining the slope coefficients for the RPE versus time relationships during 3 or 4 rides on a cycle ergometer at different power outputs. The slope coefficients are then plotted as a function of the power outputs and the y-intercept reflects the power output that corresponds to a slope coefficient for the RPE versus time relationships of zero and is defined as the PWC_{RPE} (76). A salient feature of the PWC_{RPE} test is that it requires only a cycle ergometer, stop watch, and RPE scale, while determining other commonly used thresholds (such as the gas exchange threshold (GET), respiratory compensation point (RCP), lactate threshold (LT), and EMG_{FT}) require specialized equipment for the measurement of expired gas samples, blood lactate, or EMG signals.

Fatigue thresholds have been used to discriminate between fatiguing and non-fatiguing work, as well as demarcate the exercise intensity domains (moderate, heavy, or severe). For example, it has been suggested that the GET demarcates the moderate from heavy domains, while the RCP and critical power (CP) demarcate the heavy from severe domains (11,26,45). Furthermore, during continuous exercise, each domain is

characterized by predictable patterns of responses for oxygen consumption rate ($\dot{V}O_2$), heart rate (HR), and blood lactate concentration (($La^-)_b$. For example, during cycle ergometery at a constant power output within the moderate exercise intensity domain, $\dot{V}O_2$, HR, and $(La^-)_b$ reach steady state within 3 min (45). In the heavy exercise intensity domain, however, $(La^-)_b$ appearance exceeds its rate of removal for the first 10 – 20 min then reaches a steady state (45). In addition, in the heavy domain, the slow component of $\dot{V}O_2$, defined as an excess $\dot{V}O_2$ cost above a predicted submaximal work rate, appears after 3 – 10 min of exercise. This slow component indicates a decreased rate of metabolic efficiency in the heavy domain compared to the moderate exercise intensity domain (45, 122). It has been suggested (41,45,95) that the reduction in metabolic efficiency associated with the slow component results from the recruitment of less efficient motor units. As previously recruited motor units fatigue, less efficient motor units are called upon to ensure that the constant power output exercise is maintained.

Changes in metabolic efficiency resulting from fatigue-induced neuromuscular responses are reflected in the time and frequency domains of the EMG signal (50,52,58, 93). For example, fatigue-induced changes in the time domain are characterized by an increase in EMG amplitude (AMP), which is a reflection of the recruitment of additional motor units, increased firing rates of activated motor units and/or synchronization (50, 58, 93). The frequency domain, however, reflects changes in action potential conduction velocity, and fatigue is characterized by a decline in EMG mean power frequency (MPF) (50). Electromyographic responses have been investigated during both constant power output and velocity exercise, and it has been shown that EMG responses differ as a function of exercise intensity (50,52,58,93). For example, Petrofsky (93) reported no

change in EMG AMP during moderate intensity cycle ergometry, but increases in EMG AMP during heavy and severe intensity exercise. In addition, EMG MPF plateaued during moderate intensity exercise, but exhibited an initial increase followed by sustained decrease during heavy and severe intensity exercise (93). During prolonged running exercise (80 min) at 75% $\dot{V}O_{2max}$, Hausswirth et al. (52) reported increases in EMG AMP and decreases in EMG MPF. Thus, during prolonged exercise at a constant power output or velocity there are fatigue-induced changes in motor unit recruitment, firing rate, and/or synchronization and inconsistent changes in action potential conduction velocity (52,93).

Previous studies (45,79,122) have suggested that the GET and LT demarcate the moderate from heavy exercise intensity domains, while CP and RCP represent exercise intensities at the upper boundary of the heavy exercise intensity domain (11,45,59,96). There is conflicting evidence, however, regarding the domain associated with a perceptual threshold, such as the PWC_{RPE}. For example, Mielke et al. (76) reported that the PWC_{RPE} reflects an intensity demarcating the moderate from heavy exercise intensity domains, similar to GET. Exercise at GET has been defined as the highest power output that can be performed without a significant increase in $(La^{-})_b$ (45,122). In contrast, Bergstrom et al. (11) reported no differences between PWC_{RPE} and RCP, which suggested an intensity demarcating the heavy and severe exercise intensity domains. More recently, Cochrane et al. (26) found the PWC_{RPE} to be less than GET and to fall within the moderate exercise intensity domain when cycling for an extended period of time at a constant RPE. Thus, the relative intensity associated with a perceptually based fatigue threshold and its relation to the moderate, heavy, and severe intensity domains remains unclear.

A number of studies have examined the physiological and perceptual responses during continuous, constant power output cycle ergometry (35,45,47,58,77,95). During fatiguing, constant power output exercise there are predictable, time-dependent patterns of responses for $\dot{V}O_2$, HR, RPE, breathing frequency ($\mathcal{F}_b$), and minute ventilation ($\dot{V}_E$). There are, however, different patterns of responses for various physiological variables when continuous exercise is maintained at a constant physiological or perceptual parameter rather than power output. For example, it has been reported (14) that during treadmill running at a constant HR within the heavy and severe exercise intensity domains, there were decreases in $\dot{V}O_2$ and velocity. In addition, Kindermann et al. (64) reported that maintaining a constant HR during treadmill running in the severe domain resulted in decreases in $\dot{V}O_2$, $(La^-)_b$, and velocity. During cycling exercise at a constant $\dot{V}O_2$, however, Ribiero et al. (99) reported increases in HR, and decreases in power output and respiratory exchange ratio (RER). Exercise at a constant perceptual intensity (27,66,114), such as a constant rating of perceived exertion (RPE) based on the Borg (16,17) or OMNI (102) perceptual scales, has also resulted in dissociations among metabolic, cardiovascular, respiratory, and neuromuscular parameters during cycling and running exercise. For example, Lander et al. (66) reported that during rowing exercise at a constant RPE, lower core temperature, $(La^-)_b$, and muscle activation values were found compared to those during exercise at a constant power output. In addition, Cochrane et al. (27) reported dissociations among RPE, $\dot{V}O_2$, HR, $\dot{V}_E$, and RER during cycling exercise at a constant RPE. It was reported (27) that $\dot{V}O_2$, HR, $\dot{V}_E$, and RER tracked the decrease in power output during the continuous rides at a constant RPE, while $\mathcal{F}_b$ tracked RPE (did not change) during the constant RPE rides. Only one previous study (114) has

investigated physiological responses while running at a constant perceptual intensity. It was reported (114) that running at the RPE associated with 2.5 mmol $(La^-)_b$ resulted in an increase in HR and a decrease in velocity over a 30 min period. No previous studies, however, have examined the metabolic, cardiovascular, respiratory, and neuromuscular patterns of responses during treadmill running at a constant RPE.

Three primary models (2-6,62,63,70-72,84,85,110,111) have been proposed to explain the perception of effort and physiological processes during cycling and running exercise. The corollary discharge model (70,71) hypothesizes that there is direct feed forward input from central command to the somatosensory and motor cortex areas of the brain that are responsible for setting the perception of effort and determining the activation level of skeletal muscle, without the input of afferent feedback (70,71). In contrast, the central governor model (110,111,84,85) suggests that an unconscious 'governor' predetermines perception and an end point to exercise, regardless of afferent feedback or feed forward inputs. This 'governor' is suggested to prevent the occurrence of catastrophic fatigue in the working athlete (84). The exercise pressor reflex model suggests that afferent feedback from type III and IV thigh, leg, and/or respiratory muscles provides the feedback to the brain centers responsible for the regulation of the perception of effort, cardiovascular, neuromuscular, and respiratory responses (2-6,62,63). It was previously reported (27) that the exercise pressor reflex model may best account for the perception of effort and respiratory responses during continuous cycle ergometry exercise at a constant RPE within the moderate intensity domain due to the close association of RPE by $\mathcal{F}_b$. No previous studies, however, have examined these models as potential

mediators of the perception of effort during sustained, constant RPE running with respect to the moderate or heavy exercise intensity domains.

The physiological and perceptual responses during constant power output or velocity exercise are well documented, but less is known about these responses at a constant perception of effort. In addition, few studies have investigated neuromuscular responses during sustained running exercise, and no previous studies have examined the neuromuscular responses during treadmill running at a constant RPE. Furthermore, there is conflicting evidence regarding the potential mediators of the perception of effort and which model of fatigue best accounts for the patterns of responses at a constant perception of effort. Therefore, the purposes of this study are to examine: 1) the metabolic ($\dot{V}O_2$ and RER), cardiovascular (HR), respiratory ($\dot{V}_E$ and $\mathcal{F}_b$), neuromuscular (EMG AMP and MPF), and velocity responses during continuous, constant RPE runs at the RPE corresponding to the velocity at the GET ($v\text{RPE}_{\text{GET}}$), and 15% above GET ($v\text{RPE}_{\text{GET+15\%}}$); and 2) the metabolic efficiency changes during continuous, constant RPE runs in the moderate and heavy domains.

CHAPTER II

REVIEW OF LITERATURE

1) Exercise Intensity Domains

Whipp (122)

The purpose of this study was to review the dynamics of pulmonary gas exchange parameters within the moderate and heavy exercise intensity domains. The characteristic responses of these parameters differ among the three domains, which are partitioned by the anaerobic threshold (AT) (a.k.a gas exchange threshold (GET), lactate threshold (LT), or ventilatory threshold (VT), and $\dot{V}O_{2Max}$. The AT represents the highest exercise (power output) that can be achieved without a sustained increase in $\dot{V}O_2$ or blood lactate ($(La^-)_b$). The AT corresponds to a significantly lower $\dot{V}O_2$ during cycle ergometry than during treadmill running. Work rates below AT are considered to occur in the moderate intensity domain, and those above AT in which $(La^-)_b$ is elevated but does not continue to increase are within the heavy exercise intensity domain. Exercise that results in a continual increase in $(La^-)_b$ and $\dot{V}O_2$ until both reach peak or supra-peak values is known to occur within the severe exercise intensity domain. Attainment of a $\dot{V}O_2$ steady state typically occurs within the first 3 min of exercise within the moderate domain and between min 3-6 within the heavy domain. The increased time to achieve a steady-state within the heavy domain and the inability to reach a steady-state within the severe domain were primarily attributed to: 1) increased ventilatory and cardiovascular cost at higher work rates; 2) reduced mechanical efficiency; 3) increased recruitment of less efficient fast-twitch motor units; and 4) increased $\dot{V}O_2$ as a result of lactate metabolism.

Thus, there are distinct $\dot{V}O_2$ kinetics and $(La^-)_b$ responses that are dependent upon changes within the working muscle, ventilatory, and cardiovascular system that define three different exercise intensity domains (moderate, heavy, and severe).

Poole et al. (95)

In this study the respiratory and metabolic responses during continuous cycle ergometry at and slightly above CP were investigated. Eight untrained males (mean ± SD, age = 22 ± 1 yr; body mass = 75.6 ± 4.8 kg; $\dot{V}O_{2Max}$ = 50.6 ± 1.7 $mL \bullet kg^{-1} \bullet min^{-1}$) performed an incremental cycling test to exhaustion to determine the VT and $\dot{V}O_{2Max}$. On a separate day, subjects performed five exhaustive constant power tests (> 1 min) to estimate CP (197 ± 12 W) from the linear power versus the inverse of time relationship ($P = (AWC \bullet t^{-1}) + CP$). The subjects then performed two constant power rides at CP and CP + 5% of the maximal power output (P_{max}) achieved during the incremental test. Critical power was 164% of VT and 69% of P_{max}. The constant power tests at CP were maintained for 24 min, while tests above CP averaged only 17.7 ± 1.2 min. During rides at CP, $\dot{V}O_2$ and $(La^-)_b$ rose rapidly in the first 3 min, followed by a gradual rise in both until a steady state was reached approximately 18 min of exercise. Rides at power outputs greater than CP, however, resulted in a continual rise in $\dot{V}O_2$ and $(La^-)_b$ until they were driven to max values. These findings indicated that work at a constant power output between VT and CP can be maintained for an extended period of time (>24 min), while work done above CP results in fatigue in 24 min or less. Thus, the authors concluded that CP demarcates the heavy (prolonged exercise despite increased acidosis) from the severe

($\dot{V}O_{2Max}$ and the maximum level of metabolic acidosis are reached) exercise intensity domain.

Gaesser and Poole (45)

In this review article, the slow component of oxygen uptake and the patterns of responses associated within the exercise intensity domains as well as those at the demarcation points were outlined. Exercise below the LT (also known as the GET, VT, or AT) can be represented by a linear relation between $\dot{V}O_2$, HR, and RPE. Exercise above LT, however, is characterized by a slowly developing increase in $\dot{V}O_2$ beyond what would be expected below the LT, which is known as the $\dot{V}O_2$ slow component. This slow component is said to represent an additional energy requirement in responses to: increases in skeletal muscle recruitment, increases in metabolites within the working muscle, and decreased efficiency. The moderate exercise intensity domain includes all work that does not result in a sustained lactic acidosis (below the LT) and there is an absence of the slow component. The heavy exercise intensity domain begins at the work rate at which $(La^-)_b$ appearance exceeds its removal. The upper boundary of the heavy domain is defined by the highest workload that allows for steady state $\dot{V}O_2$ and $(La^-)_b$, and the LT has been set as the demarcation point between the moderate and heavy exercise intensity domains. Within the severe domain, $\dot{V}O_2$ and $(La^-)_b$ continue to rise and are driven to max levels. It was reported that the lower boundary of the severe domain (upper bound heavy) is the W-t asymptote (CP) and typically occurs at 50% of the difference between LT and $\dot{V}O_{2Max}$. Thus, the authors concluded that there are unique relationships for physiological responses within the three exercise intensity domains

(moderate, heavy, and severe). Furthermore, during incremental or constant exercise at a set power output, velocity, or alternative parameter, the patterns of change for these parameters ($\dot{V}O_2$, $(La^-)_b$, and HR) can be examined to determine which exercise intensity domain the exercise occurred within.

Carter et al. (24)

The purpose of this study was to examine $\dot{V}O_2$ kinetics during treadmill running across the moderate, heavy, and severe exercise intensity domains. Nine recreationally trained subjects (mean ± SD, age = 27 ± 7 yr; body mass = 69.8 ± 9.0 kg; $\dot{V}O_{2Max}$ = 4,137 ± 697 mL•min^{-1}) performed three stages of testing: 1) an incremental test for the determination of LT and $\dot{V}O_{2Max}$; 2) seven sessions (2-3 reps each) of 'square-wave' transitions from rest to one of seven intensities (range = 80% LT – 100% Δ (Δ = difference between LT and $\dot{V}O_{2Max}$); and 3) determination of critical velocity (CV) from four treadmill runs to exhaustion. Blood lactate concentration was measured at the end of every 4 min stage from the incremental test to determine LT. Critical velocity was calculated using the linear model of velocity versus time to exhaustion as proposed by Whipp (115). The results indicated that the combined amplitudes of the cardiodynamic phase and monoexponential rise in $\dot{V}O_2$ (characteristic of the first 2-3 min of exercise) increased with exercise intensity. In addition, the $\dot{V}O_2$ slow component, which characterizes an additional 'slow' rise in $\dot{V}O_2$ for several min until a delayed steady state is achieved (heavy domain), also increased with exercise intensity from 139 mL•min^{-1} at 20% Δ to 487 mL•min^{-1} 80% Δ. The authors concluded that there are intensity-dependent

changes in the amplitude and kinetics of $\dot{V}O_2$ responses that may be associated with changes in muscle fiber recruitment patterns.

Summary

The articles outlined in this section provided the basis for categorizing exercise based on three distinct “domains”, moderate, heavy, and severe. The LT (GET, VT, and AT) has been suggested as the demarcation point between the moderate and heavy exercise intensity domain, while CP is said to demarcate the heavy from severe. Thus, exercise below the LT and CP is, theoretically, sustainable for an extended period of time (>24 min), while exercise above CP may result in fatigue in < 24 min.

2) Fatigue Thresholds

1.1 The Development of the Two-Parameter Model

Monod and Scherrer (79)

The authors developed the critical torque (CT) and CP model for intermittent isometric and dynamic muscle actions. The authors defined CP as the maximum power output that can be maintained without exhaustion. Critical power was described by the relationship between the time to exhaustion (T_{lim}) and the total amount of work performed ($W_{lim} = P \times T_{lim}$). The T_{lim} and W_{lim} were determined from three separate constant work rate tests performed to exhaustion. A mathematical model was used to linearly relate W_{lim} and T_{lim} described by the equation $W_{lim} = a + b(T_{lim})$. Three separate parameters can be identified from this mathematical model: 1) CP, defined as the slope

(*b*); 2) anaerobic work capacity (AWC), where the y-intercept (a) represents the anaerobic work capacity (AWC), which is the total amount of work that can be performed above CP using only stored energy sources within the active muscles; and 3) T_{lim} for any power output greater than CP ($T_{lim} = \frac{a}{P-b}$).

1.2 The Development of the Physical Working Capacity Model

deVries et al. (36)

The purpose of this study was to establish the relationship between CP and the neuromuscular fatigue threshold (EMG_{FT}) as estimated from electromyography (EMG) during cycle ergometry. Five men and six women (age 19- 32 yr) completed an incremental test to exhaustion to determine peak oxygen consumption, the VT, and on a separate day each completed four exhaustive, constant power output rides (1.73 – 4.96 min) to estimate CP and EMG_{FT}. The CP was defined as the slope of the total work versus time to exhaustion. The slope coefficient for the EMP amplitude versus time relationship was determined for each subject for each power output. The power outputs were plotted as a function of the slope coefficients and the y-intercept was the EMG_{FT}. The mean (± SEM) CP (169.5 ± 12.8 W) was significantly lower than the FT (190.5 ± 14.0 W), but the two thresholds were highly correlated (r = 0.869). There was no difference between CP and the VT (187.1 ± 15.9 W) and they were correlated at r = 0.877. The EMG_{FT} and VT were also highly correlated (r = 9.903). Based on the significant correlations among these thresholds (CP, EMG_{FT}, and VT), the authors suggested that each represented a similar underlying physiological mechanism. It was

further suggested that lactate led to an increase in motor unit recruitment, and firing rate, and decreases in force production, resulting in greater EMG amplitude to power output ratio.

1.3 The Development and Application of Perceptually Based Fatigue Thresholds

Mielke et al. (76)

The primary aims of this study were to determine if the mathematical model proposed by deVries (36) to estimate EMG_{FT} could be applied to ratings of perceived exertion to estimate the physical working capacity at the Borg and OMNI thresholds (PWC_{BORG} and PWC_{OMNI}) and to compare the power outputs associated with both perceptual thresholds to those of the VT, physical working capacity at the heart rate (PWC_{HRT}), and oxygen consumption ($PWC_{\dot{V}O_2}$) thresholds. Fifteen subjects (6 men and 9 women; mean ± SD, age = 22 ± 1 yr; body mass = 75.2 ± 19.2 kg; height = 193.9 ± 67.6 cm; $\dot{V}O_{2Max}$ = 40.8 ± 5.8 mL•kg^{-1}•min^{-1}) subjects performed an incremental test to exhaustion on an electronically braked cycle ergometer to determine peak values as well as VT. On four separate days, all subjects completed 4 continuous work bouts to exhaustion at different power outputs to determine PWC_{BORG} and PWC_{OMNI}. During the 4 continuous work bout rides, RPE (Borg 620 and OMNI 0-10), $\dot{V}O_2$, and HR values were collected. For the determination of PWC_{BORG} and PWC_{OMNI}, the rate of rise for HR, $\dot{V}O_2$, and RPE as a function of time were calculated for each of the 4 power outputs for each subject. The power outputs were then plotted as a function of the slope coefficients of each HR, $\dot{V}O_2$, and RPE value vs. time relationship. The fatigue thresholds were defined

as the y-intercepts of the power output vs. slope coefficient plots. The RPE values that corresponded to the PWC_{BORG} and PWC_{OMNI} as well as the HR at the PWC_{HRT} were determined using linear regression analyses from the results of the incremental test. There were no significant differences among the thresholds. These findings indicated that the application of the mathematical model used to determine EMG_{FT} could be applied for use with perceptual ratings.

Nakamura et al. (82)

This study sought to determine if the OMNI scale using the cycle ergometer pictorial format could be used to estimate a perceived exertion based threshold (PET) and to compare this threshold to a PET based on the Borg scale, and to CP. On two separate days, thirteen men (mean ± SD, age = 22 ± 2.1 yr; body mass = 73 ± 8.3 kg; 175 ± 5.5 cm) performed high-intensity exercise on a cycle ergometer using 4 different constant loads using either the OMNI scale (test 1) or the Borg scale (test 2) to estimate the PET_{OMNI}, PET_{Borg}, and CP. Individual results were fit to the CP model using the equation [Time = AWC/(Power-CP)], where AWC was solved using nonlinear regression analyses. The PET_{OMNI} and PET_{Borg} were highly correlated ($r = 0.77$). In addition, PET_{OMNI} and PET_{Borg} were significantly correlated with CP ($r = 0.79$ and 0.94). Thus, the authors concluded that a perceptually grounded fatigue threshold could be used to assess the maximal sustainable power output during cycle ergometry.

Bergstrom et al. (11)

In this study, times to exhaustion and power outputs at the rating of perceived exertion threshold (PWC_{RPE}), GET, and RCP were compared. Eight subjects (3 men and

5 women; mean ± SD, age = 22.4 ± 2.8 yr; body mass = 68.2 ± 12.2 kg; height = 174 ± 9.5 cm) performed an incremental test to exhaustion on a cycle ergometer followed by 4 randomly ordered constant power output rides to exhaustion, on separate days, at intensities that corresponded to 85%, 90%, 100%, and 10% maximal power output at $\dot{V}O_{2Peak}$. The GET and RCP were determined from the incremental test to exhaustion, while PWC_{RPE} was determined using the procedures of Mielke et al. (2008) using the Borg 6-20 scale. Power curve analysis was used to determine T_{lim} values for GET, RCP, and PWC_{RPE}. The GET (155 ± 42 W) was significantly less than PWC_{RPE} (176 ± 55 W) and RCP (181 ± 54 W). In addition, the T_{lim} for GET was significantly greater than PWC_{RPE} and RCP. The authors concluded that the perception of effort may not be mediated by the same mechanisms that underlie the GET, however, those that mediate RCP (increased interstitial potassium) may influence the perception of effort.

Cochrane et al. (26)

The primary purposes of this study were to 1) compare relative exercise intensities defined by the peak oxygen consumption rate (% $\dot{V}O_{2Peak}$) that corresponded to the gas exchange threshold (GET), VT, the respiratory compensation point (RCP), $PWC_{\dot{V}O_2}$, PWC_{HRT}, and PWC_{OMNI}; and 2) examine the relationships among the fatigue thresholds and their relation to the exercise intensity domains (moderate, heavy, and severe). Thirteen subjects (6 men and 7 women; mean ± SD, age = 21.8 ± 2.6 yr; body mass = 70.9 ± 12.6 kg; height = 171.7 ± 11.9 cm; $\dot{V}O_{2Peak}$ = 40.54 ± 6.82 $mL\bullet kg^{-1}\bullet min^{-1}$) performed an incremental test to exhaustion and 4, 8 min, submaximal constant power output exercises designed to elicit positive slope coefficients for $\dot{V}O_2$, HR, and RPE vs.

time relationships. The GET, VT, and RCP were determined from the incremental test while PWC_{HRT}, $PWC_{\dot{V}O_2}$, and $PWC_{\dot{V}O_2}$ were determined using the mathematical model of deVries et al. (36). The $PWC_{\dot{V}O_2}$, PWC_{HRT}, and PWC_{OMNI} threshold values were significantly less than GET, VT, and RCP, which suggested they were within the moderate exercise intensity domain. The findings of this study further supported the application of the mathematical model of deVries (1982) to perceptual ratings and suggested that mechanisms related to afferent feedback associated with sympathetic activation, temperature changes, and motor unit recruitment may underlie $\dot{V}O_2$, HR, and RPE responses at a non-fatiguing exercise intensity.

Dantas et al. (31)

The purpose of this study was to estimate the RPE values that corresponded to two $(La^{-})_b$ training zone boundaries (2 and 4 mmol• L^{-1}) in moderately trained runners using an adaptation of the Borg scale (Borg CR-10 scale). Ninety-five runners (89 men and 6 women, mean ± SD; age = 40.2 ± 7.0 yr; body mass = 70.1 ± 8.2 kg; height = 175.3 ± 7.2 cm) performed a single test session, which consisted of a submaximal incremental running test on a treadmill. Each submaximal run consisted of 4 stages, the first of which was set at 70% of the runners average competition speed, followed by increases of 1.5 km• h^{-1} every four minutes. Blood samples were collected between each 30 s state for the calculation of $(La^{-})_b$ and RPE was collected during the last 20 s of each stage. The RPE values that corresponded to 2 and 4 mmol• L^{-1} $(La^{-})_b$ were determined by linear regression. RPE was strongly correlated (r = 0.82) with $(La^{-})_b$ training zones. It was reported that RPE could be accurately estimated at each of the $(La^{-})_b$ tested using the