Perceptual and Physiological Fatigue Thresholds during Cycle Ergometry

Kristen C. Cochrane¹, Terry J. Housh¹, Haley C. Bergstrom², Nathaniel D. M. Jenkins¹, Glen O. Johnson¹, Richard J. Schmidt¹, Joel T. Cramer¹

¹Department of Nutrition and Health Sciences, Human Performance Laboratory, University of Nebraska-Lincoln, Lincoln, NE, ²Department of Kinesiology and Health Promotion, University of Kentucky, Lexington, KT

ABSTRACT

Cochrane KC, Housh TJ, Bergstrom HC, Jenkins NDM, Johnson GO, Schmidt RJ, and Cramer JT. Perceptual and Physiological Fatigue Thresholds during Cycle Ergometry. JEPonline 2014;17(5): 95-107. Thirteen subjects (mean ± SD age: 21.8 ± 2.6 yrs) performed an incremental cycling test and 4, 8-min submaximal rides (65 to 80% of VO2 peak) to: (a) compare power outputs and relative intensities that corresponded to the gas exchange threshold (GET), ventilatory threshold (VT), respiratory compensation point (RCP), physical working capacity (PWC) at oxygen consumption PWCVO2, heart rate (PWCHRT), and rating of perceived exertion (PWCOMNI) thresholds; and (b) examine the relationships among the fatigue thresholds and the exercise intensity domains. The RCP (184 ± 47 W) was significantly (P ≤ 0.0033) greater than the GET (142 ± 38 W), VT (143 ± 40 W), PWCVO2 (106 ± 34 W), PWCHRT (108 ± 34 W), and PWCOMNI (112 ± 34 W). The GET and VT were significantly greater than the PWCVO2, PWCHRT, and PWCOMNI, but there were no differences among the PWCVO2, PWCHRT, and PWCOMNI. These findings suggest that the PWCVO2, PWCHRT, and PWCOMNI fell within the moderate intensity domain, and share a common physiological mechanism that was different from those associated with the GET, VT, and RCP.

Key Words: Exercise Intensity, Power Output, Perception of Effort, Aerobic Evaluation
INTRODUCTION

Fatigue thresholds such as the lactate threshold, gas exchange threshold (GET), ventilatory threshold (VT), onset of blood lactate accumulation, physical working capacity (PWC) at the fatigue threshold (PWC-FT), PWC at the heart rate threshold (PWC-HRT), PWC at the oxygen consumption threshold (PWC-VO₂), PWC at the rating of perceived exertion threshold (PWC-RPE), electromyography (EMG) fatigue threshold (EMG-FT), and the respiratory compensation point (RCP) have been used to differentiate fatiguing from non-fatiguing work (13,14,20), demarcate the exercise intensity (moderate, heavy, and severe) domains (3,4,14,15,22,23,26,35), identify the onset of metabolic acidosis (10,29), prescribe exercise intensity (1,8), and examine the mechanisms associated with neuromuscular fatigue (18,20,37). The problem is that these fatigue thresholds are derived from various measures including gas exchange parameters, heart rate (HR), blood lactate, VO₂, or the EMG signal. Hence, more often than not these fatigue thresholds result in different exercise intensities that reflect different physiological mechanisms of fatigue. For example, the GET, VT, and RCP are determined from gas exchange parameters (VCO₂, Vₑ, and VO₂) that reflect fatigue-related metabolic activity (15). Typically, there is no difference between the intensities at the GET and VT, but both are less than the RCP (2,5,15). The PWC-FT (13) is estimated using EMG fatigue curves, and the PWC-RPE (7) is based on subjective ratings of perceived exertion (Borg or OMNI-Leg scale) that reflect the relative “hardness” of the exercise bout (19). Recently, Bergstrom et al. (3) found that the PWC-FT was 17% greater than the GET, and the PWC-RPE was not significantly different from the RCP. Mielke et al. (22), however, reported a close agreement between the PWC-RPE and GET. Thus, the exercise intensities that define specific fatigue thresholds are dependent upon the unique physiological and/or perceptual responses associated with the onset of fatigue.

The PWC-VO₂, PWC-HRT, and PWC-RPE tests utilize the mathematical model that deVries et al. (13) used to estimate the EMG fatigue threshold (EMG-FT). The EMG-FT is based on EMG amplitude versus time relationships from three or four fatiguing work bouts at different power outputs. The power outputs are plotted as a function of the slope coefficients for the EMG fatigue curves, with the y-intercept defined as the EMG-FT. Thus, theoretically, the EMG-FT represents the maximal power output that can be maintained with no evidence of neuromuscular fatigue (i.e., a slope coefficient of zero for the EMG amplitude vs. time relationship) (13). For the PWC-VO₂, PWC-HRT, and PWC-RPE tests, VO₂, HR, and RPE replace EMG amplitude in the mathematical model. Thus, in theory, during continuous cycle ergometry, the PWC-VO₂, PWC-HRT, and PWC-RPE represent the maximal power outputs associated with “steady state” VO₂, HR, and RPE responses, respectively.

Comparisons among fatigue thresholds can be used to examine the physiological and psychological mechanisms that underlie the onset of fatigue. For example, Bergstrom et al. (4) compared the times to exhaustion and power outputs associated with the PWC-Borg (PWC-RPE based on the Borg scale), GET, and RCP during cycle ergometry. It was reported (4) that the PWC-Borg was greater than the GET but similar to the RCP, which suggested that similar mechanisms may underlie both the ventilatory response at RCP and the perception of effort at the PWC-Borg. In contrast, Mielke et al. (22) reported that the PWC-Borg and PWC-OMNI (PWC-RPE based on the OMNI scale) did not differ from the GET, PWC-VO₂, or PWC-HRT, which indicated that there may be similarities among the perceptual, metabolic, and physiological responses within the moderate intensity domain. Furthermore, Miller et al. (23) found that there were no significant differences in power outputs among the GET, PWC-VO₂, and PWC-HRT. Thus, there is conflicting evidence regarding the specific mechanisms associated with the onset of fatigue and the perception of effort during fatiguing cycling exercise. Furthermore, no previous study has simultaneously compared the PWC-OMNI to fatigue thresholds based on gas exchange (GET and RCP), ventilation (VT), and physiological (HR and VO₂) parameters during cycle ergometry.
Therefore, the purpose of this study was: (a) to compare the power outputs and relative exercise intensities defined by the peak oxygen consumption rate (%VO₂ peak) that corresponded to the GET, VT, RCP, PWC-VO₂, PWC-HRT, and PWC-OMNI; and (b) to examine the relationships among the fatigue thresholds and exercise intensity domains (moderate, heavy, and severe). Based on the findings of previous studies (22,23,35), it was hypothesized that there would be differences in power outputs and/or %VO₂ peak values among the GET, VT, RCP, PWC-VO₂, PWC-HRT, and PWC-OMNI (4,15,22,23). In addition, it was hypothesized that the GET, VT, PWC-VO₂, PWC-HRT, and PWC-OMNI would demarcate the moderate from the heavy exercise intensity domains and share a common physiological mechanism, while the RCP would demarcate the heavy and severe domains, and reflect a mechanism of fatigue that was different from the other fatigue thresholds (3,4,15,22).

METHODS

Subjects
Six male and 7 female subjects (Table 1) volunteered for this study. The subjects were moderately trained (34), and none were competitive cyclists. According to the American College of Sports Medicine (34), moderate training includes aerobic activity performed for a minimum of 30 min, 5 times·wk⁻¹. The subjects’ physical activities included running (N = 8), walking and elliptical (N = 3), and cycling (N = 5). This study was approved by the University’s Institutional Review Board for Human Subjects. All subjects completed a health history questionnaire and signed a written informed consent document prior to testing.

Table 1. Descriptive Characteristics of the Subjects (N = 13).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yr)</td>
<td>21.8 ± 2.6</td>
</tr>
<tr>
<td>Body Mass (kg)</td>
<td>70.9 ± 12.6</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>171.7 ± 11.9</td>
</tr>
<tr>
<td>VO₂ Peak (L·min⁻¹)</td>
<td>2.80 ± 1.03</td>
</tr>
<tr>
<td>VO₂ Peak (mL·min⁻¹)</td>
<td>40.54 ± 6.82</td>
</tr>
<tr>
<td>VO₂ Peak (W)</td>
<td>220 ± 63</td>
</tr>
<tr>
<td>PWC-OMNI (RPE)</td>
<td>4 ± 1</td>
</tr>
</tbody>
</table>

Procedures
The subjects visited the laboratory on 5 occasions, with 24 to 48 hrs between visits. During the first visit, the subjects performed an incremental cycle ergometer test to exhaustion for the determination of VO₂ peak, GET, VT, and RCP. During the next four visits, the subjects completed four (one during each visit) randomly ordered, 8-min submaximal, continuous rides at power outputs that ranged from 65 to 80% of the power output at VO₂ peak (range = 70 to 244 W) to determine PWC-VO₂, PWC-HRT, and PWC-OMNI. The power outputs were selected to be low enough so that the subject could
complete the full 8 min, but high enough to result in positive slope coefficients for the VO2, HR, and RPE versus time relationships.

**Determination of VO2 Peak, GET, VT, and RCP**
Each subject performed an incremental test to exhaustion on a calibrated Lode (Corval V3, Groningen, Netherlands) electronically braked cycle ergometer at a pedal cadence of 70 rev·min⁻¹. The ergometer seat height was adjusted so that the subject’s lower limbs were near full extension at the bottom of the pedal revolution. Toe clips were used to maintain pedal contact throughout the test. Each subject wore a nose clip and breathed through a 2-way valve (Hans Rudolph 2700 breathing valve, Kansas City, MO). Expired gas samples were collected and analyzed using a calibrated TrueMax 2400 metabolic cart (Parvo Medics, Sandy, UT). The gas analyzers were calibrated with room air and gases of known concentration prior to all testing sessions. The O2, CO2, and ventilatory parameters were expressed as 30-sec averages (28) and the subjects were fitted with a Polar Heart Watch system (Polar Electro Inc., Lake Success, NY). After 1-min of unloaded cycling, the test began at 50 W and the power was increased by 30 W every 2 min until voluntary exhaustion or the subject’s pedal rate decreased below 70 rev·min⁻¹ for more than 10 sec, despite strong, verbal encouragement. The VO2 peak was defined as the highest 30-sec VO2 value recorded during the test.

The GET, VT, and RCP were determined using the V-slope method described by Beaver et al. (2). The GET, VT, and RCP were defined as the VO2 value corresponding to the intersection of 2 linear regression lines derived separately from the data points below and above the breakpoint in the VCO2 versus VO2, minute ventilation (VE) versus VO2, and VE versus VCO2 relationships, respectively (Figures 1-3). Power outputs from the incremental test were plotted versus VO2 values, and the resulting regression equation was used to estimate the power outputs that corresponded to the GET, VT, and RCP.

![Figure 1. An Example of the Determination of the Gas Exchange Threshold (GET) from the Breakpoint in VCO2 versus VO2 during the Incremental Cycle Ergometer Test for 1 Subject.](image-url)
Figure 2. An Example of the Determination of the Ventilatory Threshold (VT) from the Breakpoint in $V_E$ versus $VO_2$ Relationship during the Incremental Cycle Ergometer Test for 1 Subject.

$VT = 3.60 \text{ (L·min}^{-1})$

Figure 3. An Example of the Determination of the Respiratory Compensation Point (RCP) from the Breakpoint in $V_E$ versus $VCO_2$ Relationship during the Incremental Cycle Ergometer Test for 1 Subject.

$RCP = 4.18 \text{ (L·min}^{-1})$
The PWC-VO₂, PWC-HRT, and PWC-OMNI thresholds were determined from the four, submaximal 8-min work bouts (22,23,35). The seat height, toe clips, and warm up procedures were the same as for the incremental test. The PWC-VO₂, PWC-HRT, and PWC-OMNI thresholds were determined using the protocols from previous studies (22,23,35). For the determination of PWC-OMNI, the OMNI picture (0-10) scale with 0 representing “extremely easy” and 10 representing “extremely hard” was presented following standardized instructions (22,30). The subjects were asked to give a rating of perceived exertion during the last 10 sec of each min during the 8-min submaximal work bouts, while VO₂ and HR values were recorded as 30-sec averages during each min. The values for the first 3 min of each work bout were discarded to account for the initial metabolic and cardiac adjustments to each power output (22,23,35). The rates of rise in VO₂, HR, and RPE as a function of time (linear slope coefficients) were calculated for each of the four, 8-min submaximal work bouts for each subject. The power outputs were then plotted as a function of the slope coefficients for the VO₂ versus time, and HR versus time, and RPE versus time relationships (4,22,23,35). The PWC-VO₂, PWC-HRT, and PWC-OMNI were defined as the y-intercepts of the power output versus slope coefficient (VO₂ vs. time, HR vs. time, and RPE vs. time) plots (22,23,35).

Statistical Analyses
Separate one-way repeated measures ANOVAs were used to determine if there were differences among the mean values for the power outputs, percent peak power outputs (%PP-output), and percent of VO₂ peak (%VO₂ peak) associated with GET, VT, RCP, PWC-VO₂, PWC-HRT, and PWC-OMNI (Table 2). Post-hoc paired t tests with Bonferonni correction were used for post-hoc analyses. An alpha level of P≤0.0033 was used for all analyses (0.05/15 = 0.0033). A zero-order correlation matrix (Table 3) was used to determine the significant (P≤0.05) relationships among the fatigue thresholds. The analysis was conducted using Statistical Package for the Social Sciences software (Version 21.0, SPSS, Chicago, IL).

<table>
<thead>
<tr>
<th></th>
<th>Power Output (W)</th>
<th>% Peak Power Output</th>
<th>%VO₂ Peak</th>
</tr>
</thead>
<tbody>
<tr>
<td>GET</td>
<td>142 ± 38*</td>
<td>65 ± 9*</td>
<td>69.1 ± 6.3*</td>
</tr>
<tr>
<td>VT</td>
<td>143 ± 40*</td>
<td>65 ± 7*</td>
<td>70.8 ± 5.5*</td>
</tr>
<tr>
<td>RCP</td>
<td>184 ± 47</td>
<td>84 ± 10</td>
<td>87.4 ± 4.8</td>
</tr>
<tr>
<td>PWC-VO₂</td>
<td>106 ± 34*</td>
<td>48 ± 8*</td>
<td>53.7 ± 6.7*</td>
</tr>
<tr>
<td>PWC-HRT</td>
<td>108 ± 34*</td>
<td>50 ± 13*</td>
<td>55.0 ± 11.7*</td>
</tr>
<tr>
<td>PWC-OMNI</td>
<td>112 ± 34*</td>
<td>51 ± 7*</td>
<td>56.2 ± 4.9*</td>
</tr>
</tbody>
</table>

*Significantly less than RCP at Bonferonni alpha of P≤0.0033
†Significantly less than GET, VT, and RCP at Bonferonni alpha of P≤0.0033
Table 3. Zero-order Correlation Matrix for the Power Outputs Associated with the Gas Exchange Threshold (GET), Ventilatory Threshold (VT), Respiratory Compensation Point (RCP), Physical Working Capacity at the OMNI Threshold (PWC-OMNI), PWC at the Oxygen Consumption Threshold PWC-VO₂, and PWC at the Heart Rate Threshold (PWC-HRT).

<table>
<thead>
<tr>
<th></th>
<th>GET</th>
<th>VT</th>
<th>RCP</th>
<th>PWC-OMNI</th>
<th>PWC-VO₂</th>
<th>PWC-HRT</th>
</tr>
</thead>
<tbody>
<tr>
<td>GET</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VT</td>
<td>0.97</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RCP</td>
<td>0.97</td>
<td>0.93</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PWC-OMNI</td>
<td>0.89</td>
<td>0.87</td>
<td>0.90</td>
<td>1.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PWC-VO₂</td>
<td>0.83</td>
<td>0.84</td>
<td>0.80</td>
<td>0.94</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>PWC-HRT</td>
<td>0.81</td>
<td>0.79</td>
<td>0.76</td>
<td>0.81</td>
<td>0.79</td>
<td>1.00</td>
</tr>
</tbody>
</table>

r(df=11) = 0.55, P≤0.05

RESULTS

The mean ± SD values for the GET, VT, RCP, PWC-VO₂, PWC-HRT, and PWC-OMNI are presented in Table 2. The r² values for the VO₂, HR, and RPE versus time relationships during the 4, 8-min work bouts to determine the PWC-VO₂, PWC-HRT, and PWC-OMNI ranged from 0.02 – 0.99, 0.14 – 0.99, and 0.50 – 0.97, respectively. The r² values for the power output vs. slope coefficient relationships (for VO₂ vs. time, HR vs. time, and RPE vs. time) ranged from 0.50 – 0.99, 0.14 – 0.99, and 0.25 – 0.99, respectively. The results of the one-way repeated measures ANOVA indicated that there were significant differences among the mean power outputs, (%PP-output), and %VO₂ peak that corresponded to the six thresholds (Table 2).

Post-hoc paired t tests with Bonferroni correction showed that the mean power outputs, %PP-output, and %VO₂ peak at RCP were significantly (P<0.0033) greater than the GET, VT, PWC-VO₂, PWC-HRT, and PWC-OMNI (Table 2). The GET and VT were not significantly different. The GET and VT were significantly greater than the PWC-VO₂, PWC-HRT, and PWC-OMNI, but there were no differences among the PWC-VO₂, PWC-HRT, and PWC-OMNI. In addition, the RCP was the highest for each subject. Furthermore, the fatigue thresholds were inter-correlated at r = 0.76 – 0.97 (Table 3). The individual threshold (GET, VT, RCP, PWC-VO₂, PWC-HRT, and PWC-OMNI) values for each subject are plotted in Figure 4.
DISCUSSION

The subjects in the present study were moderately fit (34) with a range of VO2 peak values of 1.2 to 4.9 L·min⁻¹ (30.56 to 55.06 mL·kg⁻¹·min⁻¹) (Table 1). The mean VO2 peak, GET, VT, and RCP values were 2.80 ± 1.03 L·min⁻¹, 1.97 ± 0.62 L·min⁻¹, 2.03 ± 0.63 L·min⁻¹, and 2.52 ± 0.75 L·min⁻¹, respectively. These GET and VT values (69.1 ± 6.3 % and 70.8 ± 5.5% of VO2 peak) were typical of those previously reported for untrained to moderately trained (54-75% VO2 peak) subjects (7,10,33). The RCP occurred at 87.4 ± 4.8% of VO2 peak, which was similar to that reported by Bergstrom et al. (4) and typical of healthy subjects (10).

The PWC-VO2 (23), PWC-HRT (35), and PWC-RPE (22) are based on the mathematical model of deVries et al. (13) for determining the EMG-FT. The PWC-VO2 and PWC-HRT are estimated using oxygen consumption (VO2) and HR responses, respectively, while the PWC-RPE can be estimated using either the OMNI (30) or Borg RPE scale (6). These thresholds rest on the assumption that there are positive, linear relationships for VO2, HR, or RPE versus time as well as power output versus slope coefficient during continuous, fatiguing, 8-min cycle ergometer work bouts (13,22,23, 35). In the present study, the r² values for the VO2, HR, and OMNI RPE versus time relationships ranged from 0.10 - 0.97 and the power output versus slope coefficient relationships ranged from 0.25-0.99. These findings were consistent with those of Miller et al. (23), Wagner et al. (35), Mielke et al. (22), and Bergstrom et al. (4) who reported coefficients of determination for the VO2, HR, and RPE (OMNI and Borg scales) versus time, and power output versus slope coefficient relationships that ranged from r²
The current findings supported the application of the mathematical model of deVries (13) for estimating the PWC-VO₂, PWC-HRT, and PWC-OMNI.

In the present study, there was no significant difference between the GET and VT, but both were less than the RCP (Table 1). These findings are consistent with previous studies (15,27,32) that reported the GET and VT demarcate the moderate from heavy exercise intensity domains (2,17). Although there is conflicting evidence (19), it has traditionally been suggested that the GET results from the production of excess CO₂ due to lactic acid buffering and the VT is the breakpoint in ventilation in response to excess CO₂ (Figure 2) (2,29,36). The RCP, however, demarcates the heavy from severe exercise intensity domains (5,12). It is defined by a non-linear increase in the $V_E$ versus $VCO_2$ relationships during an incremental exercise test (2). It has been suggested that the mechanism underlying the dissociation of $V_E$ from $VCO_2$ at the RCP is related to the stimulation of peripheral chemoreceptors by elevated levels of interstitial and/or arterial potassium [K⁺] (11,25). Thus, the mean differences among fatigue thresholds in the current study supported previous findings that have suggested that different physiological mechanisms underlie the GET and VT (metabolic acidosis) versus the RCP (hyperkalemia).

In the present study, the power outputs that corresponded to the PWC-VO₂, PWC-HRT, and PWC-OMNI were significantly less than the GET and VT and, therefore, within the moderate exercise intensity domain (4,5,15). These findings were not consistent with previous studies (4,22) that have reported PWC-VO₂, PWC-HRT, and PWC-OMNI values that were greater than or equal to the GET. For example, Mielke et al. (22) reported no mean differences among the GET, PWC-VO₂, PWC-HRT, PWC-OMNI, and PWC-Borg, and found that the PWC-OMNI was more highly correlated with the GET, PWC-VO₂, and PWC-HRT than was the PWC-Borg. The authors (22) hypothesized that the PWC-OMNI, which is based on the OMNI-Leg scale, is more specific to fatigue of the legs than is the PWC-Borg, which provides an assessment of overall body fatigue (22). Furthermore, the differences among the fatigue thresholds and their associations with GET, VT, and RCP between the current study and previous studies (4,22,23,35) may be attributable to differences in testing protocols.

Mielke et al. (22) and Bergstrom et al. (4) determined the PWC-VO₂, PWC-HRT, and PWC-OMNI from rides to exhaustion at power outputs (85 to 105% VO₂ peak) that were greater than those used in the current study. However, in the present study, as well as the previous studies (23,35), 8-min non-exhaustive rides were used to estimate the PWC-VO₂, PWC-HRT, and PWC-OMNI. Thus, the magnitudes of the slope coefficients for the VO₂, HR, and RPE versus time relationships used to determine the PWC-VO₂, PWC-HRT, and PWC-OMNI may have been affected by the intensities and durations of the work bouts as well as their exhaustive versus non-exhaustive natures. For example, the exhaustive rides of Mielke et al. (22) ranged from 8 to 20 min, while those of Bergstrom et al. (4) were all less than 10 min in duration and resulted in slope coefficients for the RPE, VO₂, and HR versus time relationships that were greater than those in the present study. Thus, it is possible that the relationships among the fatigue thresholds and estimations of PWC-VO₂, PWC-HRT, and PWC-OMNI were affected by differences in rates of increases in RPE, VO₂, and HR across time during the 8-min non-exhaustive rides used in the present study versus the exhaustive rides used in previous studies (4,22).

Theoretically, PWC-VO₂, PWC-HRT, and PWC-OMNI represent the maximal exercise intensities that can be maintained continuously without increases in VO₂ (8), HR (10), and RPE (22), respectively. However, during moderate intensity exercise (i.e., 50 to 75% VO₂ peak), there are slight increases in VO₂ (called the O₂ drift) and HR (called the cardiovascular drift) that Coyle and Gonzalez-Alonso (9) suggested result from increases in core temperature and/or fatigue-induced increases in sympathetic activation. Therefore, it is likely that continuous work bouts at the PWC-VO₂ and PWC-HRT in the
present study would not result in true zero slope coefficients for the VO₂ and HR versus time relationships, but rather small increases in VO₂ of less than approximately 200 mL (15) and HR of less than or equal to 0.1 beats·min⁻¹ (31). Wagner et al. (35) found that 1-hr rides at the PWC-HRT resulted in a mean increase in HR (0.066 beats·min⁻¹) that Rohmert (31) suggested could be maintained across an 8-hr workday. Thus, although the precise pattern and magnitude of responses for RPE at the PWC-OMNI is unknown, it may include a “drift” upward similar to that expected for the PWC-VO₂ and PWC-HRT (9,23,35).

CONCLUSIONS

The results of the present study supported the application of the mathematical model of deVries et al. (13) for estimating the PWC-VO₂, PWC-HRT, and PWC-OMNI (22,23,35). However, the relative intensities of these fatigue thresholds differed from those previously reported (4,22). These results indicate that the estimations of PWC-VO₂, PWC-HRT, and PWC-OMNI may be influenced by differences in the testing protocol. Hence, the use of exhaustive versus non-exhaustive work bouts, heavy versus severe exercise intensities, and shorter (1 to 10 min) versus longer (8 to 20 min) duration constant power output rides must be taken into consideration.

In the present study, the PWC-VO₂, PWC-HRT, and PWC-OMNI were less than the GET and VT, and, therefore, were within the moderate intensity domain. These findings suggest that different physiological mechanisms underlie the various fatigue thresholds. At exercise intensities similar to the present study, it was hypothesized that afferent feedback associated with increases in the subjects’ core temperature, sympathetic activation, and motor unit recruitment may underlie VO₂, HR, and RPE responses seen at PWC-VO₂, PWC-HRT, and PWC-OMNI (9,22,23). Other studies have suggested that sensory information fed from the central command links the sensations from locomotor and respiratory muscles, thus contributing to the integration of the perception of effort during aerobic exercise (17,21,24).

However, the GET and VT are mediated by metabolic acidosis (15). The RCP, which was greater than all of the other fatigue thresholds, may be related to hyperkalemia. Future studies should investigate the effects of exhaustive versus non-exhaustive work bouts as well as the intensities and durations of the constant power output rides on the VO₂, HR, and RPE responses versus time relationships. Furthermore, additional research is needed to determine the effect of changes in core temperature and sympathetic activation on the VO₂, HR, and RPE responses during continuous work bouts at the PWC-VO₂, PWC-HRT, and PWC-OMNI.

Address for correspondence: Kristen C. Cochrane, Department of Nutrition and Health Science, University of Nebraska-Lincoln, Lincoln, NE, USA, 68583, Email: kcochrane@unl.edu

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