Published in final edited form as:

Int J Sports Med. 2016 September ; 37(10): 831–837. doi:10.1055/s-0042-103029.

Cross-validation of Peak Oxygen Consumption Prediction Models from OMNI Perceived Exertion

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Abstract

This study cross-validated statistical models for prediction of peak oxygen consumption using ratings of perceived exertion from the Adult OMNI Cycle Scale of Perceived Exertion. Seventy-four participants (men: n=36; women: n=38) completed a graded cycle exercise test. Ratings of perceived exertion for the overall body, legs, and chest/breathing were recorded each test stage and entered into previously developed 3-stage peak oxygen consumption prediction models. There were no significant differences ($p>0.05$) between measured and predicted peak oxygen consumption from ratings of perceived exertion for the overall body, legs, and chest/breathing within men (mean±standard deviation: 3.16±0.52 vs. 2.92±0.33 vs. 2.90±0.29 vs. 2.90±0.26 L·min⁻¹) and women (2.17±0.29 vs. 2.02±0.22 vs. 2.03±0.19 vs. 2.01±0.19 L·min⁻¹) participants. Previously developed statistical models for prediction of peak oxygen consumption based on subpeak OMNI ratings of perceived exertion responses were similar to measured peak oxygen

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disclosures

The other authors note no conflicts.

consumption in a separate group of participants. These findings provide practical implications for the use of the original statistical models in standard health-fitness settings.

Keywords

prediction equations; cycle ergometry; undifferentiated and differentiated RPE; exercise testing

Introduction

Evaluation of peak oxygen consumption ($\text{VO}_{2\text{peak}}$) using graded exercise tests aids in the development of exercise prescriptions to improve cardiorespiratory fitness. Direct assessment of $\text{VO}_{2\text{peak}}$ is considered the criterion measure of cardiorespiratory fitness [1], however such a laboratory-based measure is not always practical. In certain health-fitness settings where it is not appropriate for an individual to undergo peak testing conditions, subpeak exercise testing to predict $\text{VO}_{2\text{peak}}$ can be employed. Typically, heart rate (HR) responses are used as predictor variables in these statistical models [4, 10, 12]. However, HR for use in cardiorespiratory prediction models may be affected by many factors, in particular the error in assessment and the need for a steady state HR at each test stage. For example, determination of the $\text{beats}\cdot\text{min}^{-1}$ using radial palpation is commonly employed in standard health-fitness settings. Human error could occur such as missing a beat during palpation or extrapolating the $\text{beats}\cdot\text{min}^{-1}$ from a shorter duration of assessment (e.g., 10 or 15 seconds) rather than obtaining HR for an entire minute [16]. Additionally, the estimation of HR using wired or telemetric monitoring equipment (e.g., electrocardiography, torso transmitter devices) may not be available or accurate due to technical difficulties [15]. Predictions of $\text{VO}_{2\text{peak}}$ are also often based on age-predicted maximal HR equations. This could result in inaccurate $\text{VO}_{2\text{peak}}$ predictions, given recent evidence suggesting substantial estimation error when calculating maximal HR from an individual's age [23, 30]. Thus, alternative methods are needed to accurately predict peak aerobic power when peak exercise testing is not practical and use of HR alone for prediction is problematic.

Ratings of perceived exertion (RPE) can be defined as a measure of the subjective intensity of effort, strain, discomfort, and/or fatigue experienced during exercise [24]. RPE are numbers from category rating scales that indicate an individual's perceptual exertion level during physical activity [26]. The rationale for the application of RPE in practice is based on the interdependence of the physiological and perceptual responses through the full spectrum of exercise levels from rest to maximal intensity [26]. An individual's perception of effort can be measured as either undifferentiated or differentiated RPE. According to Pandolf [25], undifferentiated RPE for the overall body (O) generally defines "...an individual's integration of various physiological sensations that have different subjective weightings." Differentiated RPE are linked to specific cardiorespiratory and peripheral signals of effort for the chest/breathing (C) and the legs (L), respectively [27]. Measures of both undifferentiated and differentiated RPE are useful in health-fitness settings, where both global and anatomically regionalized perceptual signals are used to assess exertional tolerance and prescribe exercise intensity.

RPE have been used to predict $\text{VO}_{2\text{peak}}$ in a variety of patient populations employing prediction methods using data derived from load incremented exercise tests and perceptually regulated exercise protocols [3, 7–9, 19]. This application recognizes that for most test protocols RPE increases concurrently with HR and oxygen uptake as exercise intensity increases. Thus, RPE assessed during subpeak exercise tests can be used in statistical models to predict $\text{VO}_{2\text{peak}}$. Recently, subpeak RPE-O, L, and C measured by the Adult OMNI Cycle Scale [28] were used to predict $\text{VO}_{2\text{peak}}$ in healthy college-age men and women [19]. Findings indicated the statistical models were accurate in predicting $\text{VO}_{2\text{peak}}$ when compared to measured $\text{VO}_{2\text{peak}}$ where data were derived from the same participants for which the models were developed. However, analyses involving predicted and measured $\text{VO}_{2\text{peak}}$ derived from independent samples is needed to determine if previously validated models can accurately translate to standard health-fitness settings.

Thus, the primary aim of the current study was to cross-validate statistical models for prediction of $\text{VO}_{2\text{peak}}$ using subpeak RPE derived from the Adult OMNI Cycle Scale during cycle ergometry. Secondary aims were to evaluate the accuracy of $\text{VO}_{2\text{peak}}$ predictions from the previously developed statistical models using only HR and combined RPE and HR (RPE/HR) with measured $\text{VO}_{2\text{peak}}$. We hypothesized that $\text{VO}_{2\text{peak}}$ predicted from subpeak RPE-O, L, and C using previously developed statistical models would be similar to measured $\text{VO}_{2\text{peak}}$ in an independent cohort of participants.

Methods

Study design

A cross-sectional, single test design was employed. The protocol was approved (Approval number PRO08060266) by the local institutional review committee and all participants provided written informed consent prior to testing. Participants were instructed to refrain from alcohol consumption and strenuous physical activity 24 hours prior to testing, and to avoid food and caffeine intake as well as tobacco use 3 hours prior to testing. The study was conducted within the ethical standards of the International Journal of Sports Medicine [14].

Participants

Men and women participants were recruited using university-wide advertisements. Participants were included if they were 18–35 years of age and sedentary or recreationally active. Recreational activity was defined as participating in light to moderate intensity aerobic exercise up to 4 days a week for a total of 160 minutes.

Peak exercise test and outcome assessments

Prior to exercise testing, height (cm) was assessed with a standard stadiometer attached to a physician's scale (Detecto, Webb City, MO). Body weight (kg) and body fat (%) was measured with a bioelectrical impedance analyzer (Tanita Corp. of America Inc., model TBF-300A, Arlington Heights, IL). Additionally, standard instructions for the Adult OMNI Cycle Scale of Perceived Exertion (Figure 1) were read to participants prior to testing as previously reported [19]. Exercise tests were performed on a cycle ergometer (Lode B.V. Medical Technology, Corival model 844, Groningen, The Netherlands) using an incremental

protocol with a pedal rate of 50 revolutions·min⁻¹ signaled by an electronic metronome (Franz Mfg. Co. Inc., model XB-700, New Haven, CT). Using the graded protocol previously reported, the test began at a power output of 75 W and increased 50 W every two minutes for men. A similar graded protocol was used for women, however, the starting power output was 50 W and increased by 25 W every two minutes. RPE for O, L, and C were measured at 90 seconds of each two minute stage in counterbalanced order. A wireless monitor (Polar Electro, Kempele, Finland) was used to measure HR (beats·min⁻¹) immediately after the measurement of RPE. Oxygen consumption (L·min⁻¹ and mL·kg⁻¹·min⁻¹) measurements were obtained from 1:45 to 2:00 minutes of each exercise stage using an automated respiratory-metabolic system (Parvo Medics, TrueOne 2400, Salt Lake City, UT). Standardized verbal encouragement was given to all subjects at the end of each stage. The test was terminated if the participant could no longer maintain the pedal cadence within 10 revolutions·min⁻¹ of the target value for 10 consecutive seconds or self-terminated the test due to exhaustion. The following physiological and perceptual criteria for achieving VO_{2peak} was also evaluated in men and women participants: 1) a plateau in absolute (<150 mL·min⁻¹) or relative (<2.1 mL·kg⁻¹·min⁻¹) VO₂ with increasing work rates, 2) HR within ±10 beats·min⁻¹ of age-predicted maximal HR (220-age), 3) a respiratory exchange ratio (VCO₂:VO₂) = 1.15, and 4) an OMNI RPE ≤ 8.

Sample size

A similar sample size employed in a prior study [19] that initially developed and validated the VO_{2peak} statistical models was used for the current trial. Thus, a sample of 40 men and 40 women participants was *a priori* chosen to evaluate the accuracy of the previously developed statistical models using measured VO_{2peak} as the criterion variable. The target sample size was increased to a maximum of 44 participants for each sex to account for potential unevaluable exercise test data (e.g., dropouts, technical error, outliers).

Statistical analyses

The simultaneous multiple linear regression equations previously developed [19] were used to predict VO_{2peak} from subpeak RPE and HR responses for the men and women participants in the current trial. Subpeak variables were entered into the 7 separate statistical models (Table 1) that had been previously developed for each sex. A within-subjects analysis of variance (ANOVA) was performed on measured and predicted VO_{2peak} within each sex. Significance was set *a priori* at $\alpha=0.05$. If a significant main effect was found among measured and predicted VO_{2peak} within each sex, *post-hoc* pairwise comparisons were performed using the Bonferroni adjustment. Pearson correlations were used to determine the relation between measured VO_{2peak} and the predicted VO_{2peak} from each statistical model. Assumptions of parametric statistics were evaluated prior to analyses. Statistical analyses were performed with IBM SPSS Statistics (v22.0. Armonk, NY).

Results

Initial screenings and outliers

Eighty-four participants (men: n=40; women: n=44) initially gave their consent to participate. Following screenings and evaluation of outliers, four men and six women

participants were removed from the trial. Assumptions of parametric statistics for 74 participants (men: $n=36$; women: $n=38$) were evaluated prior to analyses. Table 2 provides baseline characteristics for participants used in the final analyses as well as those who were deemed outliers and removed from the trial. Table 3 lists physiological and RPE responses to the cycle exercise test for those participants who were used in the final analyses.

For men, the Shapiro-Wilk test indicated that data were not normally distributed ($p<0.05$) for predicted VO_{2peak} from the RPE-L and RPE-C statistical models. Data were normally distributed for measured VO_{2peak} and all predicted VO_{2peak} values for women participants. A natural log transformation of VO_{2peak} data was applied to women participant values only. Distribution of VO_{2peak} values predicted from subpeak RPE-L was normalized but not predicted values using the RPE-C ($p=0.01$) statistical model. Additionally, sphericity for the main effect in both men and women was not met ($p<0.001$). Thus, Greenhouse-Geisser adjustments were used for interpretation of the main effect prior to any *post-hoc* pairwise comparisons.

Primary and secondary analyses

Figure 2 presents arithmetic means and standard deviations for measured and predicted VO_{2peak} for men. The within-subjects ANOVA based on log-transformed data for men demonstrated significant differences among measured and predicted VO_{2peak} ($F_{0.22, 1.22}=6.46$, $p<0.001$). For the primary analysis, *post-hoc* pairwise comparisons within the men participants showed no differences between measured VO_{2peak} and VO_{2peak} predicted from RPE-O, L, and C ($p>0.05$). When using subpeak HR as predictor variables in the statistical models for men, there were no differences between measured VO_{2peak} and the predicted VO_{2peak} from subpeak HR, combined RPE-O/HR, and RPE-C/HR ($p>0.05$) models. However, the VO_{2peak} predicted from combined subpeak RPE-L/HR was lower than measured VO_{2peak} in the men participants ($p=0.036$).

For women participants, the within-subject ANOVA indicated there were significant differences among the measured and predicted VO_{2peak} ($F_{2.57, 95.17}=12.84$, $p<0.001$). The measured VO_{2peak} was not significantly different than predicted VO_{2peak} for RPE statistical models ($p>0.05$). There were no significant differences between measured VO_{2peak} and predicted VO_{2peak} from the subpeak HR and the combined subpeak RPE-L/HR and RPE-C/HR models for women ($p>0.05$). *Post-hoc* pairwise comparisons indicated a higher measured VO_{2peak} compared to predicted VO_{2peak} when data were derived from combined subpeak RPE-O/HR ($p=0.003$). Results of measured and predicted VO_{2peak} for women are depicted in Figure 3.

Correlation and limits of agreement analyses and achievement of peak oxygen consumption

Correlation analyses for men participants indicated significantly moderate to strong positive relations between log-transformed measured VO_{2peak} and predicted VO_{2peak} from individual RPE statistical models (RPE-O: $r=0.50$, $p=0.002$; RPE-L: $r=0.57$, $p<0.001$; RPE-C: $r=0.41$, $p=0.013$). The analysis demonstrated a moderate significant relation for measured VO_{2peak} and VO_{2peak} predicted from the HR model ($r=0.36$, $p=0.03$). Moderate positive relations

were found between measured $\text{VO}_{2\text{peak}}$ and combined RPE-O/HR ($r=0.49$, $p=0.002$) and RPE-C/HR ($r=0.42$, $p=0.011$) models, with a significantly strong relation found with the RPE-L/HR ($r=0.56$, $p<0.001$) statistical model. For women participants, the analysis indicated no significant relation between measured $\text{VO}_{2\text{peak}}$ and $\text{VO}_{2\text{peak}}$ predicted from RPE-O ($r=0.11$, $p=0.512$), RPE-L ($r=0.20$, $p=0.235$), or RPE-C ($r=0.14$, $p=0.409$). The statistical model that predicted $\text{VO}_{2\text{peak}}$ from subpeak HR demonstrated a moderate positive relation with measured $\text{VO}_{2\text{peak}}$ ($r=0.43$, $p=0.008$). Moderate positive relations were found between measured $\text{VO}_{2\text{peak}}$ and predicted $\text{VO}_{2\text{peak}}$ from RPE-O/HR ($r=0.36$, $p=0.027$), RPE-L/HR ($r=0.41$, $p=0.01$), and RPE-C/HR ($r=0.40$, $p=0.014$) statistical models. An analysis of the Limits of Agreement (LOA) was evaluated between predicted and measured $\text{VO}_{2\text{peak}}$ for both men and women and results are depicted in Table 4 [6]. Finally, all participants voluntarily terminated the cycle exercise test or demonstrated an inability to maintain pedal cadence in addition to satisfying at least one additional physiological or perceptual criteria indicative of the attainment of $\text{VO}_{2\text{peak}}$. Table 5 describes the specific indicators met for men and women participants.

Discussion

The primary purpose of the present study was to cross-validate previously developed $\text{VO}_{2\text{peak}}$ prediction models using subpeak RPE-O, RPE-L, and RPE-C measured with the OMNI Perceived Exertion Scale during cycle ergometry for young adult men and women. Twelve of the 14 (85.71%) previously developed RPE and HR models accurately predicted $\text{VO}_{2\text{peak}}$ in an independent cohort of men and women participants, providing strong evidence for the potential use of these equations in health-fitness settings.

Several studies have evaluated the use of subpeak RPE for predicting $\text{VO}_{2\text{peak}}$ for participants and patients performing a graded exercise test [7, 11, 18]. The current study however cross-validated predictive applications of the Adult OMNI Cycle Scale of Perceived Exertion. This metric has gained considerable momentum as a valid tool for application in sport and clinical and health-fitness settings for both children and adults performing a variety of exercise modalities [5, 17, 20, 22, 28, 29, 31, 32]. The OMNI scale spans a narrow numerical category range of 0–10 and provides both verbal and pictorial descriptors throughout the perceptual response range to further refine an individual's ability to rate their perceptions of effort [28, 29]. The current cross-validation study as well as previous studies that have developed RPE-based methods to predict $\text{VO}_{2\text{peak}}$, provide additional verification for the use of perceived exertion in defining peak cardiorespiratory fitness levels.

The results of the present trial suggest that both subpeak RPE and HR may be valid for predictive purposes, as they are linearly related throughout graded exercise from low to maximal levels. Unexplained variance may have caused the mismatch of measured $\text{VO}_{2\text{peak}}$ vs. $\text{VO}_{2\text{peak}}$ predicted from subpeak RPE-L/HR for men and RPE-O/HR for women. However, differences in the arithmetic means of measured and predicted $\text{VO}_{2\text{peak}}$ were minimal for men ($0.27 \text{ L}\cdot\text{min}^{-1}$) and women ($0.21 \text{ L}\cdot\text{min}^{-1}$), in addition to demonstrating significant positive moderate and strong relations and a lack of wide 95% LOA when compared to the other $\text{VO}_{2\text{peak}}$ predictions. The inclusion criteria for level of fitness and type of physical activity regularly performed were contingent on participant self-report of

previous and current physical activity patterns for both the current trial and the study that validated the $\text{VO}_{2\text{peak}}$ prediction models. Self-reported physical activity is said to be adversely affected by unreliable reporting or natural variations in behavior over time [2]. Thus, trials developing predictive models should provide more specific criteria or direct testing to determine fitness levels of participants, as the current equations may only be valid for a specific subset of college-age men and women. The current study participants may have underestimated the amount of exercise they typically accomplish, thus the non-significant but lower predicted $\text{VO}_{2\text{peak}}$ values. Our findings however agree with the conclusions of the initial validation study [19] that $\text{VO}_{2\text{peak}}$ statistical models using subpeak RPE or HR alone, in addition to combinations of RPE/HR, could potentially be used in standard health-fitness settings.

From a practical application perspective, the models could potentially be employed in health-fitness, sport, and selected clinical settings to estimate $\text{VO}_{2\text{peak}}$. Many of these facilities may lack automated and often expensive respiratory-metabolic analyzers. Thus, the translation of laboratory-based statistical models that employ subpeak RPE to predict oxygen uptake could be useful, in particular if HR assessment is difficult to obtain or inaccurate. Once the predicted $\text{VO}_{2\text{peak}}$ is determined using the statistical models, the exercise prescription of clients could be refined, specifically outlining the optimal range of subpeak exercise intensity based on the predicted peak value. An important next step however, is to determine the accuracy of the models for predicting $\text{VO}_{2\text{peak}}$ in a standard health-fitness setting. The current trial was based in a laboratory setting to evaluate the efficacy of the prediction models, where the optimal exercise setting and standardized testing procedures were assured. Future trials should evaluate the translation of the statistical models to standard health-fitness settings to ensure their feasibility and effectiveness in healthy college-age men and women participants where variability in the assessment of outcomes could differ. Additionally, the validation of relative $\text{VO}_{2\text{peak}}$ prediction models for weight bearing exercise (such as treadmill walking and running) is needed to account for the range of potential modalities that individuals may use for the completion of physical activity.

An important aspect of this cross-validation study was the evaluation of $\text{VO}_{2\text{peak}}$ prediction models that included submaximal undifferentiated and differentiated RPE responses. With various exercise modalities, the anatomical region of the most active skeletal muscle may provide the dominant (i.e. highest) RPE throughout an exercise test [13]. This differentiated RPE response (e.g. RPE-L during cycle exercise) may provide a more accurate prediction of peak aerobic power since local muscle fatigue is a primary reason for test termination. It has been suggested that the dominant differentiated RPE signal may explain a greater amount of the variance in $\text{VO}_{2\text{peak}}$ prediction in comparison to undifferentiated RPE [13]. However, the results of the current investigation suggest undifferentiated and differentiated RPE responses are similar in their ability to accurately predict $\text{VO}_{2\text{peak}}$. It may be of no consequence which RPE are obtained during a submaximal exercise test, as the critical requisite step is to ensure the undifferentiated or differentiated RPE are used with the appropriate statistical model.

This cross-validation trial provides strong evidence for the use of OMNI RPE to predict $\text{VO}_{2\text{peak}}$. Further validation studies from other research laboratories are needed to ensure the statistical models derived from subpeak OMNI RPE are efficacious for predicting $\text{VO}_{2\text{peak}}$.

in the participant cohort that was studied. However, the current findings demonstrate the utility of RPE for predicting $\text{VO}_{2\text{peak}}$, resulting in accurate assessment of cardiorespiratory fitness when true peak exercise testing is not feasible or warranted in young adult men and women.

Acknowledgments

Preliminary data for this project were presented at the American College of Sports Medicine's 56th Annual Meeting [21]. The current study was supported by a University of Pittsburgh School of Education Research grant. Dr. Mays is principal investigator of two National Institutes of Health grants funded by the National Heart, Lung, and Blood Institute (K01HL115534) and the Mountain West Clinical Translational Research - Infrastructure Network National Institute of General Medical Sciences (under the parent award 1U54GM104944). Dr. Mays also receives funding from Providence Medical Group for the conduct of quality improvement projects. Neither of these grants or consultant work are related to the current study.

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Figure 1. Adult OMNI Cycle Scale of Perceived Exertion. Used with permission from Lippincott, Williams, and Wilkins. *Med Sci Sports and Exerc* 2004; 36(1): 102–108 [28].

Figure 2. Measured and predicted peak oxygen consumption: derived from subpeak OMNI ratings of perceived exertion, heart rate, and combined OMNI ratings of perceived exertion/heart rate for men (n=36)

Data are presented as mean±standard deviation. *Significantly lower than measured peak oxygen consumption, $p=0.036$.

C, ratings of perceived exertion for the chest/breathing; C/HR, combined ratings of perceived exertion for chest/breathing and heart rate statistical model; HR, heart rate statistical model; L, ratings of perceived exertion for the legs statistical model; L/HR, combined ratings of perceived exertion for the legs and heart rate statistical model; O, ratings of perceived exertion for the overall body statistical model; O/HR, combined ratings of perceived exertion for the overall body and heart rate statistical model; VO_{2peak}, peak oxygen consumption.

Figure 3. Measured and predicted peak oxygen consumption: derived from subpeak OMNI ratings of perceived exertion, heart rate, and combined OMNI ratings of perceived exertion/heart rate for women (n=38)

Data are presented as mean±standard deviation. *Significantly different than measured peak oxygen consumption, $p=0.003$.

C, ratings of perceived exertion for the chest/breathing; C/HR, combined ratings of perceived exertion for chest/breathing and heart rate statistical model; HR, heart rate statistical model; L, ratings of perceived exertion for the legs statistical model; L/HR, combined ratings of perceived exertion for the legs and heart rate statistical model; O, ratings of perceived exertion for the overall body statistical model; O/HR, combined ratings of perceived exertion for the overall body and heart rate statistical model; VO_{2peak}, peak oxygen consumption.

Table 1

Previously validated peak oxygen consumption prediction equations for sedentary and recreationally active, college-aged men and women participants.

Sex	Subpeak Variables	VO _{2peak} Prediction Models
Men	RPE	O 3.87–(0.034·O1)+(0.012·O2)–(0.162·O3)
		L 3.92+(0.005·L1)–(0.009·L2)–(0.149·L3)
		C 3.70–(0.043·C1)+(0.054·C2)–(0.161·C3)
	HR	6.118–(0.007·HR1)+(0.017·HR2)–(0.029·HR3)
	RPE/HR	O/HR 5.503+(0.004·O1)+(0.039·O2)–(0.154·O3)–(0.012·HR1)+(0.023·HR2)–(0.022·HR3)
		L/HR 5.704+(0.04·L1)+(0.006·L2)–(0.132·L3)–(0.008·HR1)+(0.014·HR2)–(0.019·HR3)
		C/HR 5.810–(0.068·C1)+(0.113·C2)–(0.153·C3)+(0.000·HR1)+(0.017·HR2)–(0.029·HR3)
Women	RPE	O 2.57–(0.073·O1)+(0.128·O2)–(0.171·O3)
		L 2.61–(0.006·L1)+(0.086·L2)–(0.162·L3)
		C 2.51–(0.028·C1)+(0.064·C2)–(0.130·C3)
	HR	4.337+(0.001·HR1)+(0.000·HR2)–(0.015·HR3)
	RPE/HR	O/HR 3.583–(0.082·O1)+(0.069·O2)–(0.095·O3)+(0.007·HR1)–(0.003·HR2)–(0.011·HR3)
		L/HR 3.740–(0.043·L1)+(0.089·L2)–(0.123·L3)+(0.008·HR1)–(0.004·HR2)–(0.010·HR3)
		C/HR 3.692–(0.052·C1)+(0.045·C2)–(0.078·C3)+(0.008·HR1)–(0.002·HR2)–(0.013·HR3)

C, ratings of perceived exertion for the chest/breathing; HR, heart rate; L, ratings of perceived exertion for the legs; O, ratings of perceived exertion for the overall body; RPE, ratings of perceived exertion; 1=subpeak variables corresponding to Stage 1; 2=subpeak variables corresponding to Stage 2; 3=subpeak variables corresponding to Stage 3

Note the slash sign (/) indicates a combination of subpeak ratings of perceived exertion and heart rate predictor variables for use in the peak oxygen consumption prediction models.

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Table 2

Baseline characteristics for participants used in the final analyses and outliers removed from final analyses.

Characteristics	Final Analyses		Outliers removed	
	Men (n=36)	Women (n=38)	Men (n=3)	Women (n=3)
Age (yrs)	21.67±3.09	21.58±3.24	20.00±1.00	24.00±1.00
Height (cm)	177.13±5.48	164.56±5.38	185.00±5.27	165.67±8.96
Weight (kg)	75.93±8.95	64.11±9.19	88.83±8.20	75.00±4.01
BMI (kg·m ⁻²)	24.19±2.25	23.66±3.19	25.97±3.71	27.37±2.80
Body fat (%)	14.25±4.25	26.30±6.62	14.70±3.75	29.17±8.72
VO _{2peak} (L·min ⁻¹)	3.16±0.52	2.17±0.29	5.02±0.40	3.08±0.16
VO _{2peak} (mL·kg ⁻¹ ·min ⁻¹)	41.92±7.25	34.22±4.73	55.97±8.46	41.13±1.99

Data are presented as mean±standard deviation. BMI, body mass index; VO_{2peak}, peak oxygen consumption.

Table 3

Physiological and ratings of perceived exertion variables measured during the load incremented cycle exercise test.

Sex	Variables	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6	Stage 7	Stage 8
Men	n (%)	36 (100.00)	36 (100.00)	36 (100.00)	35 (97.22)	19 (52.78)	3 (8.33)	0 (0.00)	0 (0.00)
	VO ₂ (L·min ⁻¹)	1.20±0.18	1.75±0.21	2.32±0.30	2.93±0.45	3.36±0.46	3.20±0.86	--	--
	HR (beats·min ⁻¹)	113.53±11.72	135.22±13.33	157.33±13.87	174.63±12.47	186.53±9.16	191.00±4.58	--	--
	O	1.11±0.95	3.08±1.71	5.89±2.00	8.17±1.65	9.26±1.15	9.33±0.58	--	--
	L	1.19±0.98	3.67±1.96	6.64±1.85	8.77±1.59	9.53±0.96	9.67±0.58	--	--
Women	C	1.14±1.07	3.19±1.67	5.72±1.85	7.80±1.89	9.00±1.49	8.33±1.53	--	--
	n (%)	38 (100.00)	38 (100.00)	38 (100.00)	37 (97.37)	33 (86.84)	11 (29.73)	1 (2.63)	1 (2.63)
	VO ₂ (L·min ⁻¹)	0.94±0.13	1.16±0.15	1.47±0.18	1.79±0.23	2.12±0.23	2.29±0.28	2.61	2.78
	HR (beats·min ⁻¹)	117.53±14.33	134.61±15.39	153.42±15.16	*168.50±14.43	179.12±12.81	176.36±14.94	171.00	176.00
	O	1.03±1.08	2.71±1.68	4.79±1.96	6.89±1.79	8.58±1.46	9.18±0.98	7.00	9.00
	L	1.18±1.11	3.08±1.73	5.16±1.90	7.30±1.78	8.85±1.12	9.55±0.82	9.00	10.00
	C	1.24±1.30	2.92±1.75	5.00±1.97	6.97±1.77	8.45±1.80	8.82±1.33	7.00	7.00

Continuous data are presented as mean±standard deviation.

* Missing heart rate for 1 woman participant during Stage 4, thus data are for n=36 only.

C, ratings of perceived exertion for chest/breathing; HR, heart rate; L, ratings of perceived exertion for the legs; O, ratings of perceived exertion for the overall body; VO₂, oxygen uptake.

Table 4

Limits of agreement analysis for measured and predicted peak oxygen consumption for men and women.

Sex	Prediction model	Mean of measured and predicted $\text{VO}_{2\text{peak}}$ ($\text{L}\cdot\text{min}^{-1}$)	Difference of measured and predicted $\text{VO}_{2\text{peak}}$ ($\text{L}\cdot\text{min}^{-1}$)	95% LOA ($\text{L}\cdot\text{min}^{-1}$)
Male	O	3.04	0.25	± 0.92
	L	3.03	0.26	± 0.88
	C	3.03	0.26	± 0.96
	HR	3.11	0.10	± 1.00
	O and HR	3.09	0.16	± 0.92
	L and HR	3.03	0.27	± 0.90
	C and HR	3.06	0.21	± 1.00
Female	O	2.10	0.15	± 0.70
	L	2.10	0.14	± 0.64
	C	2.09	0.16	± 0.66
	HR	2.16	0.02	± 0.56
	O and HR	2.07	0.21	± 0.60
	L and HR	2.18	-0.02	± 0.56
	C and HR	2.11	0.13	± 0.58

LOA, limits of agreement; O, overall-body; L, legs; C, chest/breathing; HR, heart rate; $\text{VO}_{2\text{peak}}$, peak oxygen consumption.* Note the limits of agreement represents 2 standard deviations from the mean difference between measured and predicted $\text{VO}_{2\text{peak}}$.

Table 5

Physiological and perceptual indicators for attainment of peak oxygen consumption for both men and women participants.

Criteria	Men Met criteria, n (%)	Women Met criteria, n (%)
Plateau absolute VO_2 ($<150 \text{ ml}\cdot\text{min}^{-1}$)	7 (19.4)	7 (18.4)
Plateau relative VO_2 ($<2.1 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$)	10 (27.8)	6 (15.8)
HR ($\pm 10 \text{ beats}\cdot\text{min}^{-1}$ of age-predicted maximal HR)	9 (25.0)	14 (36.8)
RER ($\text{VCO}_2\cdot\text{VO}_2^{-1}$)	31 (86.1)	28 (73.7)
OMNI RPE (O, L, or C 8)	36 (100.0)	38 (100.0)
OMNI RPE (O, L, or C 9)	33 (91.7)	37 (97.4)

C, chest/breathing; HR, heart rate; L, legs; O, overall-body; RER, respiratory exchange ratio; RPE, ratings of perceived exertion; VCO_2 , carbon dioxide production; VO_2 , oxygen consumption

Note blood lactate was not assessed in the current trial.