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PREDICTION OF VO_{2PEAK} USING OMNI RATINGS OF PERCEIVED EXERTION FROM A SUBMAXIMAL CYCLE EXERCISE TEST

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Summary

The primary aim of this study was to develop statistical models to predict peak oxygen consumption (VO_{2peak}) using OMNI Ratings of Perceived Exertion measured during submaximal cycle ergometry. Men (mean $\pm$ standard error: 20.90 ± 0.42 yrs) and women (21.59 ± 0.49 yrs) participants ($n = 81$) completed a load-incremented maximal cycle ergometer exercise test. Simultaneous multiple linear regression was used to develop separate VO_{2peak} statistical models using submaximal ratings of perceived exertion for the overall body, legs, and chest/breathing as predictor variables. VO_{2peak} ($L \cdot min^{-1}$) predicted for men and women from ratings of perceived exertion for the overall body (3.02 ± 0.06 ; 2.03 ± 0.04), legs (3.02 ± 0.06 ; 2.04 ± 0.04) and chest/breathing (3.02 ± 0.05 ; 2.03 ± 0.03) were similar with measured VO_{2peak} (3.02 ± 0.10 ; 2.03 ± 0.06 , $ps > .05$). Statistical models based on submaximal OMNI Ratings of Perceived Exertion provide an easily administered and accurate method to predict VO_{2peak} .

Ratings of perceived exertion are commonly used in health-fitness and clinical settings to assess exercise tolerance and to prescribe and regulate therapeutic training intensities. The perception of physical exertion is defined as the subjective intensity of effort, strain, discomfort, and/or fatigue that is experienced during physical exercise (Noble & Robertson, 1996). Ratings of perceived exertion can be assessed using category metrics, most notably the Borg 15 Category (6–20) Perceived Exertion Scale which was initially validated in the 1970's to assess exertional perceptions in adults performing aerobic exercise (Borg, 1971).

There are a number methodological and semantic limitations of the Borg 15 Category (6–20) Perceived Exertion Scale (Robertson & Noble, 1997; Robertson, Goss, Boer, Peoples, Foreman, Dabayebbeh, *et al.*, 2000), particularly an exertional response range (e.g., 6–20) that some patients may find confusing when rating their respective level of exertion. In response to these limitations, the OMNI Picture System of Perceived Exertion was developed and systematically validated within the past several decades using a numerical response range of 0–10, with verbal and pictorial descriptors positioned throughout the perceptual range. The initial development of the psychometric format of the scale used a “four part sequential paradigm” that focused on children. The findings of this initial investigation indicated that the OMNI Scale was a valid perceived exertion metric (Robertson, *et al.*, 2000). Follow-on investigations demonstrated response validity for ratings of perceived for the overall body, legs, and chest/breathing derived from the OMNI Picture System of Perceived Exertion for adults performing a number of modalities including weight bearing, partial weight bearing, and non-weight bearing aerobic exercise as well as resistance exercise (Robertson, Goss, Rutkowski, Lenz, Dixon, Timmer, *et al.*, 2003; Robertson, Goss, Dube, Rutkowski, Dupain, Brennan, *et al.*, 2004; Utter, Robertson, Green, Suminski, McAnulty, & Nieman, 2004; Lagally & Robertson, 2006; Nakamura, Perandini, Okuno, Borges, Bertuzzi, & Robertson, 2009; Mays, Goss, Schafer, Kim, Nagle-Stilley, & Robertson, 2010). Thus, the various formats of the OMNI Rating of Perceived Exertion Scales are practical and valid category metrics, appealing to adult populations because of the comparative small numerical response range typical of everyday ratings (e.g., 0–10). In addition, the scale was formatted using a valid semantic and visual differentiation analysis for both the verbal and pictorial descriptors of exertion. The practical applications of the OMNI Scale are numerous, given that the category metric is inexpensive and easy to administer in standard healthcare settings (e.g., fitness centers).

Determination of an individual's peak oxygen consumption ($\text{VO}_{2\text{peak}}$) derived from a graded exercise test can be used as the basis for developing exercise prescriptions to improve cardiovascular fitness. Assessment of $\text{VO}_{2\text{peak}}$ is generally recognized as one of the best methods for establishing the upper physiological limit of oxygen transport and utilization systems. However, for reasons of participant burden, safety, and cost, these peak tests are not always practical in clinical and health-fitness settings. Alternatively, submaximal exercise testing is often used to predict $\text{VO}_{2\text{peak}}$ to avoid the high participant burden and clinical risk of peak testing. Heart rate responses during the submaximal tests are typically the primary predictor variables (Astrand & Rhyming, 1954; Golding, Meyers, & Sinning, 1989; Fairbairn, Blackie, McElvaney, Wiggs, Pare, & Pardy, 1994). However, there are a number of limitations when using submaximal heart rate to predict $\text{VO}_{2\text{peak}}$ that merit the use of alternative variables in statistical models. Models using submaximal heart rate assume steady state at each stage of the exercise test and often employ an age adjusted normative value for maximal heart rate (American College of Sports Medicine, 2010). This steady state assumption may not be consistently met, potentially leading to inaccurate predictions of $\text{VO}_{2\text{peak}}$. Additionally, age-predicted maximal heart rate may not precisely indicate an individual's true maximal heart rate (Tanaka, Monahan, & Seals, 2001). As such, exercise prescriptions that are based on submaximal predictions using age-predicted maximal heart rate may fall outside of the optimal training intensities, decreasing the

effectiveness of the conditioning stimulus. Statistical models to predict $\text{VO}_{2\text{peak}}$ using submaximal ratings of perceived exertion may not be influenced by the physiological factors that limit statistical models using heart rate. In contrast to the statistical limitations of physiological based models, there are distinct advantages of prediction models based on ratings of perceived exertion such as ease of assessment during exercise, low cost of instrumentation and decreased participant burden. These methodological advantages provide merit for the use of perceived exertion category metrics in clinical and health-fitness settings to predict $\text{VO}_{2\text{peak}}$.

Concurrent validity of perceived exertion metrics is evidenced by the concomitant increase in ratings of perceived exertion and criterion physiological variables such as heart rate and oxygen consumption measured during load-incremented exercise protocols. Thus, ratings of perceived exertion assessed during load-incremented submaximal exercise tests have the potential to be used in statistical models to predict $\text{VO}_{2\text{peak}}$. A number of studies have demonstrated the utility of the Borg 15 Category Scale in prediction of maximal oxygen consumption or $\text{VO}_{2\text{peak}}$ from ratings of perceived exertion determined during field tests (Davies, Rowlands, & Eston, 2008), perceptually regulated exercise bouts (Eston, Lamb, Parfitt, & King, 2005; Eston, Faulkner, Mason, & Parfitt, 2006; Faulkner, Parfitt, & Eston, 2007; Eston, Lambrick, Sheppard, & Parfitt, 2008; Morris, Lamb, Hayton, Cotterrell, & Buckley, 2010; Al-Rahamneh & Eston, 2011b; Eston, Evans, Faulkner, Lambrick, Al-Rahamneh, & Parfitt, 2012) and graded exercise tests (Dunbar & Bursztyn, 1996; Okura & Tanaka, 2001; Faulkner & Eston, 2007; Coquart, Lemaire, Dubart, Douillard, Luttenbacher, Wibaux, *et al.*, 2009; Lambrick, Faulkner, Rowlands, & Eston, 2009; Coquart, Eston, Grosbois, Lemaire, Dubart, Luttenbacher, *et al.*, 2010; Al-Rahamneh & Eston, 2011a; Al-Rahamneh, Faulkner, Byrne, & Eston, 2011). Faulkner and Eston (2007) reported an accurate prediction of maximal oxygen consumption using ratings of perceived exertion for the overall body (Borg 15 Category Scale) determined during a load-incremented submaximal cycle ergometer protocol involving men and women of high and low fitness levels. Using individual linear regression analysis, submaximal oxygen consumption was extrapolated to maximal oxygen consumption from exercise intensities corresponding to ratings of perceived exertion for the overall body of 13, 15, and 17. Results indicated that predicted maximal oxygen consumption from submaximal ratings of perceived exertion for the overall body of 13, 15, and 17 (mean $\pm$ standard deviation: 42.1 ± 12.5 , 43.4 ± 11.5 , $44.2 \pm 11.3 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) were similar to measured maximal oxygen consumption ($43.3 \pm 10.0 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) and were not influenced by sex or fitness level. Additionally, ratings of perceived exertion for the overall body distributed as a positive linear function when correlated with oxygen uptake for both men and women participants ($r = 0.965$ to 0.975). These findings indicated that ratings of perceived exertion assessed during graded submaximal exercise tests may be a valid tool for predicting $\text{VO}_{2\text{peak}}$.

To date, OMNI Ratings of Perceived Exertion have not been used as predictor variables in models to estimate $\text{VO}_{2\text{peak}}$. It is important to determine the validity of a perceived exertion metric using both submaximal differentiated and undifferentiated ratings of perceived exertion as predictor variables when developing statistical models. The exercise modality may influence a participant's perceptual response, particularly the differentiated perceptual

signal arising from the activated anatomical region. Thus a comprehensive understanding of the accuracy of prediction models for global and regional measures of exertion are needed. Thus, the primary aim of the present study was to develop separate statistical models using submaximal ratings of perceived exertion for the overall body, legs, and chest/breathing derived from the Adult OMNI Cycle Scale to predict $\text{VO}_{2\text{peak}}$ in young adult men and women. A secondary aim was to compare $\text{VO}_{2\text{peak}}$ predicted from models that used ratings of perceived exertion to predictions derived from models that employed heart rate separately and combined ratings of perceived exertion/heart rate. It was hypothesized that $\text{VO}_{2\text{peak}}$ predicted from submaximal ratings of perceived exertion for the overall body, legs, and chest/breathing would be similar to measured $\text{VO}_{2\text{peak}}$ in both men and women.

Method

Participants

Eighty-one sedentary to recreationally active ($<150 \text{ min} \cdot \text{week}^{-1}$ of exercise), college-aged men ($n = 40$) and women ($n = 41$) volunteered for the study. Characteristics of the men and women were as follows (mean $\pm$ standard error), age (yrs): 20.90 ± 0.42 , 21.59 ± 0.49 ; height (cm): 176.98 ± 0.95 , 165.42 ± 0.91 ; weight (kg): 77.15 ± 1.73 , 69.00 ± 2.54 ; body fat (%): 13.77 ± 3.03 , 29.42 ± 1.29 . Testing was conducted in the Center for Exercise and Health-Fitness Research at the University of Pittsburgh. The University of Pittsburgh Institutional Review Board approved all procedures for the study. Participants provided written informed consent prior to testing. Participants were instructed to avoid alcohol consumption and strenuous physical activity 24 hours prior to testing as well as to not consume food and caffeine or to use tobacco products 3 hours prior to testing (American College of Sports Medicine, 2010).

Procedures and Outcomes

Maximal cycle ergometer exercise test—A cross-sectional, perceptual estimation paradigm was used in the present study. Exercise tests were completed on an electronically braked cycle ergometer (Corival model 844, Lode, Groningen, Netherlands) using a load-incremented protocol. The exercise test began at a power output of 75 W for men and 50 W for women. Power output for each two min exercise stage increased 50 W for men and 25 W for women. Pedal cadence ($50 \text{ revolutions} \cdot \text{min}^{-1}$) was signaled by an electronic metronome (Model XB-700, Franz Mfg. Co. Inc., New Haven, CT, USA). Standard verbal encouragement was given at the end of each stage. The test was terminated (a) by the participant due to exhaustion or (b) by the investigator when the participant could not maintain pedal cadence within ten $\text{revolutions} \cdot \text{min}^{-1}$ of the target rate for ten consecutive seconds.

Respiratory-metabolic and heart rate measurements—An open circuit respiratory-metabolic system (TrueOne 2400, Parvo Medics, Salt Lake City, UT, USA) was used to measure oxygen uptake ($\text{L} \cdot \text{min}^{-1}$ and $\text{mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$, STPD) in 15 second intervals. The last two oxygen uptake measurements for each stage were averaged and used in data analyses. A standard respiratory valve (Model 2700, Hans Rudolph, Inc., Kansas City, MO, USA) with an adult mouthpiece was used for all respiratory-metabolic measurements. The

respiratory-metabolic system was calibrated before each maximal cycle ergometer exercise test according to the manufacturer's specifications. A wireless monitoring system (Model FS3C, Polar Electro, Kempele, Finland) was used to measure heart rate ($\text{beats} \cdot \text{min}^{-1}$) each stage. The heart rate measurement at the end of each stage of the cycle ergometer exercise test was used in data analyses.

Ratings of perceived exertion—The definition of perceived exertion as well as standard instructions and anchoring procedures for the Adult OMNI Cycle Scale (Fig. 1) were read to participants prior to the start of the maximal cycle ergometer exercise test. The following standard definition of perceived exertion was read to participants: “The perception of physical exertion is defined as the subjective intensity of effort, strain, discomfort, and/or fatigue felt during exercise” (Noble & Robertson, 1996). A visually interfaced cognitive procedure was used to establish low and high perceptual scale anchors (Robertson, *et al.*, 2000). The following was read to participants prior to the test:

“We would like you to exercise on a cycle ergometer. Please use the numbers on this scale to tell us how your body feels when you are exercising. Please look at the person at the bottom of the hill (indicate the cyclist is located at the base of the incline) who is just starting to exercise. If you feel like this person when you are exercising, the exertion will be *Extremely Easy*. In this case, your rating should be the number 0. Now look at the person who is exhausted at the top of the hill (indicate the cyclist is located at the peak of the incline). If you feel like this person when exercising, the exertion will be *Extremely Hard*. In this case, your rating should be the number 10. If your exertion feels somewhere between *Extremely Easy* (0) and *Extremely Hard* (10), then give a number between 0 and 10. We will ask you to point to the number that tells how your whole body feels, a number that tells how your legs feel and a number that tells how your chest and breathing feel. There is no right or wrong answer. Use both the pictures and the words to help select a number. Use any of the numbers to tell how you feel when you are exercising” (Robertson, *et al.*, 2004).

Ratings of perceived exertion for the overall body, legs, and chest/breathing were measured in counterbalanced order at 90 seconds of each stage. The Adult OMNI Cycle Scale was in full view of the participant throughout the cycle ergometer exercise test. Participants were asked to point to their level of exertion as the mouthpiece prohibited verbal responses.

Statistical Analyses

Descriptive data were calculated as mean $\pm$ standard error. Simultaneous multiple linear regression was performed with $\text{VO}_{2\text{peak}}$ as the dependent variable and ratings of perceived exertion for the overall body, legs, chest/breathing, and heart rate measured at three submaximal cycle ergometer exercise stages as independent variables. Separate statistical models were developed from ratings of perceived exertion for the overall body, legs, chest/breathing, and heart rate within each sex grouping. Additionally, multiple regression analyses were used to develop separate statistical models that incorporated combined variables as follows: 1) ratings of perceived exertion for the overall body/heart rate, 2) ratings of perceived exertion for the legs/heart rate and 3) ratings of perceived exertion for

chest/breathing/heart rate. Assumptions of multiple linear regression were examined to assess the stability of the statistical models. Within-subjects analyses of variance were performed to examine the differences between measured $\text{VO}_{2\text{peak}}$ and predicted $\text{VO}_{2\text{peak}}$ derived from the ratings of perceived exertion, heart rate, and combined ratings of perceived exertion/heart rate statistical models for each sex. To find the pattern of differences among measured and predicted $\text{VO}_{2\text{peak}}$, *post hoc* pairwise comparisons were performed using the Bonferroni adjustment. Assumptions of analyses of variance were examined prior to analyses. Significance was set at $\alpha = 0.05$. Statistical analyses were performed with the IBM SPSS statistics package (Version 20.0, IBM Corp., Armonk, NY, USA).

Sample size was determined for the statistical power required for a multiple regression with a maximum of six predictor variables. This power requirement was the most rigorous of the statistical models employed and as such required the greatest number of participants for each contrast cell. Using a power = 0.80, $\alpha = 0.05$ and an effect size = 0.90, it was determined that a minimum of $n = 23$ men and $n = 23$ women were required for significant model development.

Results

Regression diagnostics and data screening

Intercorrelations of $\text{VO}_{2\text{peak}}$ predictor variables within the separate ratings of perceived exertion for the overall body, legs, and chest/breathing statistical models were not a concern for both men and women, as the variance inflation factors were not above 10 and tolerance values were not less than 0.1. However, there were multicollinear patterns demonstrated for submaximal heart rate predictor variables for men and women in the separate heart rate statistical models (heart rate Stage 2: variance inflation factor = 12.70 and 10.75; tolerance = 0.079 and 0.093). Additionally, for men the heart rate Stage 2 predictor variable demonstrated multicollinear patterns in the combined ratings of perceived exertion for the overall body/heart rate (variance inflation factor = 13.18; tolerance = 0.076), legs/heart rate (variance inflation factor = 13.31; tolerance = 0.075) and chest/breathing/heart rate (variance inflation factor = 13.05; tolerance = 0.077) statistical models. Multicollinearity was most frequent in the combined ratings of perceived exertion/heart rate statistical models for women, with variance inflation factors above 10 and tolerance values below 0.1 for the following: 1) ratings of perceived exertion Stage 2, Stage 3, and heart rate Stage 2 predictor variables in the overall body/heart rate model (variance inflation factor = 10.39, 10.60, and 10.79; tolerance = 0.096, 0.094, and 0.093), 2) heart rate Stage 2 predictor in the legs/heart rate model (variance inflation factor = 13.31; tolerance = 0.09), and 3) heart rate Stage 2 predictor in the chest/breathing/heart rate model (variance inflation factor = 10.85; tolerance = 0.092). The assumption of sphericity was not met for the model main effect for either sex (men: Mauchly's $W < 0.001$, $\chi^2(2) = 287.42$, $p < .001$; women: Mauchly's $W < 0.001$, $\chi^2(2) = 296.03$, $p < .001$) thus Greenhouse-Geisser adjustments were used. The assumption of normality was met for measured and predicted $\text{VO}_{2\text{peak}}$ for both men and women except $\text{VO}_{2\text{peak}}$ predicted from submaximal ratings of perceived exertion for the legs for men (Shapiro-Wilk $W = 0.99$, $p = .02$). All other assumptions of multiple regression and analyses of variance were met.

Table 1 lists selected perceptual and physiological responses during submaximal cycle ergometer exercise for men and women. The overall *F-tests* for the separate ratings of perceived exertion for the overall body, legs, and chest/breathing statistical models were significant for both men and women ($ps < .05$). These models, along with their adjusted R^2 values and standard error of estimate (SEE), are presented in Table 2. The overall *F-tests* for the separately developed heart rate statistical models were significant for both men ($F_{3,36} = 3.98, p = .02$) and women ($F_{3,37} = 7.23, p = .001$). The statistical models to predict $\text{VO}_{2\text{peak}}$ ($\text{L} \cdot \text{min}^{-1}$) using submaximal heart rate for men and women were as follows:

Heart rate models

Men:

$$\text{VO}_{2\text{peak}} (\text{L} \cdot \text{min}^{-1}) = 6.118 - (0.007 \cdot \text{HR1}) + (0.017 \cdot \text{HR2}) - (0.029 \cdot \text{HR3})$$

(adjusted $R^2 = 0.187$, SEE = $0.544 \text{ L} \cdot \text{min}^{-1}$)

where HR1, HR2, and HR3 refers to heart rate assessed at Stage 1, 2, and 3.

Women:

$$\text{VO}_{2\text{peak}} (\text{L} \cdot \text{min}^{-1}) = 4.337 + (0.001 \cdot \text{HR1}) + (0.000 \cdot \text{HR2}) - (0.015 \cdot \text{HR3})$$

(adjusted $R^2 = 0.318$, SEE = $0.289 \text{ L} \cdot \text{min}^{-1}$)

where HR1, HR2, and HR3 refers to heart rate assessed at Stage 1, 2, and 3.

The *F-tests* for the combined ratings of perceived exertion/heart rate statistical models developed from the three submaximal exercise stages were also significant for men and women for overall body/heart rate ($F_{6,33} = 4.66, p = .002$; $F_{6,34} = 7.38, p < .001$), the legs/heart rate model ($F_{6,33} = 4.24, p = .003$; $F_{6,34} = 8.95, p < .001$), and the chest/breathing/heart rate model ($F_{6,33} = 3.18, p = .014$; $F_{6,34} = 5.67, p < .001$). The statistical models to predict $\text{VO}_{2\text{peak}}$ developed from combined ratings of perceived exertion/heart rate for men and women are presented below.

Overall body/heart rate models

Men:

$$\text{VO}_{2\text{peak}} (\text{L} \cdot \text{min}^{-1}) = 5.503 + (0.004 \cdot \text{O1}) + (0.039 \cdot \text{O2}) - (0.154 \cdot \text{O3}) - (0.012 \cdot \text{HR1}) + (0.023 \cdot \text{HR2}) - (0.022 \cdot \text{HR3})$$

(adjusted $R^2 = 0.360$, SEE = $0.482 \text{ L} \cdot \text{min}^{-1}$)

where O1, O2, and O3 refers to ratings of perceived exertion for the overall body assessed at Stages 1, 2, and 3 and HR1, HR2, and HR3 refers to heart rate assessed at Stages 1, 2, and 3.

Women:

$$\text{VO}_{2\text{peak}} (\text{L} \cdot \text{min}^{-1}) = 3.583 - (0.082 \cdot \text{O1}) + (0.069 \cdot \text{O2}) - (0.095 \cdot \text{O3}) + (0.007 \cdot \text{HR1}) - (0.003 \cdot \text{HR2}) - (0.011 \cdot \text{HR3})$$

(adjusted $R^2 = 0.489$, SEE = $0.250 \text{ L} \cdot \text{min}^{-1}$)

where O1, O2, and O3 refers to ratings of perceived exertion for the overall body assessed at Stages 1, 2, and 3 and HR1, HR2, and HR3 refers to heart rate assessed at Stages 1, 2, and 3.

Legs/heart rate models

Men:

$$\text{VO}_{2\text{peak}} (\text{L} \cdot \text{min}^{-1}) = 5.704 + (0.041 \cdot \text{L1}) + (0.006 \cdot \text{L2}) - (0.132 \cdot \text{L3}) - (0.008 \cdot \text{HR1}) + (0.014 \cdot \text{HR2}) - (0.019 \cdot \text{HR3})$$

$$(\text{adjusted } R^2 = 0.333, \text{ SEE} = 0.493 \text{ L} \cdot \text{min}^{-1})$$

where L1, L2, and L3 refers to ratings of perceived exertion for the legs assessed at Stages 1, 2, and 3 and HR1, HR2, and HR3 refers to heart rate assessed at Stages 1, 2, and 3.

Women:

$$\text{VO}_{2\text{peak}} (\text{L} \cdot \text{min}^{-1}) = 3.740 + (0.043 \cdot \text{L1}) + (0.089 \cdot \text{L2}) - (0.123 \cdot \text{L3}) + (0.008 \cdot \text{HR1}) - (0.004 \cdot \text{HR2}) - (0.010 \cdot \text{HR3})$$

$$(\text{adjusted } R^2 = 0.544, \text{ SEE} = 0.236 \text{ L} \cdot \text{min}^{-1})$$

where L1, L2, and L3 refers to ratings of perceived exertion for the legs assessed at Stages 1, 2, and 3 and HR1, HR2, and HR3 refers to heart rate assessed at Stages 1, 2, and 3.

Chest/breathing/heart rate models

Men:

$$\text{VO}_{2\text{peak}} (\text{L} \cdot \text{min}^{-1}) = 5.810 - (0.068 \cdot \text{C1}) + (0.0113 \cdot \text{C2}) - (0.153 \cdot \text{C3}) + (0.000 \cdot \text{HR1}) + (0.017 \cdot \text{HR2}) - (0.029 \cdot \text{HR3})$$

$$(\text{adjusted } R^2 = 0.251, \text{ SEE} = 0.522 \text{ L} \cdot \text{min}^{-1})$$

where C1, C2, and C3 refers to ratings of perceived exertion for chest/breathing assessed at Stages 1, 2, and 3 and HR1, HR2, and HR3 refers to heart rate assessed at Stages 1, 2, and 3.

Women:

$$\text{VO}_{2\text{peak}} (\text{L} \cdot \text{min}^{-1}) = 3.692 - (0.052 \cdot \text{C1}) + 0.045 \cdot \text{C2} - (0.078 \cdot \text{C3}) + (0.008 \cdot \text{HR1}) - (0.002 \cdot \text{HR2}) - (0.013 \cdot \text{HR3})$$

$$(\text{adjusted } R^2 = 0.412, \text{ SEE} = 0.268 \text{ L} \cdot \text{min}^{-1})$$

where C1, C2, and C3 refers to ratings of perceived exertion for chest/breathing assessed at Stages 1, 2, and 3 and HR1, HR2, and HR3 refers to heart rate assessed at Stages 1, 2, and 3.

The within-subjects analyses of variance indicated there were no differences among measured $\text{VO}_{2\text{peak}}$ and $\text{VO}_{2\text{peak}}$ predicted from separate ratings of perceived exertion, heart rate, and combined ratings of perceived exertion/heart rate statistical models for men

($F_{2,750, 107,244} = 0.71, p = .54$, partial $\eta^2 = 0.02$). There was, however, a significant main effect among measured $\text{VO}_{2\text{peak}}$ and $\text{VO}_{2\text{peak}}$ predicted from separate ratings of perceived exertion, heart rate, and combined ratings of perceived exertion/heart rate statistical models for women ($F_{3,499,139,948} = 11.76, p < .001$, partial $\eta^2 = 0.23$). Ratings of perceived exertion for the overall body, legs, and chest/breathing statistical models predicted a significantly higher $\text{VO}_{2\text{peak}}$ than that derived from overall body/heart rate models ($ps < .01$) and lower than from the legs/heart rate models ($ps < .01$). There were no significant differences among $\text{VO}_{2\text{peak}}$ predicted from separate ratings of perceived exertion for the overall body, legs, chest/breathing, and heart rate statistical models with measured $\text{VO}_{2\text{peak}}$ for women ($ps = 1.00$). Fig. 2 presents measured and predicted $\text{VO}_{2\text{peak}}$ data for both men and women.

Discussion

The primary aim of this study was to develop statistical models to predict $\text{VO}_{2\text{peak}}$ where independent variables were derived from a load-incremented cycle ergometer exercise test. The findings indicated that predicted $\text{VO}_{2\text{peak}}$ from separate statistical models using ratings of perceived exertion for the overall body, legs, and chest/breathing were similar to measured $\text{VO}_{2\text{peak}}$ in both men and women. Additionally, findings indicated that $\text{VO}_{2\text{peak}}$ predicted from ratings of perceived exertion based statistical models were not different than $\text{VO}_{2\text{peak}}$ predicted from heart rate statistical models. There were differences among measured $\text{VO}_{2\text{peak}}$ and $\text{VO}_{2\text{peak}}$ predicted from separate ratings of perceived exertion for the overall body, legs, and chest/breathing statistical models when compared to the combined ratings of perceived exertion/heart rate statistical model predictions of $\text{VO}_{2\text{peak}}$ for women. From a practical application standpoint, the differences were minimal but the mismatch of these values could be due to unexplained variance. More importantly however, the separate ratings of perceived exertion statistical models predicted $\text{VO}_{2\text{peak}}$ with greater accuracy than all models that included heart rate as a submaximal predictor variable.

The findings from this study are in agreement with other studies that predicted $\text{VO}_{2\text{peak}}$ using ratings of perceived exertion determined by the Borg 15 Category Scale during submaximal cycle exercise (Okura & Tanaka, 2001; Faulkner & Eston, 2007; Coquart, *et al.*, 2009; Lambrick, *et al.*, 2009; Coquart, *et al.*, 2010). Briefly, Lambrick, *et al.* (2009) used a ramped cycle ergometer protocol to compare measured and predicted maximal oxygen consumption in low-fit women participants ($n = 11$). Maximal oxygen consumption was predicted by extrapolating submaximal oxygen uptake measured at a Borg Scale (6–20) rating of perceived exertion of 13. Statistical regression expressed oxygen uptake as a function of ratings of perceived exertion, with maximal oxygen uptake determined as the extrapolated value equivalent to a ratings of 19 and 20. Specifically, the results indicated that measured and predicted values were similar (measured: $30.9 \pm 6.5 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$; predicted (range): 29.6 ± 6.8 to $33.2 \pm 8.3 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$). The study findings indicated maximal oxygen consumption was accurately predicted from the oxygen uptake corresponding to a rating of perceived exertion of 13 (Borg 15 Category Scale) during cycle ergometry in low-fit women. There are similarities between the current and the aforementioned study for predicting $\text{VO}_{2\text{peak}}$ from submaximal ratings of perceived exertion including the use of cycle ergometry in young lower-fit women. However, there are also contrasting methods employed between studies. We developed $\text{VO}_{2\text{peak}}$ prediction models

using a different type of regression analysis approach for both men and women (i.e., simultaneous multiple linear regression) and did not use submaximal oxygen uptake as a predictor variable for the development of statistical models. Additionally, we used a different exercise protocol (i.e., graded exercise test vs. ramp protocol) and also derived ratings of perceived exertion from the Adult OMNI Cycle Scale rather than from the Borg 15 Category Scale. Of importance regarding generalizability of regression findings, the design of the current project as well as the previously mentioned studies employed valid perceived exertion metrics as well as simple and easy to use testing and data analysis procedures (e.g., standard graded and ramp protocol tests, understandable and easy to use prediction equations). These common approaches proved to be accurate and simple, providing a rationale for use of submaximal ratings of perceived exertion to predict $\text{VO}_{2\text{peak}}$ in clinical and health-fitness settings.

The accuracy of statistical models to predict $\text{VO}_{2\text{peak}}$ using ratings of perceived exertion is important in both clinical and health-fitness settings where responses to submaximal exercise tests are often used to estimate $\text{VO}_{2\text{peak}}$. However, as noted previously, many of the existing prediction models employ submaximal heart rate as an independent variable. Such models have many limitations including, but not limited to: 1) assumptions of steady state heart rate at each exercise stage (American College of Sports Medicine, 2010), 2) the linear relation needed between work rate and heart rate throughout the exercise test (Brooks, Fahey, & Baldwin, 2005), 3) inaccurate predictions owing to considerable inter-individual differences of age-predicted maximal heart rate (Londeree & Moeschberger, 1982), 4) potentially greater error of estimating peak aerobic endpoints using submaximal heart rate as predictor variables (Morgan & Borg, 1976; Esco, Olson, Williford, Mugu, Bloomquist, & McHugh, 2012), and 5) medications (e.g., beta-blockades, pseudoephedrine) that affect heart rate (Reybrouck, Amery, & Billiet, 1977; Salerno, Jackson, & Berbano, 2005). The findings of the current study provide additional evidence that ratings of perceived exertion may be an effective alternative to heart rate in developing statistical models to predict $\text{VO}_{2\text{peak}}$ using submaximal exercise responses. This conclusion is based on the psychophysiological properties of category metrics where the terminal rating of perceived exertion is expected to be similar for all clinically normal individuals, i.e. one of the basic tenants of Borg's Range Model (Borg, 1998). In this case, the terminal ratings of perceived exertion may not be adversely affected by the factors that alter heart rate responses to both submaximal and maximal exercise.

An additional limitation to combined ratings of perceived exertion/heart rate models is that a high number of predictor variables (i.e., six predictor variables) will arbitrarily inflate R^2 values. The adjusted R^2 statistic did compensate for the additional predictor variables, resulting in similar explanations of the overall variance of the $\text{VO}_{2\text{peak}}$ predictions among all statistical models. Nevertheless, care must be taken when interpreting the coefficient of determination of a prediction model that employs many predictor variables. Because the combined ratings of perceived exertion/heart rate models are slightly more complex by design, additional mathematical calculations are needed that also require the assessment of both ratings of perceived exertion and heart rate throughout the exercise test. Statistical models using ratings of perceived exertion alone as an independent variable provided not

only an easier, less complicated alternative to prediction models that include heart rate, but also yielded a more accurate prediction of $\text{VO}_{2\text{peak}}$.

There were also several instances in the present findings where the regression coefficients for the statistical models with heart rate as a predictor were “0.000.” Thus, regardless of how high or low the heart rate value assessed during the particular stage, a calculated outcome of zero would occur and not influence the $\text{VO}_{2\text{peak}}$ prediction. From a practical application standpoint, a perceived exertion based model would be useful in the event heart rate is not assessed during a particular stage of the exercise test (e.g., technical error). In this case, the regression coefficient does not affect the rate of change in the $\text{VO}_{2\text{peak}}$ prediction. However, this finding was a potential weakness for statistical models that included heart rate as a predictor, as heart rate at a given absolute submaximal exercise intensity should be inversely related to a participant’s $\text{VO}_{2\text{peak}}$.

Other limitations of both the heart rate and combined ratings of perceived exertion/heart rate statistical models were the high intercorrelations exhibited, particularly between the heart rate predictor variables in the combined ratings of perceived exertion/heart rate statistical models. Typically, multicollinearity does not affect the prediction of $\text{VO}_{2\text{peak}}$ or the overall fit of the models. However, analyses would be difficult if attempting to identify the separate effects of the submaximal predictor variables (e.g., heart rate) on predicted $\text{VO}_{2\text{peak}}$, as these variables are highly related. This affects the stability of the model, ultimately creating interpretation complexity because the prediction of the dependent variable (i.e., $\text{VO}_{2\text{peak}}$) results in regression weights that inadequately reflect the true variable relations (Kraha, Turner, Nimon, Zientek, & Henson, 2012). There are remedial measures for addressing multicollinearity (e.g., removing certain predictor variables, centering). However, the primary aim for this study was to predict $\text{VO}_{2\text{peak}}$ from statistical models based on submaximal ratings of perceived exertion. Multicollinearity was not present within the separate statistical models using submaximal ratings of perceived exertion for the overall body, legs, and chest/breathing for men or women, thus remedial measures were not needed.

In addition to using valid $\text{VO}_{2\text{peak}}$ prediction models, the type of exercise test selected for assessing $\text{VO}_{2\text{peak}}$ should also be considered. The convenience and safety of participants performing maximal exercise tests can be of concern. Maximal exercise tests are often difficult to complete, owing to participant discomfort, pain and general fatigue, all factors that may result in an invalid test (Noonan & Dean, 2000). Risk of adverse cardiovascular events during maximal graded exercise tests for the generally healthy adult population are low, estimated at approximately 1 for every 10,000 patients tested (Gibbons, Blair, Kohl, & Cooper, 1989). However, the risk is much lower for submaximal exercise testing, with event rates 1.9 times lower than that of maximal exercise tests (Juneau, Colles, Theroux, de Guise, Pelletier, Lam, *et al.*, 1992; Fletcher, Balady, Amsterdam, Chaitman, Eckel, Fleg, *et al.*, 2001). The statistical models developed in the present study using OMNI Ratings of Perceived Exertion responses have strong practical application in clinical and health-fitness settings, circumventing patient discomfort and potential safety issues that may arise during maximal exercise testing.

In conclusion, the use of ratings of perceived exertion-based statistical models to predict $\text{VO}_{2\text{peak}}$ appears to be valid and accurate for use with healthy, college-aged participants. Given the advantages of the OMNI Picture System of Perceived Exertion (e.g., low participant and investigator burden, inexpensive instrumentation, visually informative structure compared to the Borg Scale), it is important to establish the prediction model capability of perceived exertion category metrics. This study was the first to use submaximal OMNI Ratings of Perceived Exertion in statistical models to predict $\text{VO}_{2\text{peak}}$. The study findings expand on the existing literature that supports application of OMNI Ratings of Perceived Exertion in clinical and health-fitness settings as an adjunct to heart rate for various exercise-related constructs (e.g., warning of impending test termination, exercise prescriptions). Ratings of perceived exertion for the overall body, legs, or chest/breathing derived from the OMNI Cycle Scale can be used separately for prediction of $\text{VO}_{2\text{peak}}$, ultimately aiding clinicians and healthcare providers in the development of appropriate exercise prescriptions. Future studies are needed to: 1) cross-validate the statistical models developed presently to determine their accuracy for men and women of varying characteristics, 2) determine statistical model accuracy outside of research settings, 3) develop $\text{VO}_{2\text{peak}}$ prediction models from submaximal OMNI Ratings of Perceived Exertion using different exercise modalities and 4) develop and evaluate the accuracy of statistical models to predict relative $\text{VO}_{2\text{peak}}$.

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Fig. 1.
Adult OMNI Cycle Scale (Used by permission from Robertson RJ, Goss FL, Dube J, et al.
Validation of the adult OMNI Scale of Perceived Exertion for cycle ergometer exercise.
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Figs 2.

a and b. Measured Peak Oxygen Consumption and Peak Oxygen Consumption Predicted from each Statistical Model for (a) Men and (b) Women. Data are presented as mean $\pm$ standard error. *Significantly lower than peak oxygen consumption predicted from all other statistical models, $p < .01$; †Significantly higher than measured peak oxygen consumption ($p = .01$) and all other statistical model predictions of peak oxygen consumption ($p < .01$) except the heart rate model ($p = 1.00$); ‡Significantly different than peak oxygen consumption predicted from heart rate, overall body/heart rate, and legs/heart rate statistical

models ($ps < .01$). ■ indicates measured peak oxygen consumption; ■ indicates ratings of perceived exertion statistical models; ■ indicates heart rate statistical model; □ indicates combined ratings of perceived exertion/heart rate statistical models; VO_{2peak} = peak oxygen consumption; O = overall body; L = legs; C = chest/breathing; heart rate = heart rate; O/HR = combined ratings of perceived exertion for overall body and heart rate model; L/HR = combined ratings of perceived exertion for legs and heart rate model; C/HR = combined ratings of perceived exertion for chest/breathing and heart rate model.

Table 1

Perceptual and Physiological Variables by Stage for Men ($n = 40$) and Women ($n = 41$).

Sex	Perceptual and Physiological variables	Stage 1	Stage 2	Stage 3	Peak
Men	O	1.05 $\pm$ 0.15	2.98 $\pm$ 0.28	5.23 $\pm$ 0.36	7.40 $\pm$ 0.27
	L	1.18 $\pm$ 0.16	3.33 $\pm$ 0.26	5.83 $\pm$ 0.37	8.28 $\pm$ 0.22
	C	0.98 $\pm$ 0.12	2.75 $\pm$ 0.28	4.90 $\pm$ 0.34	7.00 $\pm$ 0.28
	HR(beats·min ⁻¹)	115.25 $\pm$ 2.03	136.83 $\pm$ 2.29	158.80 $\pm$ 2.38	178.30 $\pm$ 1.71
	VO ₂ (L·min ⁻¹)	* 1.18 $\pm$ 0.04	1.66 $\pm$ 0.03	2.20 $\pm$ 0.04	3.02 $\pm$ 0.10
	PO (watts)	75.00 $\pm$ 0.00	125.00 $\pm$ 0.00	175.00 $\pm$ 0.00	236.25 $\pm$ 6.33
Women	O	1.44 $\pm$ 0.22	3.22 $\pm$ 0.31	4.95 $\pm$ 0.36	7.73 $\pm$ 0.29
	L	1.56 $\pm$ 0.24	3.12 $\pm$ 0.32	5.15 $\pm$ 0.37	7.90 $\pm$ 0.30
	C	1.29 $\pm$ 0.20	2.85 $\pm$ 0.28	4.76 $\pm$ 0.34	7.49 $\pm$ 0.31
	HR(beats·min ⁻¹)	119.63 $\pm$ 1.82	138.07 $\pm$ 1.99	156.22 $\pm$ 2.23	176.59 $\pm$ 1.74
	VO ₂ (L·min ⁻¹)	0.90 $\pm$ 0.01	1.14 $\pm$ 0.01	1.44 $\pm$ 0.02	2.03 $\pm$ 0.05
	PO (watts)	50.00 $\pm$ 0.00	75.00 $\pm$ 0.00	100.00 $\pm$ 0.00	137.80 $\pm$ 3.92

Data are presented as mean $\pm$ standard error;

* $n = 39$; missing submaximal oxygen consumption data for one man;

O = ratings of perceived exertion for the overall body; L = ratings of perceived exertion for the legs; C = ratings of perceived exertion for the chest/breathing; HR = heart rate; VO₂ = oxygen consumption; PO = power output

Table 2
Peak Oxygen Consumption Statistical Models Using Submaximal Ratings of Perceived Exertion for Men and Women.

Sex	Predictor variables		Constant (β_0)	Coefficient ($\beta_1, \beta_2, \beta_3$)	Adjusted R ²	SEE (L·min ⁻¹)
	RPE	Stage				
Men	O	1	3.866	-0.034	0.328	0.494
		2		0.012		
		3		-0.162		
	L	1	3.915	0.005	0.300	0.504
		2		-0.009		
		3		-0.149		
	C	1	3.700	-0.043	0.173	0.548
		2		0.054		
		3		-0.161		
	O	1	2.571	-0.073	0.455	0.259
		2		0.128		
		3		-0.171		
Women	L	1	2.610	-0.006	0.475	0.254
		2		0.086		
		3		-0.162		
	C	1	2.505	-0.028	0.333	0.286
		2		0.064		
		3		-0.130		

RPE = ratings of perceived exertion; O = overall body; L = legs; C = chest/breathing; SEE = standard error of estimate