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The Predictability of Peak Oxygen Consumption Using Submaximal Ratings of Perceived Exertion in Adolescents

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ABSTRACT

International Journal of Exercise Science 11(4): 1173-1183, 2018. Rating of perceived exertion (RPE) extrapolation involves mathematically extending the submaximal relationship between RPE and oxygen consumption (VO_2) to maximal intensity. This technique allows practitioners to forego, potentially dangerous, maximal exertion testing while attaining accurate measures of maximal oxygen consumption used for exercise prescription. This method has been proven accurate in adults, but much less in known when applied to an adolescent population. The purpose of this study was to assess the accuracy of the RPE extrapolation as method for estimating VO_{2max} in adolescents. Twenty-two healthy, asymptomatic adolescents performed a graded exercise test (GXT) to exhaustion. Heart rate and VO_2 were recorded throughout the bout with RPE being queried every two minutes using the Borg (6-20) RPE scale. Individual regression lines were fitted for each subject using RPE and VO_2 for RPE values up to 13,15, and 17. Theoretical maximal RPE values of 20 and 19 were entered into the equation to calculate an estimated VO_{2max}. Repeated measures ANOVA with planned contrasts showed that all VO_{2max} estimation methods significantly overpredicted measured VO_{2max} ($p < .001$). Error analysis via Bland-Altman plots revealed large limits of agreement between the all methods, indicating large variability in error between estimated and measured VO_{2max}. The results suggest that submaximal RPE values using the Borg scale cannot be used to predict VO_{2max} in children due to the amount of error in the prediction equations. These inaccuracies could lead to potential under or over-prescription of exercise intensity and adverse effects on the person's health.

KEY WORDS: Perception, aerobic capacity, submaximal exercise testing

INTRODUCTION

Maximal or peak oxygen consumption ($VO_{2max/peak}$) is known to be the criterion measure of cardiorespiratory fitness and cardiovascular disease risk in children and adults (2, 4, 10). Traditionally, a plateau in VO_2 is the criterion used to establish that a VO_{2max} was achieved, a phenomenon that rarely occurs in child and adolescent populations (37). However, findings suggest that there are no significant differences between the highest achieved VO_2 value (i.e., VO_{2peak}) and the plateaued VO_2 value (i.e., VO_{2max}) (3). While measurement of $VO_{2max/peak}$ is the gold standard, this test requires graded exercise testing (GXT) to maximal physiological exertion. While generally safe in normal populations, GXT could pose a potential safety concern to younger populations with congenital heart disease or build-up of plaque and fatty streaks within the coronary artery. While atherosclerosis is often associated with older adults and the elderly, it has been shown that ~60% of children between the ages of 15-19 have lesions in the right coronary artery (42). This problem becomes even more serious when examining the trends of increasing childhood obesity (40) and the impact of obesity on cardiometabolic risk factors in children (e.g., low HDL, elevated systolic and diastolic blood pressure, and elevated triglycerides) (39). It is clear that the measurement of $VO_{2max/peak}$ in children is important for identifying those at risk and potentially for exercise programming in an attempt to alleviate some of that risk. While a variety of submaximal and field tests have been developed to estimate $VO_{2max/peak}$ in adult populations, there is evidence that these methodologies are less accurate when applied to children (12, 13).

Recently, a new method of estimating maximal oxygen consumption has been created in which the trend in submaximal ratings of perceived exertion (RPE) and oxygen consumption is extrapolated to predict $VO_{2max/peak}$. This extrapolation method can be broken down into two different procedures: estimation and production. Briefly, RPE production is a perceptually mediated exercise test in which participants perform work at specific RPE values. The other procedure is referred to as RPE estimation. This method involves participants completing a GXT protocol while being asked to rate their perceived exertion for a given workload. A linear equation is then established between oxygen consumption and RPE which researchers can use to predict a VO_{2max} by inputting a maximal RPE value (19). For a more thorough explanation of both RPE production and estimation procedures, we refer readers to the review by Coquart et al. (16). The extrapolation of RPE using the estimation protocol has shown moderate to high accuracy in able bodied, adult populations with a mean bias and limits of agreement of -0.3 ± 3.7 $ml.kg^{-1}.min^{-1}$ (17). Additionally, RPE extrapolation has shown promising results in children using 0-10 RPE scales. For example, Lambrick et al. (28) found that extrapolating to a maximal RPE (RPE_{10}) from a submaximal RPE (RPE_7) yielded a mean difference of just 1.29 $ml.kg^{-1}.min^{-1}$ with a standard error of the estimate of 6.63 $ml.kg^{-1}.min^{-1}$. The accuracy of RPE extrapolated $VO_{2peak/max}$ has been assessed in adults (19), children (28), athletes (14), non-athletes (29), diseased (15), and healthy populations (22), no study has assessed the accuracy of RPE extrapolation in adolescents.

Most of the literature involving RPE extrapolation involves the use of the Borg (6-20) RPE scale in adult populations. This may pose a problem to practitioners attempting to extend this methodology and scale to younger adolescent populations, for there appears to diverging opinions as to the validity of Borg RPE in adolescent populations (26). For example, Gillach et al. (24) found a strong relationship for Borg RPE and heart rate (HR) for both children and adults ($r > .90$). Similar results were observed by Lamb (27) who found that RPE correlated strongly with both HR and work rate, $r = .90$ and .93, respectively. Conversely, Pfeiffer et al. (36) found the correlation between RPE and physiological measures (HR, VO_2, ventilation and respiratory rate) to range from $r = .64-.67$ during a submaximal GXT. A lower relationship in Borg RPE and physiological measures in adolescents may cause inaccuracies in the extrapolation method.

Therefore, the purpose of this study was to determine whether submaximal ratings of perceived exertion collected during a graded exercise test can be extrapolated to predict VO_{2peak} in adolescents.

METHODS

Participants

Twenty-two adolescent males volunteered to participate in the study. To be included in the study, participants needed to be asymptomatic of cardiovascular, metabolic, and pulmonary diseases as well as present no musculoskeletal injuries. The study was approved by the local human subject review board and informed consent was obtained from both the participant and parent prior to the testing session. An *a priori* power analysis indicated that a minimum of 6 subjects were needed to yield a power of 0.80 for detecting a moderate effect size (f = 0.25) for ten highly correlated measures (r = 0.80) at an alpha level of 0.05.

Protocol

Upon arrival to the laboratory, participants' height (cm) and body mass (kg) were assessed using a stadiometer and beam scale (Detecto Scale Company, Webb City, Missouri, USA). Body fat percentage was assessed via dual energy X-ray absorptiometry (GE Lunar Prodigy, Software version 14.10.022; GE Lunar Corporation, Madison, WI, USA). The descriptive data for all subjects are listed in Table 2. The Borg RPE scale was then explained using a standardized script that was read to all participants individually and any questions were answered before beginning the graded exercise test (GXT) (8, 9). Subjects were then asked to complete GXT to assess peak oxygen consumption (VO_{2peak}). Following a brief warm-up (i.e., a 4-min walk at 3.5 mph), participants began exercising at a self-selected pace of either 6 or 6.5 mph at a 0% grade on a motorized treadmill (TMX428CP, Trackmaster Treadmills, Newton, KS, USA). Treadmill speed was held constant throughout the exercise bout with grade being increased 2% every two minutes until volitional exhaustion occurred.

Throughout the trial, breath by breath analysis of expiratory gases was performed via an automatic gas analyzer which was previously calibrated per the manufacturers specifications (ParvoMedics Inc., Sandy, UT, USA). Respiratory variables of interest (e.g., respiratory exchange ratio and oxygen consumption) were transformed into 30 second averages recorded during the trial. VO_{2peak} was defined as the average oxygen consumption, expressed in $ml.kg^{-1}.min^{-1}$, during the final 30 seconds of the test. Heart rate was assessed continuously throughout the test via a telemetered HR monitor (Polar Electro Oy, Kemple, Finland), fixed at the level of the xiphoid process, as a secondary measure of exertion. Additionally, the RPE scale was explained to the participants before the beginning of the GXT. Participants reported their undifferentiated RPE at 15 seconds left within each stage using the Borg (6-20) RPE scale (8, 9).

Rating of perceived exertion extrapolation was used to estimate VO_{2peak} from the submaximal relationship between RPE and the average VO_2 collected within the last 30 seconds of the stage. Individual regression analysis was performed for RPE and VO_2 for each subject for three different RPE ranges (6-13, 6-15, 6-17). The linear regression was then solved for the theoretical (RPE_{20}) and typical (RPE_{19}) maximal RPE reported during a GXT [Estimated VO_{2peak} = a+b (RPE_{19} or RPE_{20})]. As an example, the data presented in Table 1 were the values from one participant in the current investigation. The equation for the line of best of the data in Table 1 is as follows:

$VO_{2peak} = 0.4 + 2.71x$

Where 0.4 is the intercept, 2.71 is the slope, and x is either the theoretical maximal RPE of 20, or the typical maximal reported RPE of 19. In order to calculate the estimated VO_{2peak} using the theoretical maximal RPE (i.e., 20), substitute x for 20 and estimated VO_{2peak} should be 54.6 $ml.kg^{-1}.min^{-1}$.

Table 1. Recorded data from individual participant

Stage	VO2 (ml.kg-1.min-1)	RPE
1	22.6	8
2	29.4	11
3	35.2	13
4	41.6	15

Table 2. Subject descriptive characteristics (n=22).

Variable	
Age (y)	14.5 ± 0.66
Height (cm)	166.3 ± 8.6
Body mass (kg)	56.1 ± 10.1
Body fat (%)	21.1 ± 3.3

Note: Mean body fat percentage places the sample in ~75^{th} percentile for adolescent males (30)

Statistical Analysis

Statistical analyses were performed using a computer spreadsheet (Microsoft Excel 2010, Microsoft Corporation, Redmond, WA, USA) and SPSS v23.0 (Somers, NY, USA). The relationship between the estimated VO_{2peak} and measured VO_{2peak} was quantified using a two-way mixed ICC for absolute agreement. Additionally, a one-way repeated measures ANOVA, with simple planned contrasts, was employed to analyze the difference between the measured and estimated VO_{2peak} values for both RPE_{19} and RPE_{20}. Simple contrasts allow for the comparison of the different prediction equations against the measured VO_{2peak}. The Shapiro-Wilk test and Mauchly's test were used to test the assumptions of normality and sphericity. If sphericity was violated then a Greenhouse-Geisser correction was applied.

The Bland-Altman method was also used to establish the 95% limits of agreement (95% LoA) between the RPE estimated VO_{2peak} and measured VO_{2peak} (7). The difference between the two methods (difference = RPE prediction – measured) was plotted against the average of both values. The mean difference and the standard deviation of the mean difference were calculated to identify the average error and the upper and lower 95% LoA (average error ± 1.96*$SD_{difference}$).

Unless otherwise stated, data are displayed as mean ± standard deviation. Statistical significance was established at an alpha level of 0.05.

RESULTS

Graded Exercise Test: measured VO_{2peak} was 53.3 ± 3.4 ml.kg^{-1}.min^{-1} during the graded exercise test. Participants reached an average HR of 206.4 ± 6.0 with 20 out 22 meeting or exceeding estimations of maximal HR and all participants being within 10 beats per minute of age predicted maximal HR. Additionally, peak respiratory exchange ratio was 1.09 ± 0.06 with all participants reaching a 1.00.

Projecting to RPE_{20}: the repeated measures ANOVA revealed a significant main effect for method on VO_{2peak} ($F_{1.504,\ 31.575}$ = 16.085, p < .001, η_p^2= .434, N-β =.995). Simple planned contrasts revealed significant differences between measured and estimated VO_{2peak} for all estimation methods when extrapolated to a maximal RPE of 20. The RPE≤13 range overpredicted VO_{2peak} by an average of 17.8 ml.kg^{-1}.min^{-1} (p<.001). Peak oxygen consumption estimates using data from RPE≤15 also overpredicted measured VO_{2peak} by 12.5 ml.kg^{-1}.min^{-1} (p < .001). Lastly, the RPE≤17 condition significantly overestimated VO_{2peak} by 9.9 ml.kg^{-1}.min^{-1} (p = .001). Descriptive data for each method and the results of the Bland-Altman analysis can be seen in Table 3.

Projecting to RPE_{19}: significant differences between measured and estimated VO_{2peak} were observed for all RPE ranges when projecting to a "maximal" RPE of 19. There was a mean difference of 14.8 ml.kg^{-1}.min^{-1} when comparing measured to estimated VO_{2peak} from RPE≤13 (p<.001), with the prediction equation significantly overpredicting measured VO_{2peak}. A similar result was observed for the RPE≤15 range which overpredicted VO_{2peak} by 10.0 ml.kg^{-1}.min^{-1} (p<.001). Lastly, extrapolation methods involving the relationship between VO_2 and RPE≤17 was 7.5 ml.kg^{-1}.min^{-1} higher than measured VO_{2peak} (p<.001). Results of the error analysis comparing measured and predicted VO_{2peak} can be observed in seen in Table 3.

Table 3. Comparison between measured and predicted VO_{2peak} (n=22)

"Maximal RPE" RPE Range	Predicted VO_{2peak} (ml.kg^{-1}.min^{-1})	95% LoA		ICC
		Lower	Upper	
RPE 20				
≤13	71.1±16.8	-12.8	48.4	.087
≤15	65.7±8.7	-3.0	28.0	.108
≤17	63.1±6.7	0.1	19.6	.214
RPE 19				
≤13	68.0±15.6	-13.2	42.77	.109
≤15	63.2±8.3	-4.5	24.4	.146
≤17	60.8±6.33	-1.3	16.4	.297

95% LoA: Limits of agreement, ICC: Intraclass correlation coefficient. Note: Mean VO_{2peak} was 53.3±3.4 ml.kg^{-1}.min^{-1}

DISCUSSION

The purpose of this study was to assess the predictability of VO_{2peak} utilizing the relationship between submaximal VO_2 and RPE. The novelty in this studies lies in the fact that it is the first study to assess the accuracy of RPE extrapolation in adolescents using Borg RPE. Results indicate that estimations overpredict measured VO_{2peak} consistently (mean difference= 7.5-17.8), regardless of RPE range or extrapolation value. Additionally, all methods produced large variability and limits of agreement. For example, extending the RPE/VO_2 relationship from a submaximal RPE value of 13 and to an RPE of 20 resulted in four subjects being within 5 $ml.kg^{-1}.min^{-1}$ and five subjects overestimating their VO_{2peak} by over 35 $ml.kg^{-1}.min^{-1}$. While there are ways to increase the accuracy by increasing the submaximal range to <17 and projecting to a lower "maximal" RPE (i.e., 19), the large mean bias and limits of agreement (7.6 ± 8.8 $ml.kg^{-1}.min^{-1}$) reported in the current investigation make Borg RPE extrapolation in adolescent males an inaccurate method of estimating VO_{2peak}.

Results from our study indicate that estimated VO_{2peak} from RPE extrapolation is no more accurate than other estimations of VO_{2peak} in youth participants. For instance, the estimated VO_{2max} from intermittent shuttle running found 95% limits of agreement of ± 11.3 $ml.kg^{-1}.min^{-1}$ when compared to VO_{2max} (12). Additionally, Castro-Pinero et al. (13) found that a common regression equation used in the one-mile walk/run test under-predicted VO_{2peak} by 10 $ml.kg^{-1}.min^{-1}$. Another option is to employ a submaximal, graded exercise test (GXT) in which HR is extrapolated to a predicted maximal HR (HR_{max}) from submaximal values. However, caution is to be used as maximal HR prediction equations have been shown to be poor predictors of HR_{max} in adolescent age groups with 95% limits of agreement being roughly 15 beats per minute (35). Lastly, the Astrand-Rhyming test, an often utilized submaximal estimation test, was shown to underestimate VO_{2max} by 12.7 and 7 $ml.kg^{-1}.min^{-1}$ in eighth and eleventh grade students, respectively (11).

As previously stated, there was a consistent overestimation and individual variability of VO_{2peak} within the current study. The cause of the erroneous results may not be due to adolescents' inability to "correctly" utilize perceptual exertion, but rather the scale used in the study. While the correlation between Borg RPE and HR is similar in adults and adolescents (24), this is merely a relationship of two measures and does not really assess accuracy. Bar-Or (5) found that while there was a linear relationship with Borg RPE and HR for adolescents and adults, adolescents tend to perceive exercise to be easier at a given relative intensity when compared to adults. Additionally, while the relationship between HR and RPE is fairly consistent in adults (i.e., RPEx10=HR), this relationship is not observed in children (46).

Projecting to an RPE of 19 rather than 20 yielded greater accuracy overall in the current study. Similar results were revealed by Evans et al. (21), who found that projecting the submaximal relationship to an RPE of 19 resulted in lower bias and smaller limits of agreement both before and after an exercise intervention when compared to an RPE of 20. Additionally, Eston et al. (18) found that projecting to an RPE of 19 from submaximal RPE range of 9-15 resulted in a reduction in bias and limits of agreement for both active and sedentary participants when compared to an RPE of 20. While reported RPE at maximal exercise has been shown to be lower than the theoretical maximum in adults (41, 44), reported maximal RPE is even lower in child (32, 33) and adolescent populations (6). For example, Belanger et al. (6) found that obese adolescents reported an RPE of 18 at cessation of exercise. Also, Mahon and Ray (33) showed that average maximal RPE reported in children during a GXT was 16.8. Interestingly, an exploratory analysis of the data revealed that extrapolating to a maximal RPE of 17 from RPE values <17 yielded the most accurate estimations of VO_{2peak}. While fascinating, the purpose of the present study was to project submaximal relationships to estimate maximal oxygen consumption and the inclusion of this information in the results section would not be appropriate.

The findings of increased accuracy with an increased RPE range have been shown in a number of studies. Logically speaking, the greater the range of RPE prediction, the less "distance" needed to extrapolate, thus a decrease in potential error. Morris et al. (34) found that agreement between estimated and measuredVO_{2max} increased (i.e., limits of agreement got smaller) as the RPE range used increased from 9-13, 9-15, to 9-17. Similarly, Eston et al. (19) found that an RPE range of 9-17 allowed for greater agreement between measured and estimated VO_{2max} when compared to 9-15 and 11-17 ranges. However, an interesting trend in limits of agreement was observed in the current study. While multiple studies have shown that limits of agreement decrease as the RPE range utilized increases, the increase in agreement was for more drastic in the current study (1, 18, 22, 34). Extending the RPE range from ≤13 to ≤15 decreased the limits of agreement by roughly 50% when projecting to both an RPE of 19 (28.0 to 14.5 $ml.kg^{-1}.min^{-1}$) and 20 (30.6 to 15.5 $ml.kg^{-1}.min^{-1}$). Additionally, extending the RPE range to <17 decreased the limits of agreement by ~68% compared to an RPE range of ≤13. A similar, albeit, less drastic trend was reported by Faulkner and Eston (22) who found that increasing the RPE range from ≤13 to ≤15 resulted in a 20% decrease in limits of agreement (15.2 to 12.3 $ml.kg^{-1}.min^{-1}$) and a 25% decrease in limits of agreement when using an RPE range of ≤17. These results may be explained by the low reliability in RPE values at lower intensities in adolescent populations. Leung et al. (31) observed that Borg RPE reliability increased as a function of intensity in adolescent boys during a graded exercise test. The first three stages of the testing protocol corresponded to estimated mean RPE values of 9.7, 11.5, and 13.8 with the test-retest reliability coefficient never surpassing 0.71. However, reliability of RPE increased to 0.89 in the following stage with a reported average RPE value of 15.4. It may be that the poor psychometric properties at the lower end of the Borg scale (e.g., ≤13) may have caused large limits of agreement. The large decrease in limits of agreement observed once the RPE range was increased from 13 to 15 may be due to the fact that this was the first point at which valid and reliable RPE values were recorded.

Additionally, adolescents tend to report a curvilinear relationship with RPE and workload (20). If this is the case then linearly projecting submaximal RPE values to a theoretical maximal value would result in an overestimation of VO_{2peak}. Lambrick et al. (28) employed both a curvilinear and linear RPE scale in an attempt to extend the relationship of submaximal workload and RPE in children (mean age=9.4). Results revealed that a curvilinear RPE scale and a subsequently applied curvilinear model resulted in a lower mean bias and standard error of the estimate than a linear RPE scale and linear regression model. However, regardless of the trend employed (e.g., linear or curvilinear), both 10-point scales produced lower mean biases than reported in the current study. It may be that the population utilized was below the critical age threshold to accurately use the 6-20 RPE scale (38). While this idea is more commonly discussed when referring to reproducibility, it stands to reason that there is also a validity component to this concept.

While the results suggest that RPE extrapolation is not accurate in adolescents using Borg RPE, there are some limitations that need to be addressed, namely the sample used. The sample was fairly homogenous with all of the subjects being fit males with an athletics background. While studies assessing the accuracy of RPE extrapolation across genders (22, 23), fitness (22), and physical activity status (18) have found that these factors do not moderate the accuracy of RPE extrapolation, less in known in adolescent and child populations.

In conclusion, the results from this study indicate that extrapolating the submaximal relationship between RPE (6-20) and VO_2 to estimate VO_{2peak} is inaccurate in adolescents due to large variability. It seems unlikely that RPE extrapolation would be accurate in both children and adults, but not adolescent populations. Future research attempting to validate RPE extrapolation in this population should look to using RPE scales specifically developed for children, such as the CERT (45), OMNI (43), and RPE-C scales (25). Additionally, a more heterogeneous population should be used in order to determine the validity of this technique in a wider range of adolescents.

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