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Verification of Maximal Oxygen Uptake in Obese and Nonobese Children

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Abstract

Purpose—The purpose of this study was to examine whether a supramaximal constant load verification test at 105% of the highest work rate would yield a higher $\dot{V}O_{2\max}$ when compared with an incremental test in 10 – 12 year old nonobese and obese children.

Methods—Nine non-obese (BMI percentile: 57.5 ± 23.2) and nine obese (BMI percentile: 97.9 ± 1.4) children completed a two-test protocol that included an incremental test followed 15 minutes later by a supramaximal constant-load verification test.

Results—The $\dot{V}O_{2\max}$ achieved in verification testing (Nonobese: 1.71 ± 0.31 and Obese: 1.94 ± 0.47 L/min) was significantly higher than that achieved during the incremental test (Nonobese: 1.57 ± 0.27 and Obese: 1.84 ± 0.48 L/min; $P < 0.001$). There was no significant interaction (group (i.e., nonobese versus obese) $\times$ test (i.e., incremental versus verification)), suggesting that there was no effect of obesity on the difference between verification and incremental $\dot{V}O_{2\max}$ ($P = 0.747$).

Conclusion—A verification test yielded significantly higher values of $\dot{V}O_{2\max}$ when compared with the incremental test in obese children. Similar results were observed in nonobese children. Supramaximal constant-load verification is a time-efficient and well-tolerated method for identifying the highest $\dot{V}O_2$ in nonobese and obese children.

Keywords

fitness; validation test; pediatric; obesity; cardiorespiratory; aerobic capacity

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Conflict of Interest

All authors declare that they have no competing financial interests related to this publication. All authors declare that the results of the study are presented clearly, honestly, and without fabrication, falsification, or inappropriate data manipulation. The results of the present study do not constitute endorsement by ACSM.

Introduction

Maximal oxygen uptake ($\dot{V}O_{2\max}$) represents the maximal ability of the body for O_2 delivery and utilization. $\dot{V}O_{2\max}$ is an important health marker for establishing levels of cardiorespiratory fitness (5) and for assessing the effects of exercise training (27, 28, 35). Low levels of $\dot{V}O_{2\max}$ are associated with a poor cardiovascular disease risk profile (14) and higher levels of $\dot{V}O_{2\max}$ are associated with a reduced risk of myocardial infarction later in life (17). In children, determination of $\dot{V}O_{2\max}$ provides information regarding cardiopulmonary and muscular growth and development (37). Therefore, obtaining accurate values of $\dot{V}O_{2\max}$ is important in a pediatric population.

$\dot{V}O_2$ has been traditionally measured using a ramp or incremental test protocol, and attainment of $\dot{V}O_{2\max}$ has been validated when $\dot{V}O_2$ displayed a plateau with an increase in work rate in adults (40). However, it has been difficult to validate $\dot{V}O_{2\max}$ using the plateau criterion in children because few children typically exhibit a plateau (6, 12, 36). In the absence of a plateau, secondary criteria such as respiratory exchange ratio (RER) ≥ 1.00 , maximal heart rate $\geq 90\%$ of age predicted maximal heart rate, and signs of intense effort such as hyperpnea, facial flushing and grimacing, unsteady gait, and sweating have been suggested (5). However, the use of secondary criteria for validating $\dot{V}O_{2\max}$ significantly underestimate $\dot{V}O_2$ max in children, which has led researchers to suggest that even these criteria should be abandoned (7, 34). The recommended approach for validating $\dot{V}O_{2\max}$ is to conduct a verification test at a workload that is higher than the highest incremental workload (29).

Supramaximal verification testing has typically been conducted at 105% of the maximal power achieved during the incremental test, 10 – 15 minutes after the maximal incremental test in nonobese children (7, 34, 36). There are no data comparing incremental and supramaximal verification tests in obese children. It is unclear whether the use of a verification test in obese children could yield a higher $\dot{V}O_{2\max}$ than the incremental test. This is important to ascertain because obesity affects 17.4% of 6 – 11 year (yr) old children in the United States (31). Hulens et al previously reported that obese adults achieved lower values of minute ventilation ($\dot{V}_E$), RER, heart rate and perceived exertion at peak exercise when compared with lean adults, which could make it difficult to determine whether they attained $\dot{V}O_{2\max}$ (19), although similar findings have not been observed in obese children (26). Moreover, as noted above, there are obvious problems associated with the validity of primary and secondary criteria in determining attainment of $\dot{V}O_{2\max}$ during an incremental test, which could lead to incorrectly accepting submaximal $\dot{V}O_2$ values as $\dot{V}O_{2\max}$ (32, 34). Inaccurate measurement of $\dot{V}O_{2\max}$ could lead to obese children being wrongly labeled as “deconditioned” and they could be offered an exercise prescription of a lower intensity than suitable. Since, accurate determination of $\dot{V}O_{2\max}$ is important for the diagnosis and treatment of obese children (11), it is imperative that uniform testing procedures and standard criteria validating $\dot{V}O_{2\max}$ be established in lieu of accepting the highest values from an incremental test and reporting them as $\dot{V}O_{2\text{peak}}$, while lacking confidence in their validity.

The purpose of this study was to examine whether a supramaximal constant load verification test at 105% of the highest work rate would yield a higher $\dot{V}O_{2\max}$ when compared with an incremental test in 10 – 12 yr nonobese and obese children. We hypothesized that obese children would achieve higher levels $\dot{V}O_2$ during verification testing when compared with incremental testing because the increased energetic costs of physical activity in obesity could potentially affect performance during an incremental test, with exhaustion occurring prior to attainment of $\dot{V}O_{2\max}$ (19). We also hypothesized that nonobese children would achieve similar levels of $\dot{V}O_2$ during verification testing when compared with incremental testing based on previous reports (4, 7, 34, 36).

Methods

All study procedures were explained in detail, the child's parent or guardian provided written, informed consent and all children provided written assent. The UT Southwestern Institutional Review Board approved this study (approval number 052012-076).

Twelve children with obesity (9 boys, body mass index (BMI) > 95th percentile for age and sex) and 11 children without obesity (5 boys, BMI between 16th and 84th percentile for age and sex) qualified for this cross-sectional study. All participants were 10 – 12 yr when they were recruited for the study and were considered otherwise healthy. Any participant with a history of smoking exposure, or a diagnosis of heart disease, hypertension, sleep disorders, or diabetes was excluded. Girls who had started their menses were also excluded. Subjects that showed evidence of bronchodilator response (improvement in FEV₁ of 12% with a minimum volume improvement of 200mL) were excluded from the study (1).

Screening Procedures

Height was recorded using a calibrated eye-level physical scale and weight was recorded using a calibrated weighing scale. BMI percentile was calculated for each child using age and specific BMI tables from the Centers of Disease and Control and Prevention (23). Participants completed a Tanner pubertal stage assessment for assessment of pubertal status. Participants also completed a physical activity readiness questionnaire (10). On a different day, participants completed a dual energy x-ray absorptiometry (DXA) scan for assessment of body composition, a maximal incremental exercise test, and a supramaximal verification test.

Dual-energy X-ray Absorptiometry

All participants underwent a DXA scan for assessment of body composition (Lunar Prodigy Advance, GE healthcare Lunar, Madison, WI). Whole body fat mass and fat-free mass were estimated using Prodigy enCore software (GE healthcare Lunar, Madison, WI).

Maximal Incremental Exercise Test

Participants were asked not to consume a heavy meal at least 3 hours prior to the test. The maximal incremental exercise test was performed on a cycle ergometer (Lode Corival, The Netherlands). Prior to the incremental exercise test, participants performed a 6-minute constant load exercise test at 40Watts on a cycle ergometer, which served as a warm-up for

the incremental test and was consistent with our protocol in adults (8). The initial work rate was 20W, and the work rate was increased by 10W or 15W every minute until volitional exhaustion. These data were part of a larger study designed to examine the respiratory effects of obesity in children.

When the study was designed, a 15W increment protocol was established. After a few participants were tested, there was uncertainty regarding attainment of $\dot{V}O_{2\max}$ during the incremental test based on secondary criteria (i.e., at least two of the following: respiratory exchange ratio (RER) ≥ 1.00 , maximal heart rate $\geq 90\%$ of age predicted maximal heart rate, signs of intense efforts) (5). To eliminate the need for secondary criteria, a supramaximal verification test was added to the study protocol. The next few tests showed that verification $\dot{V}O_{2\max}$ was substantially higher than the incremental $\dot{V}O_{2\max}$ and that the duration of the incremental test tended to be below 8 minutes. Therefore, the increment of the incremental test was reduced from 15W to 10W, and this was maintained for the remainder of the study. As part of a larger study, all children were invited to return for repeat testing 1 yr later, and all repeat incremental tests had 10W increments (Figure 1).

Participants were asked to maintain a cadence of 60 – 70 revolutions per minute (rpm) and were allowed to increase cadence towards the end of the test. The test was stopped when participants were unable to maintain a cadence of 50 rpm for five consecutive seconds despite gentle but firm encouragement. Heart rate, ratings of perceived breathlessness (RPB; Borg 0–10 scale), and ratings of perceived exertion (RPE; Borg 6–20 scale) were monitored and recorded during the test. The Borg scales for exertion and breathlessness have been previously validated in a pediatric population (18, 42). $\dot{V}_E$, $\dot{V}O_2$ and expired carbon dioxide ($\dot{V}CO_2$) were measured using the Douglas bag technique where expired gases were collected for 60 seconds in each stage in a polyurethane bags. Gas fractions were measured using a mass spectrometer (Marquette Electronics, model 1100, Milwaukee, WI) and expired volume was measured using a 200 L Tissot spirometer. The highest $\dot{V}O_2$ from a stage that lasted at least 20 seconds was recorded as maximal $\dot{V}O_2$ from the incremental test.

Verification Test

After at least 15 minutes of seated rest, participants performed a constant-load supramaximal verification test at 105% of the maximal work rate achieved during the incremental test. The participants warmed up by cycling for 2 minutes at 20W. Work rate was increased to 105% maximal work rate within 30 seconds and participants were encouraged to pedal at a cadence of their choice for as long as possible. The test was stopped when participants were unable to maintain a cadence of 50 rpm for five seconds despite encouragement. The procedure for the verification test was consistent with previous studies (7, 34). After the first minute, expired air was collected for 30 seconds in polyurethane bags and analyzed as described above. The highest $\dot{V}O_2$ from a bag that collected air for at least 20 seconds was recorded as maximal $\dot{V}O_2$ from the verification test.

Data analyses

Data were expressed as mean and standard deviations (S.D.), unless otherwise specified. $P < 0.05$ was considered statistically significant using a two-tailed distribution. Using data from

Poole et al (32), we estimated that a sample size of 16 participants would detect differences between incremental and verification tests at 80% power ($\alpha = 0.05$; effect size = 0.759; two tailed hypothesis; based on a t test analysis) (15). The sample size of this study is comparable to other studies that have examined differences in $\dot{V}O_2$ between incremental and verification tests (7, 22, 38) and to studies that have examined the validity of secondary criteria for establishing $\dot{V}O_{2\max}$ (7, 32). All data were checked to ensure normal distribution.

$\dot{V}O_2$ plateau calculations were performed for each participant. A linear regression was fit to the linear portion of the $\dot{V}O_2$ –Work rate relationship after excluding the last minute of the incremental test. Regression equations for each participant were used to calculate predicted $\dot{V}O_2$ at maximal work rate. $\dot{V}O_2$ plateau attainment was accepted when the difference in measured $\dot{V}O_2$ from the penultimate stage and measured $\dot{V}O_2$ from the maximal stage was less than half of the difference between measured $\dot{V}O_2$ from the penultimate stage and the predicted $\dot{V}O_2$ for the maximal stage (13). Similarly, regression equations for each participant were also used to calculate predicted verification $\dot{V}O_{2\max}$ at the verification work rate (i.e., 105% of maximal work rate). Measured verification $\dot{V}O_{2\max}$ was considered higher than measured incremental $\dot{V}O_{2\max}$ when difference between measured verification $\dot{V}O_{2\max}$ and incremental $\dot{V}O_{2\max}$ was greater than the difference between predicted verification $\dot{V}O_{2\max}$ and incremental $\dot{V}O_{2\max}$. This approach was considered because using an absolute cut off value for the difference between incremental and verification $\dot{V}O_{2\max}$ (i.e., 150 mL·min⁻¹) may not be appropriate for obese and nonobese children who may have different energy costs of cycling.

Sensitivity and specificity analyses as well as calculations regarding positive predictive value and negative predictive value were conducted to evaluate whether primary and secondary criteria can correctly identify attainment of $\dot{V}O_{2\max}$ from the incremental test. Attainment of $\dot{V}O_{2\max}$ during the incremental test was confirmed when difference between measured verification $\dot{V}O_{2\max}$ and incremental $\dot{V}O_{2\max}$ was less than the difference between predicted verification $\dot{V}O_{2\max}$ and incremental $\dot{V}O_{2\max}$. True positive, false positive, true negative, and false negative rates were determined for each of the primary and secondary criteria. The following calculations were performed for each of the primary and secondary criteria (24).

$$\text{Sensitivity} = \text{True positives} / (\text{True positives} + \text{False negatives})$$

$$\text{Specificity} = \text{True negatives} / (\text{True negatives} + \text{False positives})$$

$$\text{Positive predictive value} = \text{True positives} / (\text{True positives} + \text{False positives})$$

$$\text{Negative predictive value} = \text{True negatives} / (\text{True negatives} + \text{False negatives})$$

Independent t-tests were used to compare differences between nonobese and obese children. A two- way repeated measures ANOVA was used to examine group (obese vs. nonobese) × test (incremental vs. verification) differences on outcome variables. Bland-Altman plots were used to examine agreement between $\dot{V}O_{2\max}$ measured by incremental versus verification tests.

Results

As explained in the methods, there were differences in the incremental test protocol at the start of the study, with some children undergoing tests with 15W increments (N=7), while others undergoing tests with 10W increments (N=8; Figure 1). Verification $\dot{V}O_{2\max}$ was higher than incremental $\dot{V}O_{2\max}$ ($P=0.001$) independent of the increment used (i.e., 10W or 15W; test $\times$ increment interaction $P = 0.528$). However, for consistency, the following analyses only include data from children that underwent 10W (N=18) increment tests followed by supramaximal verification tests, either before or after 1 yr of starting the study (see shaded boxes in Figure 1). Participant characteristics are presented in Table 1.

Performance in the Verification Tests

Time to exhaustion during the verification test ranged from 90 – 210 seconds for all children. Time to exhaustion was 135 ± 34 seconds for nonobese children and 125 ± 33 seconds for obese children, with no differences between groups ($P = 0.549$).

Comparing responses between incremental and verification tests

$\dot{V}O_2$ (L/min) was significantly higher during the verification test when compared with the incremental test in both nonobese and obese children ($P=0.001$; Table 2). There was no significant group $\times$ test interaction ($P=0.747$). Since there were no differences between nonobese and obese children, pooled data showed that verification test elicited higher $\dot{V}O_{2\max}$ to a similar extent for both boys and girls ($\dot{V}O_2$ Verification – Incremental: 0.10 ± 0.12 and 0.14 ± 0.09 L/min respectively, $P=0.466$). The verification test resulted in higher $\dot{V}O_2$ when expressed relative to body mass, fat free mass, and as a percent of predicted $\dot{V}O_{2\max}$ based on ideal body weight ($P<0.001$ for all comparisons), with no significant group $\times$ test interactions ($P=0.170$, $P=0.534$, and $P=0.686$, respectively). Bland-Altman analysis showed wide limits of agreement (-92 to 329 mL $\cdot$ min $^{-1}$) but there was no proportional bias and no obvious obesity status difference (Figure 2).

There were no significant differences in maximal heart rate (beats per minute or expressed as a percent of age predicted maximal heart rate) between incremental and verification tests for both nonobese and obese children ($P=0.071$ and $P=0.070$, respectively), with no significant test $\times$ obesity status interactions ($P=0.332$ and $P=0.335$, respectively; Table 2). Respiratory exchange ratio and $\dot{V}_E$ were also similar between incremental and verification tests for both nonobese and obese children ($P=0.363$ and $P=0.430$, respectively), with no significant group $\times$ test interactions ($P=0.750$ and $P=0.743$, respectively; Table 2).

Primary and secondary criteria for validity of an incremental exercise test

Table 3 shows individual subject data from the maximal exercise test, demonstrating attainment of primary and secondary validity criteria as well as individual differences between the incremental and verification tests. Seven out of 9 nonobese children and 5 out of 9 obese children achieved a verification $\dot{V}O_{2\max}$ that was higher than predicted verification $\dot{V}O_{2\max}$ (Table 3).

Using pooled data for nonobese and obese children, 7 out of 18 children achieved a $\dot{V}O_2$ plateau as defined by <50% increase in $\dot{V}O_2$ with an increase in work rate based on the $\dot{V}O_2$ – Work rate regression from the incremental exercise test (13). Five out of 7 children that achieved a plateau during the incremental test had verification test $\dot{V}O_{2max}$ values that were higher than predicted verification $\dot{V}O_{2max}$ and none of these 7 children attained a maximal heart rate during the incremental test that was 90% of age predicted maximal heart rate. 44% of children attained a maximal heart rate that was 90% of age predicted maximal heart rate, 94% of children attained an RER 1.00, and 61% of children attained an RER 1.10 during the incremental test.

None of the primary or secondary criteria for validating an incremental test achieved high levels of both sensitivity and specificity, limiting their usefulness in validating an incremental test. Similarly, none of the primary or secondary criteria for validating an incremental test achieved high positive and negative predictive values. If participants achieved either a maximal heart rate that was 90% of age predicted maximal heart rate or an RER 1.10, the sensitivity of detecting a valid $\dot{V}O_{2max}$ was estimated at 56%, specificity was 11%, while requiring both criteria to be present in the same test reduced the sensitivity to 11% and increase the specificity to 56%.

Discussion

Comparing responses between incremental and verification tests

This is the first study to show that verification $\dot{V}O_{2max}$ was significantly higher than incremental $\dot{V}O_{2max}$ in obese children as well as in nonobese children. In contrast, four previous studies (4, 7, 34, 36) have not shown a higher verification $\dot{V}O_{2max}$ when compared with the incremental $\dot{V}O_{2max}$ in nonobese children. Three (4, 7, 36) of these studies included a very active population of children, with average $\dot{V}O_{2max}$ ranging from 50 – 62 mL·min⁻¹·kg⁻¹, which was substantially higher than the average $\dot{V}O_{2max}$ in the current study for nonobese children (see Table 2). It is possible that the higher fitness levels and increased motivation for performance (36) during the incremental and supramaximal tests allowed participants to achieve $\dot{V}O_{2max}$ during the incremental and supramaximal tests. The study by Robben et al (34) was conducted in children with a broad range of fitness levels (i.e. 17 – 47 mL·min⁻¹·kg⁻¹), which was similar to the current study. Robben et al showed that verification testing yielded $\dot{V}O_{2max}$ values that were significantly (i.e., 150 mL/min) higher than values obtained using incremental testing in some nonobese prepubescent children (20). However, Robben et al repeated the incremental test in this study until the final difference in $\dot{V}O_{2max}$ between incremental and verification tests was below 150 mL·min⁻¹ (20), and consequently, there were no significant differences between incremental and verification $\dot{V}O_{2max}$. Therefore, the current study is the first to show that supramaximal verification testing yielded higher levels of $\dot{V}O_2$ when compared with incremental testing for obese and nonobese children that represented a broad range of fitness levels (i.e. 24 – 52 mL·min⁻¹·kg⁻¹).

In obese adults, a study by Sawyer et al (38) did not find significantly higher verification $\dot{V}O_2$ when compared with incremental $\dot{V}O_2$, even though they did show substantial individual variability in the results with 13 out of 19 subjects achieving a $\dot{V}O_2$ during

verification testing that was 2 to 21% higher than the incremental test. The authors did not observe any relationship between BMI and performance on the verification test, which is consistent with the lack of differences between obese and nonobese groups in the present study. The authors also reported significantly higher maximal heart rate during the verification test compared with the incremental test, which is not consistent with other studies comparing the two tests in adults (22, 43) or the present data that do not show significant differences in maximal heart rate between the two test protocols.

Average verification $\dot{V}O_2$ was significantly higher than incremental $\dot{V}O_2$, which could be because the incremental test did not yield $\dot{V}O_{2max}$, while slow component of $\dot{V}O_2$ during the supramaximal verification test yielded “true” $\dot{V}O_{2max}$ (20). The difference in measured $\dot{V}O_2$ between the incremental and verification tests exceeded the difference in predicted $\dot{V}O_2$ between the incremental and verification tests, suggesting that the end-exercise gain in $\dot{V}O_2$ may have exceeded $9 - 16 \text{ mL} \cdot \text{min}^{-1} \cdot \text{Watt}^{-1}$ for obese and nonobese children (16, 20). It is also possible that the incremental test produced a “priming” effect, which resulted in faster $\dot{V}O_2$ kinetics and increased time to exhaustion leading to attainment of $\dot{V}O_{2max}$ during the verification test (21).

Performance in the Verification Tests

Cardiorespiratory fitness is not affected by obesity as evidenced by similar levels of $\dot{V}O_{2max}$ expressed relative to fat free weight in obese and nonobese individuals (9). Nevertheless, obese children have lower physical fitness than their nonobese counterparts (41), which could raise questions regarding the feasibility of supramaximal verification testing for obese children. The average time to exhaustion during the verification tests in the present study (i.e., 130 ± 63 seconds) was longer than other studies that have reported average times of 66 and 91 seconds in children (7, 34). There were no differences in the time to exhaustion during the verification test between obese and nonobese children, suggesting that obesity may not adversely affect performance at supramaximal work rates for cycle ergometer exercise. Moreover, studies have reported that there are no differences in $\dot{V}O_2$ kinetics or oxygen deficit during exercise between obese and nonobese children (25, 33), suggesting that obese children may not need to exercise for a longer duration at supramaximal workloads to attain $\dot{V}O_{2max}$ when compared with nonobese children.

Mortensen et al previously reported achievement of peak cardiac output, leg blood flow and oxygen delivery within 60–90 seconds of supramaximal cycling in adults, suggesting that verification tests may need to last at least 60 seconds in order to yield $\dot{V}O_{2max}$ (30). Phase II $\dot{V}O_2$ kinetics, which represents the phase of rapid increase in $\dot{V}O_2$ during moderate to very heavy intensity exercise, may be faster in children when compared with adults (2, 3). Therefore, it is possible that the minimum time needed for attainment of $\dot{V}O_2$ max during a verification test is could be lower than 60 seconds in children (34), including obese children that have similar kinetics as nonobese children (25, 33). Finally, all the children in this study were able to complete incremental and verification tests without any adverse events. In fact, most children expressed that they found the verification testing both challenging and enjoyable, although it should be noted that this was a subjective assessment by the investigator rather than a formal validated assessment.

Primary and secondary criteria for validity of an incremental exercise test

The current study showed that achievement of a $\dot{V}O_2$ plateau in an incremental test did not confirm attainment of $\dot{V}O_{2max}$ in 5 out of 7 participants. These data agree with Scharhag-Rosenberger et al who demonstrated higher verification $\dot{V}O_{2max}$ values were possible in untrained adults despite achieving a plateau during the incremental test (39). Furthermore, 7 out of 11 participants in the current study did not achieve a $\dot{V}O_2$ plateau but still had a verification test $\dot{V}O_2$ that was higher than predicted verification $\dot{V}O_{2max}$, suggesting that absence of the plateau does not imply that $\dot{V}O_{2max}$ was not achieved during the incremental test. These data are consistent with Armstrong et al who showed that children (9.9 ± 0.4 yr) achieved $\dot{V}O_{2max}$ during an incremental test as confirmed by two verification tests even in the absence of a plateau (4). Similarly in adults, Wood et al showed that 39% of overweight and obese participants did not attain a $\dot{V}O_2$ plateau during the incremental test and were not able to achieve higher $\dot{V}O_2$ during a verification protocol, confirming that absence of a $\dot{V}O_2$ plateau during the incremental test did not indicate failure to reach $\dot{V}O_{2max}$ (43).

Previously, Robben et al showed that using a two-step protocol that included an incremental and supramaximal constant load verification test in prepubertal children with and without expiratory flow limitation allowed for unambiguous determination of $\dot{V}O_{2max}$ (34). They also reported that the RER criterion on 1.00 was erroneous for confirming attainment of $\dot{V}O_{2max}$, which we confirm because 17 out of 18 of the children in this study were able to achieve an RER over 1.00, even though $\approx 70\%$ of these children still achieved a verification $\dot{V}O_{2max}$ that was higher than predicted verification $\dot{V}O_{2max}$. Robben et al also showed that many of their prepubertal children were not able to achieve the heart rate criterion of 90% age predicted maximal heart rate, which is consistent with the present data where less than half of our participants were able to reach this heart rate criterion. Based on the present data, none of the primary or secondary criteria meet an acceptable combination of sensitivity and specificity for predicting a valid incremental test in 10 – 12 yr old children and therefore, using a two-step approach (incremental and verification testing) may be the best approach for determining $\dot{V}O_{2max}$.

Limitations

This study has a relatively small sample size ($n=18$) and narrow age range (i.e., 10 – 12 yr). Future studies should include children of different fitness and obesity levels and a larger sample size to further support and encourage the use of verification testing in assessment of $\dot{V}O_{2max}$. There could be an effect of pubertal status on the results, but the small sample size and varied pubertal stages in our participant population precluded any statistical comparisons based on pubertal status. Some studies have either repeated the supramaximal test (4, 39) or repeated the incremental test (34) on a different day to confirm attainment of $\dot{V}O_{2max}$. However, like Barker et al (7), the present study only conducted one incremental test followed by a verification test on the same day. The verification test could be repeated on a different day to confirm $\dot{V}O_{2max}$, although a study that used a similar approach did not find significant differences in $\dot{V}O_{2max}$ between verification tests performed on two separate days in adults (39).

Since there was a change in the work rate increment from 15W to 10W after the study had already commenced, almost half of the participant population included children that returned for testing 1 yr later. Thus, the final sample reported in this paper included only children that had undergone an incremental test with 10W work rate increments, including two children that were 12.5 and 12.8 yr. We believe that comparing children that underwent the same incremental test protocol followed by the verification test was the best methodological approach. Our analyses demonstrated that the difference between incremental and verification test $\dot{V}O_2$ values were similar for tests that used 15W and 10W increments, which supports our results. It is also difficult to ascertain whether the children who returned after 1 yr performed better during the incremental test due to habituation with the protocol. However, the difference between incremental and verification $\dot{V}O_2$ was similar for children that were tested either before or after 1 yr using a 10W increment protocol (data not reported), suggesting that any effects of habituation may have been minimal.

Conclusion

We showed that the highest verification $\dot{V}O_2$ values were significantly higher than incremental values for 10 – 12 yr obese and nonobese children. We also showed that a two-step protocol that includes both incremental and verification testing should be utilized instead of primary or secondary criteria, which lack adequate sensitivity and specificity for validating an incremental test. Since cardiorespiratory fitness is an important marker for health and there are inherent difficulties in validating an incremental exercise test in children, researchers should utilize a two-step protocol that includes both incremental and verification testing for measuring $\dot{V}O_{2max}$.

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Figure 1.

Study flowchart. Dotted lines show participant follow-up after 1 year of initial testing. [#]

Indicates participants included in the final analyses comparing incremental and verification tests (N=18); *Positive for bronchodilator reversibility (N=5), Did not meet BMI percentile criteria for nonobese or obese (N=1), Could not tolerate mouthpiece (N=1); [†]Time constraints for parent (N=1), Nose clip fell off during test and child did not agree to repeat testing (N=1)

Figure 2.

Bland-Altman plot showing difference in oxygen uptake ($\dot{V}O_2$) between the highest $\dot{V}O_2$ achieved during the verification tests (Verif) and the incremental test (Incr) for each participant. Mean bias is showed by the solid line and ± 1.96 S.D is showed by dotted lines; numbers at the end of each line represent the values for mean bias and ± 1.96 S.D.

Table 1

Characteristics for participants that underwent a maximal exercise test with 10W increments followed by a verification test.

	Nonobese (N = 9)	Obese (N = 9)	P value
Sex (N)	5 M/4 F	6 M/3 F	0.500
Tanner Stage (1 to 5, N)	3,4,1,0,1	1,1,4,3,0	0.072
Age (year)	11.3 ± 0.6	11.7 ± 0.7	0.130
Height (cm)	146.9 ± 5.7	151.9 ± 8.8	0.167
Weight (kg)	39.3 ± 5.4	69.1 ± 17.4	0.001
BMI (kg·m ⁻²)	18.2 ± 1.8	29.5 ± 4.6	<0.001
BMI percentile (CDC)	57.5 ± 23.2	97.9 ± 1.4	0.001
BMI z-score	0.21 ± 0.67	2.13 ± 0.33	<0.001
Body Fat (%)	28.2 ± 6.0	45.9 ± 3.3	<0.001
Fat free mass (kg)	28.2 ± 4.1	37.2 ± 8.7	0.017

CDC: Centers for Disease Control

Table 2

Physiological parameters obtained at maximal exercise during the incremental and verification exercise tests for nonobese and obese children.

	Nonobese		Obese	
	Incremental	Verification	Incremental	Verification
$\dot{V}O_2$				
L·min ⁻¹	1.57 ± 0.27	1.71 ± 0.31 *	1.84 ± 0.48	1.94 ± 0.47 *
% Predicted $\dot{V}O_{2max}$ #	103 ± 6	113 ± 11 *	107 ± 16	113 ± 16 *
mL·min ⁻¹ ·kg body mass ⁻¹	39.9 ± 4.6	43.4 ± 4.6 *	26.8 ± 4.3	28.2 ± 3.5 *
mL·min ⁻¹ ·kg fat free mass ⁻¹	55.5 ± 3.8	60.4 ± 4.0 *	49.4 ± 5.7	52.2 ± 5.3 *
Heart Rate				
beats per minute	189 ± 6	184 ± 8	190 ± 13	188 ± 12
% Age Predicted HR _{max}	88 ± 3	86 ± 4	88 ± 6	88 ± 6
RER	1.12 ± 0.05	1.10 ± 0.09	1.07 ± 0.07	1.03 ± 0.12
$\dot{V}_E$ (L·min⁻¹)	65.4 ± 9.7	69.1 ± 12.7	67.2 ± 12.3	68.1 ± 19.4
$\dot{V}_E/\dot{V}CO_2$	37.7 ± 3.8	35.1 ± 5.2	37.0 ± 3.2	34.2 ± 4.2
Work Rate (W)	109 ± 24	114 ± 25 *	113 ± 23	119 ± 24 *
Time to Exhaustion (s)	575 ± 145	135 ± 34	606 ± 149	125 ± 33
$\dot{V}O_2$/Work Rate (mL·min⁻¹·W⁻¹)	12.5 ± 1.1	—	11.6 ± 2.2	—

RER: Respiratory exchange ratio; $\dot{V}O_2$: oxygen uptake; $\dot{V}_E$: minute ventilation; $\dot{V}CO_2$: expired carbon dioxide; W: Watts; s: seconds;

* Indicates a significant main effect of Incremental vs Verification test $P < 0.05$;

Predicted using equations from Krahenbuhl et al (13)

Attainment of primary and secondary validity criteria from the maximal exercise test and measured vs. predicted difference in $\dot{V}O_2$ at maximum levels between incremental and verification tests for individual participants. Sensitivity, specificity, positive predictive value, and negative predictive value analyses are shown for primary and secondary criteria.

Table 3

Primary Criterion		Secondary Criteria								
Participants	$\dot{V}O_2$ Plateau	HR 90% APHR _{max}	RER 1.00	RER 1.10	Signs of intense effort	INCR $\dot{V}O_{2max}$ (L·min ⁻¹)	VERIF $\dot{V}O_{2max}$ (L·min ⁻¹)	Measured $\dot{V}O_2$ (mL·min ⁻¹)	Predicted $\dot{V}O_2$ * (mL·min ⁻¹)	Measured> Predicted?
Nonobese										
1			x	x	x	1.378	1.493	115	58	Yes
2			x	x	x	1.298	1.417	119	52	Yes
3		x	x	x	x	1.206	1.341	135	41	Yes
4	x		x	x	x	1.632	1.922	290	76	Yes
5		x	x		x	1.583	1.588	5	67	No
6	x		x	x	x	1.522	1.554	32	75	No
7	x		x	x	x	1.955	2.059	104	90	Yes
8		x	x	x	x	1.545	1.727	182	61	Yes
9	x		x		x	1.977	2.267	290	92	Yes
Obese										
10		x	x	x	x	1.479	1.470	-9	61	No
11		x	x	x	x	2.336	2.494	158	94	Yes
12			x		x	1.322	1.519	197	49	Yes
13	x		x		x	2.568	2.457	-111	119	No
14			x	x	x	1.468	1.467	-1	44	No
15		x			x	2.206	2.239	33	66	No
16		x	x	x	x	1.267	1.406	139	37	Yes
17	x		x		x	2.14	2.356	216	74	Yes
18	x		x		x	1.769	2.014	245	64	Yes
Sensitivity: TP/(TP+FN)		27%	100%	43%	100%					
Specificity: TN/(TN+FP)		44%	8%	27%	0%					
PPV: TP/(TP+FP)		29%	29%	27%	33%					
NPV: TN/(TN+FN)		36%	100%	43%	—					

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$\dot{V}O_2$: oxygen uptake; HR: heart rate; $APHR_{max}$: age predicted maximal heart rate; RER: respiratory exchange ratio; INCR: incremental test; VERIF: verification test. x= criterion achieved; TP: true positive; TN: true negative; FP: false positive; FN: false negative; PPV: Positive predictive value; NPV: Negative predictive value;

$$\begin{aligned} \dot{V}O_{2\text{ Measured}} &= \text{Measured Verification } \dot{V}O_2 - \text{Measured Incremental } \dot{V}O_2; \\ \dot{V}O_{2\text{ Predicted}} &= \text{Predicted Verification } \dot{V}O_2 - \text{Predicted Incremental } \dot{V}O_2 \end{aligned}$$