Using the Oxygen Uptake Efficiency Slope as an Indicator of Cardiorespiratory Fitness in the Obese Pediatric Population

Peter G. Breithaupt, Rachel C. Colley, and Kristi B. Adamo
Children’s Hospital of Eastern Ontario Research Institute and University of Ottawa

The aim of the current study was to investigate the relationship between the Oxygen Uptake Efficiency Slope (OUES) and traditional measures of cardiorespiratory function in an overweight/obese pediatric sample. Maximal treadmill exercise testing with indirect calorimetry was completed on 56 obese children aged 7–18 years. Maximal OUES, submaximal OUES, VO2peak, V̇Epeak, and ventilatory threshold (VT) were determined. In line with comparable research in healthy-weight samples, maximal and submaximal OUES were both correlated with VO2peak, V̇Epeak, and VT (r^2 = 0.44–0.91) in the obese pediatric sample. Correlations were also found with anthropometric variables, including height (cm), body surface area (m^2), body mass (kg), and fat free mass (kg). In comparing our data to a published sample of healthy weight children, maximal and submaximal exercise OUES were both higher in our obese sample. However, when we adjusted for any of body mass (kg), BSA (m^2), or FFM (kg) the obese children were found to be less efficient. The results of this study suggest the use of OUES to be an appropriate measure of efficiency of ventilation and cardiorespiratory function in obese children, while also showing that our sample of obese children were less efficient on a per kilogram basis when compared with their healthy weight peers.

Rates of obesity and its associated comorbidities are high among children and youth worldwide (14,18,20,27). As childhood obesity has increased, there has been a concurrent decline in fitness in this population (23–25). When compared with healthy-weight individuals, obese individuals display the poorest cardiorespiratory fitness, muscle endurance, and performance on explosive power tests (10).

Cardiorespiratory fitness is a powerful indicator of health in children (19). Therefore, accurate measurements of cardiorespiratory fitness are essential for

Breithaupt is with the Healthy Active Living and Obesity Research Group, Children’s Hospital of Eastern Ontario Research Institute, Ottawa, Ontario, Canada; the School of Human Kinetics, Faculty of Health Sciences, University of Ottawa, Ottawa, Ontario, Canada; and Colley and Adamo are with the Healthy Active Living and Obesity Research Group, Children’s Hospital of Eastern Ontario Research Institute, Ottawa, Ontario, Canada; the School of Human Kinetics, Faculty of Health Sciences, University of Ottawa, Ottawa, Ontario, Canada; and the Faculty of Medicine, Pediatrics, University of Ottawa, Ottawa, Ontario, Canada.
gaining a better understanding of the relationships between fitness and health as well as facilitating the rigorous evaluation of intervention programs and behavior change strategies (3,19). Maximal exercise testing; or the measurement of maximal oxygen uptake (VO$_{2\text{max}}$), is generally regarded as the gold standard for assessing cardiorespiratory fitness and equates to the highest rate at which an individual can consume oxygen during exercise without physiologic, psychological or biomechanical strain (21). Given that successful maximal exercise testing is difficult for a fit population, it is not surprising that this difficulty is magnified in an obese, pediatric population (13). Submaximal indicators of cardiorespiratory fitness hold promise for this population because these intensities are better tolerated and more reflective of the intensity of movement obese children would undertake in the real world (17).

Originally proposed by Baba et al. (4) as a submaximal index of cardiorespiratory functional reserve, the oxygen uptake efficiency slope (OUES) has been examined in multiple healthy-weight samples (4,5,9,16). There has also been work examining the use of OUES in those with heart disease (4,26). OUES is derived from the relationship between oxygen uptake (VO$_2$ [mL/min]) and minute ventilation (VE [L/min]). OUES is determined by:

$$\text{VO}_2 = a \log \text{VE} + b,$$

where $a =$ OUES (4)

OUES has been found to be sensitive to the effects of physical training, making it a strong predictor of change in cardiorespiratory fitness over time (2). Since OUES is highly dependent on anthropometric variables, it has been recommended that it should be expressed relative to body surface area (BSA) or fat free mass (FFM; 1); a methodology often employed to examine differences in oxygen uptake between healthy-weight and obese individuals. To the best of our knowledge there has been limited research exploring OUES in overweight or obese children and adolescents (9,15).

Although wide interindividual variation in OUES has been reported (9), its strong correlations with VO$_{2\text{peak}}$ (16), peak minute ventilation (VE peak), and ventilatory threshold (VT; 1) suggest OUES has the ability to be a valid index for cardiorespiratory reserve. In addition, the development of appropriate reference values is lacking for specific populations (e.g., pediatric obesity; 1, 2, 4, 16). Taking into account these suggestions and gaps, the aim of the current study was to characterize submaximal and maximal OUES in an obese pediatric sample and compare these parameters to published data from a healthy-weight pediatric sample (1).

**Methods and Procedures**

**Subjects**

A sample of obese children ($³$ 95th WHO body mass index (BMI) percentile, 7–18 years; www.who.int/growthref) were recruited from the Children’s Hospital of Eastern Ontario (CHEO) pediatric endocrinology clinic to participate in the Physiological and psychological predictors and determinants of metabolic complications of pediatric obesity (POC) study (Canadian Diabetes Association Innovation Grant #IG-1–07–2307-KA). All new patients visiting the pediatric endocrinology clinic for obesity assessment were eligible to participate. POC Participants were required to complete a maximal cardiorespiratory fitness test as part of their study assessment.
The study protocol was approved by the CHEO Research Ethics Board. Informed consent (≥16 years) or parental consent and assent (<16 years) was obtained before study initiation as required by the institutional ethics board.

**Instrumentation**

**Anthropometric Measures.** Body mass (kg) was assessed by use of a medical-grade SECA 634 digital scale. Height (cm) was assessed using a SECA 222 stadiometer. BMI (kg/m²) was calculated and BMI percentiles were determined based on WHO BMI percentiles (www.who.int/growthref). Based on the equation of Haycock et al. (12), which has been validated in infants, children, and adults, BSA was calculated using (where Ht is height in cm and Wt is body mass in kg):

\[
BSA (m^2) = 0.024265 \cdot Ht^{0.03964} \cdot Wt^{0.5378}
\]

**Body Composition Measures.** Percentage body fat and FFM (kg) were estimated using a DXA scan which was required as part of the study participants’ initial POC assessment (7). Measurements were made by a Medical Radiation Technologist using the GE Lunar Prodigy ADVANCE DEXA scanner (GE Healthcare, Madison, WI). Before any measurements, secondary calibration and quality assurance measurements of the DXA machine were completed. The Prodigy ADVANCE provides direct calculation of total fat, lean tissue mass, and bone mineral content, density and area for the pediatric population. Results are calculated automatically, via DXA software, for bone mineral density (BMD), fat tissue, and lean tissue for the total body & subregions. Scan analysis was performed using GE enCORE 11.40 software (GE Healthcare, Madison, WI).

**Cardiorespiratory Fitness Measures.** Cardiorespiratory fitness was measured using a progressive maximal treadmill test, developed by Gutin et al. (11). This assessment was completed by all participants as part of their POC study assessment. Oxygen consumption (VO₂) was measured using breath-by-breath analyses via a MedGraphics Ultima (Medical Graphics Corporation, St. Paul, Minn.) metabolic cart. Before each exercise test, the gas analyzers and flowmeter were calibrated using gas mixtures of known concentrations and a 3-L syringe. Exercise heart rate (HR) was measured with a Polar HR monitor (Polar FT7, Polar Electro Canada Inc., Lachine, Quebec). Following a 4-min warm-up at a self-selected walking speed, participants were asked to walk at a speed of 2.0, 2.5, 3.0, or 3.5 miles per hour (mph) and a grade of 0%. The speed was then increased by 0.5 mph after 2 min and remained at this speed for the remainder of the test. The grade was increased by 2% every 2 min from then on until the participant indicated that they were unable to continue. Data from this protocol supplied maximal exercise indicators such as peak HR, peak respiratory exchange ratio (RER), and measured peak oxygen consumption values. To be considered a maximal effort the participant must have achieved 2 of the following 4 criteria: i) oxygen plateau achieved (< 2 mL·kg⁻¹·min⁻¹ increase in VO₂ with increasing work rate), ii) HR > 200bpm, iii) RER > 1.0, or iv) volitional fatigue. Maximal OUES was measured by assessing the slope of the line up throughout maximal testing. Submaximal OUES was measured by assessing the slope of the line up to a standard indicator point. Ventilatory threshold (VT), was used as the indicator for submaximal OUES measures, and was estimated using the V-slope method (6,22) in all participants.
Statistical Analysis

All statistical analyses were completed using SPSS 19.0 (SPSS, Chicago, IL). All data are presented as mean values ± SD and range where appropriate. Descriptive statistics were used to summarize the characteristics of the group with respect to BMI status, age, gender and cardiorespiratory testing parameters. Nonparametric T-tests were used to explore differences between male and female participants.

Continuous variables were summarized using mean, standard deviation, range, and interquartile range. Independent group t tests provided comparisons between maximal and submaximal OUES in obese and healthy-weight children. Both absolute and relative (i.e., OUES by body mass, BSA, and FFM) values were compared. Pearson correlation coefficients were calculated to examine the strength of relationship between both maximal and submaximal OUES in absolute and relative terms with exercise parameters (e.g., VO2peak, VT, VEpeak). One-way ANOVA was used to examine the impact of age and gender on all cardiorespiratory testing measures. Significance was set at $p < .05$.

Results

Fifty six participants consented to participate in this study (mean age = 14.4, 45% boys). Participant characteristics are depicted in Table 1. No significant differences were found between boys and girls in age, height, body mass, BMI; however, FFM and BSA were higher in boys when compared with girls and conversely, % BF was higher in girls when compared with boys.

Boys were found to have higher values of VT, VO2peak and VEpeak (Table 2). Moderate correlations were found between the submaximal OUES and basic anthropometric variables including height ($r = .61, p = .01$), BSA ($r = .50, p = .01$), body mass ($r = .61, p = .01$), age ($r = .39, p = .01$) and FFM ($r = .58, p = .01$), and BMI ($r = .33, p \leq .05$).

Table 1 Sample Characteristics

<table>
<thead>
<tr>
<th></th>
<th>Boys (n = 25)</th>
<th>Girls (n = 31)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean ± SD</td>
<td>(Range)</td>
</tr>
<tr>
<td>Age (years)</td>
<td>14.25 ± 1.70 (7.4–17.8)</td>
<td>14.50 ± 2.36 (9.4–18.2)</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>169.54 ± 10.41 (148.5–190.5)</td>
<td>162.06 ± 9.04 (145.0–180.0)</td>
</tr>
<tr>
<td>Body mass (kg)</td>
<td>106.26 ± 20.25 (68.8–150.0)</td>
<td>97.73 ± 20.07 (56.4–130.6)</td>
</tr>
<tr>
<td>BMI (kg·m⁻²)</td>
<td>36.95 ± 6.48 (28.1–51.9)</td>
<td>35.76 ± 6.00 (26.5–53.5)</td>
</tr>
<tr>
<td>BSA (m²)</td>
<td>*2.27 ± 0.26 (1.8–2.8)</td>
<td>2.04 ± 0.36 (.72–2.5)</td>
</tr>
<tr>
<td>%BF (%)</td>
<td>*44.1 ± 7.29 (33.7–57.7)</td>
<td>50.56 ± 3.60 (45.8–55.4)</td>
</tr>
<tr>
<td>FFM (kg)</td>
<td>*58.10 ± 11.17 (30.7–74.8)</td>
<td>44.71 ± 8.92 (29.7–63.1)</td>
</tr>
</tbody>
</table>

Abbreviations: BMI = body mass index; BSA = body surface area; BF = percentage of body fat; FFM = fat free mass; *p £ 0.05.

*Only 21/25 boys, and 29/31 girls included.
<table>
<thead>
<tr>
<th></th>
<th>Boys ($n = 25$)</th>
<th>Girls ($n = 31$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean ± SD (Range)</td>
<td>Mean ± SD (Range)</td>
</tr>
<tr>
<td>HR$_{\text{peak}}$ (beats·min$^{-1}$)</td>
<td>192.7 ± 9.4 (178–207)</td>
<td>195.1 ± 10.4 (176–215)</td>
</tr>
<tr>
<td>RER$_{\text{peak}}$</td>
<td>1.09 ± 0.10 (0.79–1.27)</td>
<td>1.11 ± 0.07 (0.95–1.30)</td>
</tr>
<tr>
<td>VT (mL·min$^{-1}$)</td>
<td>1775.8 ± 545.1 (1025.0–2901.0)</td>
<td>1421.4 ± 347.4 (912.0–2633.0)</td>
</tr>
<tr>
<td>% VO$<em>2$$</em>{\text{peak}}$ at VT (%)</td>
<td>57.9 ± 10.9 (39.50–91.19)</td>
<td>57.2 ± 9.8 (41.1–78.9)</td>
</tr>
<tr>
<td>VO$<em>2$$</em>{\text{peak}}$ (mL·min$^{-1}$)</td>
<td>3113.3 ± 784.9 (1798.4–4320.5)</td>
<td>2498.9 ± 450.3 (1276.7–3585.9)</td>
</tr>
<tr>
<td>VO$<em>2$$</em>{\text{peak}}$/kg (mL·min$^{-1}$·kg$^{-1}$)</td>
<td>29.4 ± 6.0 (17.7–41.3)</td>
<td>27.2 ± 5.4 (18.51–37.5)</td>
</tr>
<tr>
<td>VO$<em>2$$</em>{\text{peak}}$/BSA (mL·min$^{-1}$·m$^{-2}$)</td>
<td>1360.5 ± 277.6 (890.0–1913.2)</td>
<td>1196.7 ± 188.3 (907.7–1608.4)</td>
</tr>
<tr>
<td>$^a$VO$<em>2$$</em>{\text{peak}}$/FFM (mL·min$^{-1}$·kg$^{-1}$)</td>
<td>54.9 ± 10.2 (28.9–67.4)</td>
<td>57.1 ± 9.1 (40.4–73.8)</td>
</tr>
<tr>
<td>V$_{\text{Epeak}}$ (L·min$^{-1}$)</td>
<td>105.1 ± 30.7 (47.6–162.5)</td>
<td>83.1 ± 20.3 (40.7–134.0)</td>
</tr>
<tr>
<td>V$_{\text{Epeak}}$/kg (L·min$^{-1}$·kg$^{-1}$)</td>
<td>1.0 ± 0.4 (0.6–2.2)</td>
<td>0.90 ±0.2 (0.4–1.3)</td>
</tr>
<tr>
<td>V$_{\text{Epeak}}$/BSA (L·min$^{-1}$·m$^{-2}$)</td>
<td>46.2 ± 13.6 (26.68–86.41)</td>
<td>39.8 ± 9.0 (18.7–57.7)</td>
</tr>
<tr>
<td>$^a$V$_{\text{Epeak}}$/FFM (L·min$^{-1}$·kg$^{-1}$)</td>
<td>1.9 ± 0.3 (1.4–2.4)</td>
<td>1.9 ± 0.4 (0.7–2.7)</td>
</tr>
</tbody>
</table>

Abbreviations: HR = heart rate; RER = respiratory exchange ratio; VT = ventilator threshold; FFM = fat free mass; VO$_2$ = oxygen uptake; BSA = body surface area; FFM = fat free mass; OUES = oxygen uptake efficiency slope. $^a$p ≤ .05.

$^a$Only 21/25 boys, and 29/31 girls included.
Maximal and submaximal measure of OUES were strongly correlated with each other \((r=0.77, p < .001)\). Maximal OUES was highly correlated with \(VO_{2peak}\) and VT, while moderately correlated with \(V_{Epeak}\). When adjusted for BSA and body mass (kg) the correlations between maximal OUES and \(VO_{2peak}\), \(V_{Epeak}\), and VT were lower but remained moderately significant, while the correlation was no longer significant after adjustment for FFM. Absolute submaximal OUES was strongly correlated with \(VO_{2peak}\) but only moderately correlated with \(V_{Epeak}\), and VT. When adjusted for body mass and BSA, correlations between submaximal OUES-\(VO_{2peak}\), \(V_{Epeak}\), and VT declined yet remained moderately significant, with the exception of submaximal OUES/kg and \(V_{Epeak}\). Once again, after adjusting for FFM these correlations were no longer significant (Table 3).

In comparing our obese sample to the healthy-weight sample described by Akkerman et al. (1), our sample of obese children had, on average, higher absolute maximal OUES \((p < .01)\) and submaximal OUES values \((p < .10)\) (Table 4). When adjusted for body mass (kg), BSA \((m^2)\), or FFM (kg), both maximal and submaximal OUES values were lower in our obese sample compared with the healthy-weight sample \((p < .01; \text{Figure 1})\).

### Discussion

This study describes the relationship between OUES and other measures of cardiorespiratory fitness in a sample of obese children, aged 7–18 years. The relationship between submaximal and maximal OUES is not yet clearly established with some studies having shown slight, but significant differences between the two (4,9,15), while others report no significant differences (1,16). Our data supports the latter case. Our study confirmed a number of published trends observed in healthy-weight

<table>
<thead>
<tr>
<th>Table 3</th>
<th>Correlation Coefficients Denoting the Relationship Between OUES and Exercise Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>VO(_{2peak}) (L/min.)</td>
<td>VO(_{2peak}) (mL/kg/min.)</td>
</tr>
<tr>
<td>Maximal OUES</td>
<td>*0.91</td>
</tr>
<tr>
<td>Maximal OUES/kg</td>
<td>*0.48</td>
</tr>
<tr>
<td>Maximal OUES/BSA</td>
<td>*0.76</td>
</tr>
<tr>
<td>αMaximal OUES/FFM</td>
<td>0.18</td>
</tr>
<tr>
<td>Submaximal OUES</td>
<td>*0.71</td>
</tr>
<tr>
<td>Submaximal OUES/kg</td>
<td>**0.35</td>
</tr>
<tr>
<td>Submaximal OUES/BSA</td>
<td>*0.54</td>
</tr>
<tr>
<td>αSubmaximal OUES/FFM</td>
<td>0.12</td>
</tr>
</tbody>
</table>

Abbreviations: BSA = body surface area; kg= kg of body mass; FFM = fat free mass; \(VO_{2peak}\) = peak oxygen consumption; \(V_{Epeak}\) = peak minute ventilation; VT = ventilatory threshold; *\(p = 0.01\), **\(p \leq 0.05\).

αOnly 21/25 boys, and 29/31 girls
<table>
<thead>
<tr>
<th></th>
<th>Obese Population</th>
<th>Healthy-Weight Population</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Boys (n = 25)</td>
<td>Girls (n = 31)</td>
</tr>
<tr>
<td><strong>HR peak (beats·min⁻¹)</strong></td>
<td>192.7 ± 9.4</td>
<td>195.1 ± 10.4</td>
</tr>
<tr>
<td><strong>RER peak</strong></td>
<td><strong>1.09 ± 0.11</strong></td>
<td><strong>1.11 ± 0.07</strong></td>
</tr>
<tr>
<td><strong>VT (mL·min⁻¹)</strong></td>
<td>***1775.8 ± 545.1</td>
<td>1421.4 ± 347.4</td>
</tr>
<tr>
<td><strong>VO₂ peak (mL·min⁻¹)</strong></td>
<td>*3113.3 ± 784.9</td>
<td>2498.9 ± 450.3</td>
</tr>
<tr>
<td><strong>VO₂ peak/kg (mL·min⁻¹·kg⁻¹)</strong></td>
<td>*29.4 ± 6.0</td>
<td>*27.2 ± 5.4</td>
</tr>
<tr>
<td><strong>VO₂ peak/BSA (mL·min⁻¹·m⁻²)</strong></td>
<td>*1360.5 ± 277.6</td>
<td>*1196.7 ± 188.3</td>
</tr>
<tr>
<td><strong>αVO₂ peak/FFM (mL·min⁻¹·kg⁻¹)</strong></td>
<td>*54.9 ± 10.2</td>
<td>57.07 ± 9.1</td>
</tr>
<tr>
<td><strong>Ve peak (L·min⁻¹)</strong></td>
<td>*105.1 ± 30.7</td>
<td>83.1 ± 20.3</td>
</tr>
<tr>
<td><strong>Ve peak/kg (L·min⁻¹·kg⁻¹)</strong></td>
<td>*1.01 ± 0.35</td>
<td>*0.90 ± 0.23</td>
</tr>
<tr>
<td><strong>Ve peak/BSA (L·min⁻¹·m⁻²)</strong></td>
<td>*46.2 ± 13.6</td>
<td>*39.8 ± 9.0</td>
</tr>
<tr>
<td><strong>αVe peak/FFM (L·min⁻¹·kg⁻¹)</strong></td>
<td>*1.86 ± 0.3</td>
<td>1.88 ± 0.4</td>
</tr>
<tr>
<td><strong>Maximal OUES</strong></td>
<td>*3362.4 ± 766.1</td>
<td><strong>2727.7 ± 509.2</strong></td>
</tr>
<tr>
<td><strong>Maximal OUES/kg</strong></td>
<td>*32.0 ± 6.1</td>
<td>*29.5 ± 5.5</td>
</tr>
<tr>
<td><strong>Maximal OUES/BSA</strong></td>
<td>**1475.0 ± 264.6</td>
<td>*1303.2 ± 196.3</td>
</tr>
<tr>
<td><strong>αMaximal OUES/FFM</strong></td>
<td>59.7 ± 10.9</td>
<td><strong>62.6 ± 8.9</strong></td>
</tr>
<tr>
<td><strong>Submaximal OUES</strong></td>
<td>*2733.4 ± 619.5</td>
<td>2315.6 ± 629.6</td>
</tr>
<tr>
<td><strong>Submaximal OUES/kg</strong></td>
<td>*25.8 ± 4.5</td>
<td>*24.8 ± 6.0</td>
</tr>
<tr>
<td><strong>Submaximal OUES/BSA</strong></td>
<td>*1191.7 ± 214.6</td>
<td>*1101.6 ± 255.9</td>
</tr>
<tr>
<td><strong>αSubmaximal OUES/FFM</strong></td>
<td>*48.7 ± 10.2</td>
<td><strong>52.1 ± 13.6</strong></td>
</tr>
</tbody>
</table>

Abbreviations: HR = heart rate; RER = respiratory exchange ratio; VT = ventilator threshold; FFM = fat free mass; VO₂ = oxygen uptake; BSA = body surface area; FFM = fat free mass; OUES = oxygen uptake efficiency slope. Presented as, Mean ± SD. Healthy-weight population values adapted from Akkerman et al., 2011 (22). Significances measured between samples are gender specific. *p ≤ 0.01, **p ≤ .05, ***p ≤ 0.10. αOnly 21/25 boys, and 29/31 girls included.
Breithaupt, Colley, and Adamo

Children (1,2,15,16), including OUES being strongly correlated with exercise parameters such as VO₂peak, Vₑpeak, and VT. Strong correlations between maximal and submaximal OUES and baseline measures of height, BSA, body mass, FFM, and age were also present.

Akkerman et al. (2010) examined the characteristics of OUES in 46 (27 boys and 19 girls) healthy-weight and similarly aged children (aged 7–17 years; 1) and reported comparable results to those in the current study. Our mean absolute OUES values, calculated during maximal exercise, were higher than those measured in a healthy-weight sample (1) for both boys and girls (3362.4 ± 766.1 vs. 2185.2 ± 676.2 for boys, and 2727.7 ± 509.2 vs. 2237.0 ± 759.5 for girls, where $p < .05$ respectively). Our higher OUES values may be explained, in part, by the use of treadmill testing given there are strong correlations between OUES and VO₂peak and that VO₂peak is generally higher on a treadmill vs. cycle ergometer test (8). Another possible contributor might be our higher mean age (14 vs. 12 years) and the linear relationship found between increasing age and OUES in other samples (2). The higher absolute maximal and submaximal exercise OUES values could be attributed to the larger body size in obese children, given its strong association with body size and BSA in other samples (2). Conversely, maximal and submaximal exercise OUES were both lower in our obese sample when compared with the healthy-weight sample described by Akkerman et al. (1) when we adjusted for any of body mass (kg), BSA (m²), or FFM (kg). Overall, these findings suggest that our sample of obese children were less efficient on a per kilogram basis when compared with their healthy-weight peers (1).

Figure 1 — Absolute and relative (by body mass, FFM, BSA) OUES and submaximal OUES values.
Only two other studies have looked at OUES in overweight (9) and obese
(15) children. Drinkard et al., (2007) compared 107 overweight children to 43
nonoverweight children and found there were stark differences between the two
groups. This study required all children to perform a maximal cycle ergometer
test and then examined OUES at three different exercise intensities. Most notably
they found that when adjusted for lean body mass, both VO_{2peak} and OUES were
lower in overweight subjects (p < .0001) at all exercise intensities (9). Marinov
and Kostianev compared 30 obese children to 30 healthy-weight children (15 boys
and 15 girls, aged 6–17 years, in each group) using standardized exercise tests
and found that despite having greater absolute values for oxygen uptake, after
adjusting for body mass, cardiorespiratory fitness in the obese was lower than
their healthy-weight counterparts. They also found powerful relationships between
OUES and both height and weight, as well as between maximal and submaximal
OUES (14). In our sample, larger body mass led to increased absolute OUES and
oxygen consumption values. This might erroneously lead one to believe that the
obese sample is more efficient than the healthy-weight group; however, this was
not the case after adjusting for body mass, FFM or BSA. In comparing different
study samples, it is most appropriate to use values that have been adjusted for
anthropometric values such as body mass, FFM, or BSA. Both previously pub-
lished studies that examined OUES in overweight/obese children found strong
correlations between OUES and VO_{2peak} (9,15); another relationship confirmed
through our analyses. Together these findings provide support for OUES as a
supplemental or alternative measure to track or assess cardiorespiratory fitness
and efficiency in obese children.

OUES does appear to have some merit as a submaximal index of cardiorespi-
atory fitness in the obese pediatric population. As found in our obese sample,
measures of both maximal and submaximal exercise OUES both have a consoli-
dated relationship with VO_{2peak}; a finding consistent across healthy-weight pediatric
(1,16) and adult (2,4,26) populations. In comparing measures of OUES in obese
vs. healthy-weight, it seems reasonable to suggest that OUES may be able to dif-
ferrate between changes in cardiorespiratory fitness in different groups, especially
when adjusting for anthropometric variables such as BMI, BSA or FFM. Given its
correlations with cardiorespiratory fitness measures, using submaximal OUES as a
supplementary or alternative measure of cardiorespiratory fitness or efficiency may
be of great benefit for assessing or tracking these outcomes in a clinically obese,
pediatric population. Further research should be completed comparing the obese
to healthy-weight samples on measures of efficiency and, to increase the clinical
usefulness of OUES measure, continuing research could lead to the development
of adequate OUES reference values in all populations.

Limitations in this study include being unable to compare more than means
and standard deviations with the healthy weight population as well as the use of
V-slope method for determination of VT. While the V-slope method has shown
good interobserver agreement between and across exercise protocols (22), this
methodology does have the potential for inaccuracy during VT estimation. Ide-
ally a healthy-weight control group would have been assessed concurrently with
the obese group to ensure consistency of measures; instead an external group of
similar age and having completed similar exercise testing was used for compara-
tive purposes. Considered potentially both a limitation and strength, our study
participants were all clinically obese (BMI > 95th percentile). This is a limitation because the homogeneous population limits our ability to extrapolate or generalize our findings. However, the specificity can also be considered a strength, because it provides much-needed data on a population known to incur difficulties with the assessment of cardiorespiratory fitness. Considering the aim of the study was to explore alternatives to maximal exercise testing in obese children, it was important to us to include participants from the highest BMI percentiles who are often excluded from exercise-based research. Other strengths of this study include the use of indirect calorimetry for the cardiorespiratory fitness testing providing robust oxygen uptake data, and having DXA scan data for precise representation of body composition allowed us to adjust OUES measures based on accurate assessments. Further strengths include equal distribution of males and females, and being one of the first studies to assess the use of OUES in a clinically obese pediatric population while providing comparisons to a healthy-weight sample population.

The usefulness of OUES as a comparative measure between differing populations has yet to be confirmed and given its responsiveness to physical training in adults (2), we can speculate that the OUES may be a useful clinical measure for tracking the cardiorespiratory fitness of participants, especially for those unable or unwilling to complete maximal exercise testing. Given submaximal OUES can be measured during exercise effort up to VT, this would be particularly useful in the obese pediatric population where there are many motivational and subjective factors that deter or prevent this population from completing maximal testing.

Conclusion

Similar to trends found in healthy-weight children, OUES was found to correlate highly with exercise parameters (such as VO$_{2\text{peak}}$, VE$_{\text{peak}}$, and VT), independent of exercise intensity. OUES is noticeably affected by anthropometrics in this population; a finding consistently reported in other populations. In comparing our obese population to published data from a healthy-weight population of similar age (1), we found that our population of obese children had higher absolute maximal and submaximal OUES values but were less efficient than their healthy-weight counterparts when OUES measures were adjusted for body mass (kg), BSA (m$^2$), and FFM (kg). Future work focusing on the utility of OUES with this unique population, as well as all other populations, is encouraged.

Acknowledgments

The authors wish to thank Jane Rutherford, Allana Leblanc and Alysha Harvey for their assistance in performing this project. A special thank you is also expressed to Dr. Stasia Hadjiyannakis, head of endocrinology at CHEO, and CHEO’s Centre for Healthy Active Living for their support. This work was funded by the Canadian Diabetes Association Innovation Grant #IG-1-07-2307-KA and equipment supplied through a CFI/ORF Leaders Opportunity Fund Grant.
References


