Oxygen-Uptake Efficiency Slope in Healthy 7- to 18-Year-Old Children

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The aim of this article was to assess the oxygen-uptake efficiency slope (OUES) throughout the age span of 7 to 18 years. One hundred fourteen healthy children (58 boys and 56 girls) exercised on a treadmill by means of a modified Balke protocol. The OUES grew in a nonlinear pattern with age, and it appeared to be significantly higher in boys than in girls. There was a very strong correlation between OUES and $V_{O2peak}$ ($r = .92$), and there was a small difference between the values of OUES calculated for different exercise intensities. Stepwise-regression analysis outlined body surface area (BSA) and sex as main determinants of OUES. OUES is an objective measure of exercise capacity that does not require a maximal effort but is considerably dependent on anthropometric variables and necessitates the generation of appropriate reference values.

Understanding the cardiorespiratory functional-reserve changes that occur throughout childhood and adolescence is a major issue in developmental exercise physiology. Data are usually limited to maximal oxygen uptake ($VO_{2max}$) (1,15,21), which has always been an intensively sought paradigm, but in certain populations with obesity, chronic diseases, or low fitness levels it is generally difficult to obtain (16). $VO_{2max}$ is effort dependent and therefore largely influenced by one’s motivation (3,23). Several research groups have already proposed a number of submaximal indices for evaluating functional capacity without requiring participants to perform maximal exercise (6,9,12). In 1996 Baba et al., in an endeavor to develop an objective and independent measure of cardiorespiratory reserve, introduced the oxygen-uptake efficiency slope (OUES)—a single-segment logarithmic curve-fitting model describing the ventilatory response to exercise. It was initially applied to a cohort of children with heart disease (3) and later validated by Hollenberg and Tager (10) on a large sample of adults. The latter also proposed prediction equations for the OUES in adults. Baba et al. (2) reported excellent reproducibility of the OUES, and Van Laethem et al. (22) recently proved that it is stable over the entire exercise duration and significantly correlated with $V_{O2peak}$. As the method gained popularity, the OUES was incorporated into research for evaluating exercise tolerance (4), monitoring the effects of exercise rehabilitation programs (20), detecting the improvement of cardiorespiratory reserve after endurance training (13), and predicting the outcomes of heart-transplant patients (13). Recently, Davies et al.
(7) declared the OUES to be better than standard cardiopulmonary-exercise-test-derived variables. To our knowledge, age and sex aspects of the OUES in children have not been systemically studied to assess developmental changes during exercise. The aim of this study was to make a cross-sectional assessment of the OUES throughout the age span of 7 to 18 years.

**Methods**

One hundred fourteen healthy children (58 boys and 56 girls) ages 7–18 years took part in the study. They were recruited from the schools of Plovdiv, South Bulgaria. All of the studied children were in good health and physically active but not engaged in competitive sports training. They were free from known chronic diseases and took no medications that might affect exercise performance. Before the test procedures, written informed consent was obtained from a parent or guardian for each participant and the associated risks and benefits were explained. The procedures used in this study were approved by the institutional ethics committee at the Medical University of Plovdiv.

**Study Design**

The applied modification of the Balke treadmill protocol was previously validated (11) on a large population-based sample of children ages 7–18 years. It consisted of two warm-up stages at 2.7 and 4.0 km/h and nine 1-min increments with constant velocity of 5.4 km/h starting at 6% incline and increasing 2% every minute until exhaustion or an incline of 22%. The recovery period was a standard 3-min duration (2.7 km/h and zero elevation). This protocol was well standardized, and the exercise intensity appeared be almost identical to that of the Bruce protocol. At the same time, the modified Balke protocol was shorter and more suitable for children of different ages. By standardizing the protocol, we intended to create a common ground for unbiased comparisons between groups.

Twelve groups with evenly distributed ages were created, and each was matched by sex. Seven height groups (intervals of 10 cm) were additionally delineated to investigate the influence of physical-growth heterogeneity on interpretation of exercise parameters.

**Treadmill Exercise Test**

The treadmill test was scheduled for the morning hours in a laboratory compliant with the guidelines of the American Heart Association (14). The children were habituated to both the general environment and the specific procedures. The cardiopulmonary exercise test was carried out on a motor-driven, electronically controlled treadmill (TrackMaster, JAS Fitness Systems, Pensacola, FL, USA). Heart rate was monitored electrocardiographically (Hellige, Freiburg, Germany), and oxygen saturation was traced with a pulse oximeter, Pulseox DP-8 (Minolta, Osaka, Japan).

At the end of each exercise increment and throughout the recovery period the children were asked to rate their perceived exertion using the category-ratio Borg
scale (5) depicting fatigue (dyspnea) from not at all to maximal by means of 10 grades.

**Gas-Exchange Measurements**

Throughout the test, gas-exchange variables were determined with an online computerized system, CardiO2 (Medical Graphics, St. Paul, MN, USA) using standard open-circuit techniques. Participants breathed through a mouthpiece, and a pneumotachometer was used for recording tidal volume (VT; ml/min, body temperature pressure saturated) and minute ventilation (VE; L/min, body temperature pressure saturated). Expired-gas samples were analyzed for oxygen and carbon dioxide by zirconium oxide and infrared analyzers, respectively. Data were averaged every 30 s and were used to calculate oxygen uptake (VO$_2$; ml/min, standard temperature pressure diluted), carbon-dioxide production (VCO$_2$; ml/min, standard temperature pressure diluted), and respiratory-exchange ratio. The system was calibrated before each test with gases of known concentrations.

Anaerobic threshold (AT) is determined as the level of VO$_2$ at which at least one of the following is present: increase in VE/VO$_2$ without simultaneous increase in VE/VCO$_2$ or disappearance of the linear relation between VCO$_2$ and VO$_2$ (V-slope method).

**Oxygen-Uptake Efficiency Slope**

The OUES is defined as a relationship between oxygen uptake (VO$_2$ in ml/min) and total exercise ventilation (VE in L/min). It is best described by an exponential function developed by Baba et al. (3):

$$VO_2 = a \log_{10} VE + b$$

The constant $a$ represents the rate of increase in VO$_2$ in response to VE and is termed the OUES. The index can be graphically presented if VO$_2$ is plotted on the $y$ axis and the VE is plotted on the semilog-transformed $x$ axis. Thus, for any given amount of ventilation, a steeper slope indicates greater oxygen uptake during exercise. Theoretically, the OUES is not affected by exercise intensity. To verify that assumption, the OUES was calculated from data up to AT (OUES$_{AT}$) and 100% of exercise duration. The data used to calculate the OUES were averaged at 30-s intervals.

To assess ventilatory efficiency, we applied the method developed recently by Sun et al. (19) using the lowest value (calculated as a mean of the three lowest values) of the ratio VE:VCO$_2$. Participants breathed through a mouthpiece and a light-weight, low-dead-space pneumotach during the test. The mechanical dead-space volume was determined by water displacement and, depending on the type of mouthpiece (with or without saliva trap, respiration), ranged from 50 to 70 ml.

**Other Measurements**

Before the test all participants underwent a thorough clinical examination and were subjected to complete anthropometric measurements including height, body mass, and skinfold thickness over the triceps and subscapular regions. The measurements were performed on the right side of the body with calipers (Harpenden, British
Indicators, UK). The values of the skinfolds were added together, and the sum was used to calculate percent body fat (and the respective fat-free mass [FFM]) using Slaughter equations (18). Maturity was not assessed because it was beyond the scope of this study. Body surface area (BSA) was calculated using the equation of Gehan and Georges (8): \( \text{BSA} (\text{m}^2) = 0.02350 \times \text{Ht}^{0.42246} \times \text{Wt}^{0.51456} \), where Ht is height in centimeters and Wt is weight in kilograms.

**Statistical Analysis**

All values are expressed as \( M \pm SD \). Differences in the mean values were evaluated by analysis of variance (ANOVA), with multiple comparisons by the Bonferroni method. A level of \( p < .05 \) was considered statistically significant. The results from peak-exercise data, lung-function measurements, and their relationships with age and anthropometric variables were assessed using correlation, stepwise regression, and curve-estimation analysis in SPSS for Windows (SPSS Inc., Chicago, IL, USA).

**Results**

The main anthropometric parameters in the individual age groups are presented on Table 1. The anthropometric parameters and their derivatives, BMI and BSA, display a stable tendency to increase with age. Girls have slightly higher anthropometric parameters, and the growth of boys and girls up to 13 years old follow almost a parallel course without significant sex differences. After that age, boys rapidly outgrow girls with regard to height (cm; 14-year-olds = 169 ± 2 vs. 162 ± 5, \( p = .02 \); 15-year-olds = 175 ± 3 vs. 167 ± 3, \( p = .005 \); 16-year-olds = 180 ± 4 vs. 167 ± 3, \( p < .001 \); 17-year-olds = 182 ± 4 vs. 173 ± 2, \( p = .01 \); 18-year-olds = 181 ±

<table>
<thead>
<tr>
<th>Age (years)</th>
<th>Height (cm)</th>
<th>Body-mass index (kg/m(^2))</th>
<th>Body surface area (m(^2))</th>
<th>Percent body fat</th>
</tr>
</thead>
<tbody>
<tr>
<td>7, 4/5</td>
<td>126 ± 4</td>
<td>16.6 ± 2.7</td>
<td>0.96 ± 0.09</td>
<td>23.9 ± 9.0</td>
</tr>
<tr>
<td>8, 5/5</td>
<td>132 ± 7</td>
<td>16.4 ± 2.6</td>
<td>1.04 ± 0.13</td>
<td>23.7 ± 3.3</td>
</tr>
<tr>
<td>9, 5/4</td>
<td>141 ± 3</td>
<td>16.9 ± 1.6</td>
<td>1.15 ± 0.06</td>
<td>24.8 ± 7.4</td>
</tr>
<tr>
<td>10, 5/5</td>
<td>147 ± 1</td>
<td>18.5 ± 2.0</td>
<td>1.28 ± 0.06</td>
<td>27.1 ± 4.9</td>
</tr>
<tr>
<td>11, 5/5</td>
<td>151 ± 2</td>
<td>17.8 ± 1.7</td>
<td>1.31 ± 0.08</td>
<td>26.5 ± 5.0</td>
</tr>
<tr>
<td>12, 5/4</td>
<td>156 ± 3</td>
<td>19.3 ± 1.5</td>
<td>1.44 ± 0.10</td>
<td>22.7 ± 5.0</td>
</tr>
<tr>
<td>13, 4/5</td>
<td>161 ± 2</td>
<td>20.0 ± 2.0</td>
<td>1.53 ± 0.10</td>
<td>24.5 ± 5.0</td>
</tr>
<tr>
<td>14, 5/4</td>
<td>166 ± 5</td>
<td>20.0 ± 1.7</td>
<td>1.60 ± 0.08</td>
<td>23.3 ± 6.0</td>
</tr>
<tr>
<td>15, 5/5</td>
<td>171 ± 5</td>
<td>19.4 ± 1.0</td>
<td>1.64 ± 0.06</td>
<td>17.5 ± 6.5</td>
</tr>
<tr>
<td>16, 5/5</td>
<td>174 ± 8</td>
<td>18.4 ± 1.6</td>
<td>1.65 ± 0.14</td>
<td>16.9 ± 4.4</td>
</tr>
<tr>
<td>17, 5/5</td>
<td>178 ± 6</td>
<td>19.1 ± 1.6</td>
<td>1.72 ± 0.11</td>
<td>17.7 ± 6.1</td>
</tr>
<tr>
<td>18, 5/4</td>
<td>175 ± 8</td>
<td>20.8 ± 2.9</td>
<td>1.76 ± 0.18</td>
<td>20.5 ± 6.9</td>
</tr>
</tbody>
</table>
3 vs. $160 \pm 3$, $p < .001$, respectively) and weight. Girls in the studied age span had higher adipose content than the boys (percent body fat = $26.2 \pm 0.7$ vs. $17.4 \pm 0.7$, $p < .01$, respectively). Significant sex differences with regard to percent body fat were found in all age groups except for the 8-, 9-, and 12-year-olds.

All participants in this study reached the end point of the standardized treadmill protocol. The oxygen uptake in the different age groups is presented in Table 2. The mean rating of perceived exertion for the whole group was $4.6 \pm 1.7$ on the Borg scale.

AT was determined in 103 of the children. In 11 (7.6%) of the participants, it could not be determined. The AT in 7-year-olds was $28.7 \pm 4.2$ ml·min$^{-1}$·kg$^{-1}$, only slightly greater in the 18-year-olds ($29.5 \pm 4.6$), and for the whole group constituted $81.7\% \pm 8.6\%$ of the achieved VO$_{2peak}$. There was a very strong correlation between VO$_2$ measured at AT and VO$_2$ at peak exercise ($r = .942$, $p < .001$).

OUES was calculated for all children and ranged from 939 to 3,515 ml·min$^{-1}$·logL$^{-1}$ ($M = 2,101 \pm 646$ ml·min$^{-1}$·logL$^{-1}$). The relationship between VO$_2$ and VE during incremental exercise in two representative participants (9- and 15-year-olds) can be seen in Figure 1. The plot illustrates the nature of the relationship in two different age groups. Peak-exercise data and the values corresponding to each age group are listed in Table 2.

There are no significant differences between studied parameters in any adjacent groups (multiple comparisons by Bonferroni’s correction). A steady trend is observed for VO$_{2peak}$, VE, and OUES to increase in the age span of 7–14 years. Nevertheless, the rise of these parameters correlates more strongly with height ($r = .858$, $r = .777$, $r = .835$, respectively) than with age ($r = .786$, $r = .767$, $r = .761$, respectively). The increase of VO$_2$ and OUES with respect to the height

<table>
<thead>
<tr>
<th>Age (years) $n$, boys/girls</th>
<th>RER</th>
<th>VO$_{2peak}$, ml·kg$^{-1}$·min$^{-1}$</th>
<th>VE, L/min</th>
<th>OUES, ml·min$^{-1}$·logL$^{-1}$</th>
<th>Lowest VE/VO$_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>7, 4/5</td>
<td>1.17 ± 0.11</td>
<td>$33.8 \pm 5.4$</td>
<td>$32.1 \pm 5.6$</td>
<td>$1,132 \pm 149$</td>
<td>30.9 ± 2.7</td>
</tr>
<tr>
<td>8, 5/5</td>
<td>1.17 ± 0.07</td>
<td>$34.3 \pm 2.1$</td>
<td>$35.1 \pm 8.3$</td>
<td>$1,311 \pm 262$</td>
<td>29.9 ± 1.4</td>
</tr>
<tr>
<td>9, 5/4</td>
<td>1.15 ± 0.14</td>
<td>$37.8 \pm 4.6$</td>
<td>$42.1 \pm 9.8$</td>
<td>$1,567 \pm 287$</td>
<td>28.7 ± 1.4</td>
</tr>
<tr>
<td>10, 5/5</td>
<td>1.06 ± 0.07</td>
<td>$36.9 \pm 2.5$</td>
<td>$45.6 \pm 7.7$</td>
<td>$1,889 \pm 269$</td>
<td>28.3 ± 2.0</td>
</tr>
<tr>
<td>11, 5/5</td>
<td>1.05 ± 0.08</td>
<td>$35.3 \pm 2.9$</td>
<td>$44.5 \pm 9.1$</td>
<td>$1,890 \pm 365$</td>
<td>27.6 ± 1.4</td>
</tr>
<tr>
<td>12, 5/4</td>
<td>1.03 ± 0.08</td>
<td>$34.7 \pm 2.4$</td>
<td>$48.5 \pm 6.6$</td>
<td>$2,009 \pm 376$</td>
<td>28.1 ± 1.4</td>
</tr>
<tr>
<td>13, 4/5</td>
<td>1.03 ± 0.06</td>
<td>$40.9 \pm 4.9$</td>
<td>$50.0 \pm 7.1$</td>
<td>$2,501 \pm 321$</td>
<td>26.9 ± 1.3</td>
</tr>
<tr>
<td>14, 5/4</td>
<td>1.07 ± 0.09</td>
<td>$40.5 \pm 4.9$</td>
<td>$62.3 \pm 9.6$</td>
<td>$2,770 \pm 412$</td>
<td>26.7 ± 2.6</td>
</tr>
<tr>
<td>15, 5/5</td>
<td>1.09 ± 0.05</td>
<td>$33.4 \pm 2.4$</td>
<td>$58.5 \pm 11.1$</td>
<td>$2,335 \pm 228$</td>
<td>26.9 ± 1.9</td>
</tr>
<tr>
<td>16, 5/5</td>
<td>1.15 ± 0.10</td>
<td>$36.2 \pm 4.4$</td>
<td>$69.9 \pm 16.6$</td>
<td>$2,548 \pm 625$</td>
<td>26.4 ± 1.4</td>
</tr>
<tr>
<td>17, 5/5</td>
<td>1.13 ± 0.09</td>
<td>$33.4 \pm 4.2$</td>
<td>$61.8 \pm 14.1$</td>
<td>$2,542 \pm 463$</td>
<td>25.4 ± 2.2</td>
</tr>
<tr>
<td>18, 5/4</td>
<td>1.17 ± 0.10</td>
<td>$35.9 \pm 5.7$</td>
<td>$77.2 \pm 14.3$</td>
<td>$2,726 \pm 602$</td>
<td>25.9 ± 1.4</td>
</tr>
</tbody>
</table>

Note. RER = respiratory-exchange ratio; VO$_{2peak}$ = peak oxygen uptake; VE = peak exercise ventilation; OUES = oxygen-uptake efficiency slope; VE/VO$_2$ = ventilatory equivalent for carbon dioxide.
Figure 1 — Relationship between oxygen uptake (VO$_2$) and minute ventilation (V$_E$) with a semilog-transformed x axis in 9- and 15-year-olds. (The data presented on this plot are averaged at an interval of 30 s, and the data points corresponding to the warm-up period were omitted.)

Concerning parameters in Table 2, sex differences throughout the whole age span were found for respiratory-exchange ratio, VO$_{2peak}$, and OUES but not for V$_E$ and V$_E$/VCO$_2$. Despite the small groups, sex differences in the age groups become apparent after age 14: VO$_{2peak}$ (ml · min$^{-1}$ · kg$^{-1}$) in 14-year-olds = 43.3 ± 3.7 vs. 37.1 ± 4.1, $p = .049$; 15-year-olds = 35.5 ± 2.7 vs. 31.8 ± 1.9, $p = .048$; 16-year-olds = 40.0 ± 2.4 vs. 32.4 ± 1.1, $p < .001$; 17-year-olds = 36.0 ± 3.1 vs. 32.1 ± 3.1, $p = .051$; and 18-year-olds = 40.2 ± 2.1 vs. 30.4 ± 2.9, $p = .002$ in boys and girls, respectively, and OUES (ml · min$^{-1}$ · logL$^{-1}$) in 14-year-olds = 3,003 ± 341 vs. 2,479 ± 306, $p = .047$; 15-year-olds = 2,512 ± 217 vs. 2,183 ± 188, $p = .05$; 16-year-olds = 3,118 ± 227 vs. 1,979 ± 131, $p < .001$; 17-year-olds = 2,785 ± 451 vs. 2,299 ± 362, $p = .05$; and 18-year-olds = 3,174 ± 201 vs. 2,165 ± 397, $p = .009$ in boys and girls, respectively. The VO$_{2peak}$ and OUES values are significantly higher in boys than in girls.

End-tidal PCO$_2$–PetCO$_2$ (mm Hg) for the whole group was significantly lower in girls than in boys (36.8 ± 3.4 vs. 39.0 ± 3.8, respectively, $p = .002$), and the same
was true for younger children (age 7–12 years) compared with teenagers (36.8 ± 2.6 vs. 39.5 ± 4.0 mm Hg, respectively, \( p < .001 \)). There is a significant positive correlation of PetCO\(_2\) with age (\( r = .321, p < .001 \)).

The values of OUES at the AT (2,095 ± 651 ml · min\(^{-1}·\)logL\(^{-1}\)) and at peak exercise (2,101 ± 646 ml · min\(^{-1}·\)logL\(^{-1}\)) were virtually the same (\( \Delta\)OUES = 10.7 ± 158.5, 95%CI = –20.2 to 41.7, \( p = .493 \) – paired-samples \( t \) test, \( n = 103 \)). From a practical point of view, it is important to point out the extremely strong correlation between OUES for the entire exercise duration and OUES at AT (OUES\(_{AT}\)), \( r = .970, p < .001 \). The distribution of the values of OUES and OUES\(_{AT}\) and the respective regression line are shown in Figure 3.

There is a very strong correlation between OUES and VO\(_{2\text{peak}}\) (\( r = .922 \)) and PetCO\(_2\) (\( r = .540 \)). Very high linear correlations were found between OUES and the basic anthropometric variables—BSA (\( r = .861 \)), weight (\( r = .852 \)), FFM (\( r = .838 \)), height (\( r = .835 \)), age (\( r = .761 \)), and BMI (\( r = .568 \)), \( p < .001 \) for all coefficients. Various applied curvilinear models did not significantly increase the relationship, with one exception—the relationship (\( r^2 \)) between OUES and age increased from .761 to .828 with the so called S-curve model (OUES = e\(^{b0 + b1/age}\)). The same tendency is observed in regard to VO\(_{2\text{peak}}\) and age, in which the coefficient of determination gains 11% with the S-curve model compared with the linear model.

**Figure 2** — Error bars (95% CI) of VO\(_{2\text{peak}}\) (ml/min) and OUES (ml · min\(^{-1}·\)logL\(^{-1}\)) referred to height groups.
VO\textsubscript{2peak} and OUES appeared to be significantly higher in boys than in girls (1,803 ± 649 vs. 1,579 ± 407 ml/min, \( p = .030 \); 2,254 ± 735 vs. 1,943 ± 497 ml \( \cdot \) min\(^{-1} \) \cdot logL\(^{-1} \), \( p = .010 \), respectively). If we follow the common practice of adjusting VO\textsubscript{2} for body mass, there are still differences (37.2 ± 4.6 vs. 34.8 ± 4.1 ml \( \cdot \) min\(^{-1} \) \cdot kg\(^{-1} \), \( p = .005 \); 48.0 ± 8.2 vs. 43.2 ± 7.5 ml \( \cdot \) min\(^{-1} \) \cdot logL\(^{-1} \) \cdot kg\(^{-1} \), \( p = .001 \), respectively). Dividing VO\textsubscript{2peak} and OUES by FFM instead of body mass removes the sex differences almost completely (VO\textsubscript{2} /FFM ml \( \cdot \) min\(^{-1} \) \cdot kg\(^{-1} \) = 45.2 ± 6.6 vs. 47.3 ± 6.6, \( p = .114 \) and OUES/FFM ml \( \cdot \) min\(^{-1} \) \cdot logL\(^{-1} \) \cdot kg\(^{-1} \) = 58.4 ± 10.2 vs. 58.9 ± 10.0, \( p = .796 \); see Figure 4). This method, however, did not remove the differences in the individual age and height groups.

Applying stepwise-regression analysis to the anthropometric factors that could influence the OUES for the whole studied population resulted in an equation in which the main determinants appear to be BSA and sex:

\[
\text{OUES (ml \cdot min}^{-1} \cdot \text{log L}^{-1}) = -398 + 1,958.1 \times \text{BSA} - 199.5 \times \text{Sex (1,2)}
\]

where 1 = boy and 2 = girl, \( r = .875 \); \( r^2 = .765 \); \( p < .001 \); SEE = 316.0. The model summary for the derived equation is given in Table 3.

Stepwise-regression analysis dealing with all parameters measured during rest and exercise yielded an equation in which the most important independent variables that could influence the OUES were VO\textsubscript{2peak} and \( V_{E} \) (\( r^2 = .885 \), SEE = 212.1 ml \( \cdot \) min\(^{-1} \) \cdot logL\(^{-1} \)), corresponding entirely to the method of calculating the OUES.
The main findings of the present study show that in the age span of 7–18 years the OUES is age and sex dependent, and it gives credible assessment of children’s cardiorespiratory reserve. There are no differences between OUES at peak exercise and that attained at AT.

The OUES is physiologically grounded on proper regulation of acid-base status, structural integrity of the lungs, and the adequacy of pulmonary perfusion. The method of calculating the OUES has some advantages in comparison with $V_{E} : \dot{V}O_2$. Measuring the slope of the relationship of $V_{E}$ and $\dot{V}O_2$ rather than a simple ratio at a certain point of exercise such as AT or at-peak exercise gives more complete information about the process. The differences can be compared provisionally.

Figure 4 — Error bars of OUES adjusted by fat-free mass and total body mass in males and females.

Table 3 Model Summary for the Regression Equation Describing Determinants of OUES

<table>
<thead>
<tr>
<th>Model</th>
<th>$R$</th>
<th>$R^2$</th>
<th>Adjusted $R^2$</th>
<th>SEE</th>
</tr>
</thead>
<tbody>
<tr>
<td>BSA</td>
<td>.861</td>
<td>.741</td>
<td>.739</td>
<td>330.17</td>
</tr>
<tr>
<td>BSA × SEX</td>
<td>.875</td>
<td>.765</td>
<td>.761</td>
<td>316.04</td>
</tr>
</tbody>
</table>

Note. OUES = oxygen-uptake efficiency slope; SEE = standard error of estimate; BSA = body surface area.

Discussion

The main findings of the present study show that in the age span of 7–18 years the OUES is age and sex dependent, and it gives credible assessment of children’s cardiorespiratory reserve. There are no differences between OUES at peak exercise and that attained at AT.

The OUES is physiologically grounded on proper regulation of acid-base status, structural integrity of the lungs, and the adequacy of pulmonary perfusion. The method of calculating the OUES has some advantages in comparison with $V_{E} : \dot{V}O_2$. Measuring the slope of the relationship of $V_{E}$ and $\dot{V}O_2$ rather than a simple ratio at a certain point of exercise such as AT or at-peak exercise gives more complete information about the process. The differences can be compared provisionally.
with the difference between longitudinal and cross-sectional measurement. For that reason, OUES represents an integral and objective measure of the relationship between oxygen uptake and minute ventilation.

The validity of the OUES as an index of cardiorespiratory capacity has undergone testing in several studies (2,10). These studies have indicated that the OUES correlates strongly with VO$_2$ and is not influenced by exercise intensity. The slope of the relationship of $V_E$ and VCO$_2$, on the other hand, is widely known as an estimate of ventilatory efficiency and a prognostic index in congestive-heart-failure patients. Both of these indices are derived from multiple data points throughout the exercise, but in the OUES the relationship stays linear during the entire exercise duration, and in the $V_E$-VCO$_2$ slope the linearity would be lost beyond the respiratory-compensation point. Moreover, the OUES appears to be stable across different exercise protocols and age groups of different health statuses.

As seen from our regression equation, the main determinants of the OUES are sex and BSA. A coefficient of determination ($r^2$) equal to .765 means that Equation 1 (see Results) could be used in practice, but it is evident that we need to study a larger population of children to define reference values with enough fidelity.

In the entire study population the significant difference between pooled boys and girls in the OUES is obviously determined by the greater height (cm) in boys age 14 years and above (177 ± 6 vs. 167 ± 5, $p = .010$). To our knowledge, the considerable dependency of the OUES on anthropometric variables has not been discussed previously. Oxygen uptake and the OUES strongly correlate and grow with age. The ostensible delay seen in children ages 10–12 years can be explained by different growth rates, as well as the presence of a large height range for the same age group. Similar findings concerning oxygen uptake in a longitudinal study (age group 8–17 years) are reported by Rutenfranz et al. (17).

The modification of the Balke protocol that we used was robust enough to express more than 80% of VO$_2$. It is a completely standardized protocol that allows us to make unbiased comparisons between age groups. Previous results from the validation study of the OUES against VO$_2$max (11) revealed that the OUES calculated from 75% and 90% of exercise duration differs from the value calculated from 100% of the duration by only 3.2% and 1.8%, respectively. These data rationalized our assumption that the standardized Balke protocol would allow us to assess the usefulness of the OUES in the age span of 7–18 years.

Most of the children did not regularly engage in strenuous exercise, so their bodies were not adapted to that kind of effort. That is why, from a practical point of view, it is very important to note that we confirm already-reported (3,10) extremely high correlation between the OUES calculated for the entire test (100% exercise duration) and the OUES at AT (81.7 ± 8.6% of VO$_2$peak). In addition, the OUES calculated up to the moment of AT differs by less than 1% (in fact, 0.3%) from OUES calculated at 100% of exercise data. In line with Baba et al. (3), we also found very high correlation between VO$_2$peak and the OUES (VO$_2$ $r = .941$ vs. $r = .922$).

The study by Hollenberg and Tager (10) engaged a contingent of elderly people. Nevertheless, some parallels could be established. Hollenberg and Tager (10) derive reference equations for the OUES with main determinants BSA and age, which is similar to ours with main determinants BSA and sex. We also observed that the correction of OUES for FFM (a lean body mass in Hollenberg et al.) removed
most of the sex differences. In the study by Hollenberg and Tager (10), a preserved tendency for higher values of OUES in men than in women is stated, a fact that we also established in boys over the age of 14.

The current study has two limitations. The first one is that we did not have blood-gas data throughout the exercise test, which would hamper the assessment of the relative contribution of $\text{PaO}_2$, $\text{PaCO}_2$, and physiologic dead-space ventilation ($V_D/V_T$) as physiologic determinants of OUES. The second limitation is that our study was cross-sectional. This is the most probable explanation for why there were no significant differences between studied parameters in any adjacent age groups. Nevertheless, the results convincingly indicate that the OUES is a largely effort-independent estimation of cardiopulmonary functional reserve but is dependent on anthropometric measures.

Conclusions

There are age and sex differences in the OUES, which is an objective measure of cardiopulmonary reserve that does not require a maximal effort but is considerably dependent on anthropometric variables and necessitates the generation of appropriate reference values.

References


