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Exercise Performance and Oxygen Uptake Efficiency Slope in Obese Children Performing Standardized Exercise

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Oxygen uptake efficiency slope (OUES) is an index meant to provide an objective measure of cardiopulmonary function at submaximal exercise. The aim was to study the exercise performance and OUES in obese children performing standardized exercise. Sixty children aged 6-17 years performed incremental treadmill exercise test. They were divided into two groups matched by age, sex and height: thirty obese subjects (15 girls/15 boys; BMI=27.4±1.7 m.kg^{-2}) and 30 controls (BMI=18.8±1.0 m.kg^{-2}). Perceived exertion was assessed by means of CR-10 Borg scale. The duration of the exercise for the obese children was significantly shorter than for controls ($p=0.010$) but obese children had greater absolute values for oxygen uptake (VO_2 peak mL.min^{-1} =1907±249 vs. 1495±208; $p=0.013$) which, adjusted for body mass, decreased significantly (VO_2/kg mL.min^{-1}.kg^{-1} =29.2±1.4 vs. 33.6±1.3; $p<0.001$). OUES correlated strongly with VO_2 peak ($r = 0.91$) and oxygen pulse ($r = 0.80$), as well as with anthropometric variables height ($r = 0.88$) and age ($r = 0.83$). Extremely high correlation was found between OUES calculated for 100% of exercise duration and OUES at AT ($r=0.979$; $p<0.001$). No significant differences were found between the studied groups concerning the absolute values of OUES. Obese children rated perceived exertion significantly higher than controls (Borg score 6.2±0.4 vs. 5.2±0.4; $p=0.001$). In conclusion, the absolute metabolic cost of exercise and perceived exertion were higher in the obesity group. OUES is an objective measure of cardiopulmonary reserve that doesn't require a maximal effort but it is considerably dependent on anthropometric variables which impedes its interpretation as exercise index in childhood. ***Acta Physiol. Pharmacol. Bulg., 27 (2003) 1-pp.***

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INTRODUCTION

Over the past two decades an epidemic of childhood obesity occurred. Numerous studies around the world demonstrate that physical fitness of obese children is worse than that of their normal counterparts in both sexes (Pongprapai et al., 1994; Goran et al., 2000; Dupuis et al., 2000). It is well established that oxygen uptake (VO_2) is significantly higher in obese subjects but expressed relative to body weight is lower. According to Dupuis et al. (Dupuis et al., 2000) obese children have poor psychomotor capacities and their perception of exercise is exaggerated. This usually exerts negative impact on their exercise competence and also contributes to increased ratings of perceived exertion. Excessive body mass does not necessarily imply a reduced ability to consume oxygen, but excess fatness does have a detrimental effect on submaximal aerobic capacity (Goran et al., 2000).

Oxygen Uptake Efficiency Slope (OUES) is a single segment logarithmic curve-fitting model that describes the ventilatory response to exercise. Proposed by Baba et al. (Baba et al., 1996), it was intended to provide an objective measure of cardiopulmonary functional reserve at submaximal exercise. Although it was first applied to a cohort of children with heart disease and tested later by Hollenberg et al. (Hollenberg et al., 2000) on a large sample of adult population, the data are scarce and to our knowledge no one studied OUES in children with obesity.

The aim of this paper was to study the exercise performance and the discriminative ability of Oxygen Uptake Efficiency Slope in obese and non-obese children performing standardised exercise.

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MATERIAL AND METHODS

Sixty children aged 6-17 years originally divided in two groups took part in the present study:

- 30 obese subjects (15 boys/15 girls; BMI=27.4±4.5 m.kg^{-2}, range = 20.1–35.9 m.kg^{-2}; ideal body weight (IBW), range = 122-185%)
- 30 controls (BMI=18.8±2.7 m.kg^{-2}) matched by age, sex and height

For stratifying children by their BMI into obese and nonobese we used the cut off points published by Cole et al. (Cole et al., 2000), based on body mass index centiles for subjects aged 2–18 years. The adopted cut off points for obesity in children in this pooled reference values correspond to BMI=30 m.kg^{-2} in adults.

All of the children were in good health, without chronic diseases, and took no medications that might affect exercise capacity. The children in the control group were generally physically active but not engaged in regular training activities.

Prior to the test all the participants were subjected to complete anthropometric measurements, including skinfold thickness over the triceps and subscapular regions.

The treadmill test was performed in the morning in a laboratory compliant with the guidelines of the AHA (Pina et al., 1995). The children were habituated to both the general environment and the actual procedures. The cardiopulmonary exercise test was carried out on a motor driven, electronically controlled treadmill (TrackMasterä, JAS Fitness Systems, Pensacola, FL, USA) using our modification of the Balke protocol (Marinov et al., 2000) which involved two warm up stages at the level of 2.7 and 4.0 km/h, respectively and nine one-minute increments with constant velocity of 5.4 km/h starting from 6% elevation and increasing by 2% every minute until exhaustion or elevation by 22%. Recovery period had standard three minutes duration (2.7 km/h and zero elevation).

Throughout the test gas exchange variables were determined with an on-line computerized system CardiO$_2$™ (Medical Graphics, St Paul, MN, USA) using standard open circuit techniques. Subjects breathed through a mouthpiece and a pneumotachometer was used for recording of tidal volume (V_T, mL.min^{-1}, BTPS) and minute ventilation (V_E; L.min^{-1}, BTPS). Expired gas samples were analyzed for oxygen and carbon dioxide by zirconium oxide and infrared analyzers, respectively. Data were averaged every 30 sec. and used to calculate oxygen uptake (VO_2; mL.min^{-1}, STPD), carbon dioxide production (VCO_2; mL.min^{-1}, STPD) and respiratory exchange ratio (RER). The system was calibrated before each test with gases of known concentrations. Heart rate was monitored electrocardiographically (Hellige, Germany) and the oxygen saturation was traced with pulseoxymeter Pulseox DP-8 (Minolta, Japan).

Anaerobic threshold (AT) was determined as the level of VO_2 at which at least one of the following was present: (i) Increase in V_E/VO_2 without simultaneous increase in V_E/VCO_2; and (ii) Disappearance of the linear relation between VCO_2 and VO_2 (V-slope method).

At the end of each exercise increment and throughout the recovery period the children were asked to rate the perceived exertion using the Category - Ratio Borg Scale (Borg, 1982) depicting fatigue (dyspnea) from “not at all” to “maximal” by means of ten grades.

In 1996 a new index of cardiorespiratory reserve was introduced - Oxygen Uptake Efficiency Slope (OUES), defined as a relationship between oxygen uptake (VO_2 in mL/min) and total exercise ventilation (V_E in L/min). It is best described by an exponential function developed by Baba et al. (Baba et al., 1996)

$$VO_2 = a.\ log_{10} V_E + b$$

The constant ***a*** represents the rate of increase in VO_2 in response to V_E and is termed OUES. The index can be graphically presented if VO_2 is plotted on the ***y*** axis and the V_E 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, OUES is not affected by exercise intensity. To verify that assumption the OUES was calculated from the data up to the anaerobic threshold ($OUES_{AT}$) and 100% of exercise duration.

The measurements of skinfold thickness over the triceps and subscapular regions by caliper were added together to give the sum of skinfolds and percentage body fat was calculated using Slaughter equations (Slaughter et al., 1988). Ideal body weight was deter-

Table 1. Anthropometric data in control and obese group.

Parameters	Controls n=30	Obese children n=30	P value
Age (yrs)	11.0±1.1	10.9±1.1	0.836
Height (cm)	150.6±6.3	151.8±6.0	0.781
Weight (kg)	43.9±5.1	65.1±7.7	<0.001
BMI (kg.m^{-2})	18.8±1.0	27.4±1.7	<0.001
BSA (m^2)	1.36±0.1	1.61±0.1	0.003
IBW (%)	100±4.4	144±6.3	<0.001

BMI – body mass index; BSA – body surface area; IBW – ideal body weight mined from the weight for a given height according to the standards established by the National Sports Academy of Bulgaria (Slunchev, 1992).

Body surface area (BSA) was calculated using the equation of Gehan & Georges (Gehan & Georges, 1970): BSA (m^2)$=0.02350 \times Ht^{0.42246} \times Wt^{0.51456}$ where Ht is the height in cm and Wt is the weight in kg.

All values are expressed as mean ± 95% confidence interval. The results from peak exercise data and anthropometric variables were assessed using descriptive statistics, independent and paired samples t-test, Kendall's tau-b (for ordered values), correlation, stepwise regression and curve estimation analysis in SPSS for Windows (SPSS Inc., Chicago, IL, USA).

RESULTS

The children's anthropometric characteristics are presented in Table 1. There were no significant differences in age, height and sex distribution in the groups. Considerable differences were found between the groups regarding the weight, BMI, BSA and IBW.

Peak exercise data of the groups are shown in Table 2. Oxygen uptake (VO_2 peak) appeared to be significantly higher in the obesity group but when "normalized" for body mass (VO_2/kg) it was significantly lower than in controls. Dividing VO_2 peak by fat-free mass instead of body mass removed the difference between groups. The "normalization" of VO_2 peak by dividing it to BSA also yielded favorable results. The difference between groups with respect to VO_2 peak was decreased from 27.5% to 15.1% in relative oxygen uptake (VO_2/kg) and finally to 7.7% ($p=0.108$, NS) when adjusted to BSA (VO_2/BSA, Table 2).

Table 2. Peak exercise variables in control and obese group.

Parameters	Controls n=30	Obese children n=30	P value
VO_2 peak (mL.min^{-1})	1495±208	1907±249	0.013
VO_2/kg (mL.min^{-1}.kg^{-1})	33.6±1.3	29.2±1.4	<0.001
VO_2/FFM (mL.min^{-1}.kg^{-1})	43.5±1.7	44.7±2.1	0.335
VO_2/BSA (mL.min^{-1}.m^{-2})	1065±70	1111±76	0.368
VO_2/HR (mL.min^{-1}.beat^{-1})	8.6±1.4	10.9±1.7	0.040
RER	1.09±0.03	1.15±0.04	0.006
VE (L.min^{-1})	46.3±5.8	62.8±8.8	0.003
V_E/VO_2	31.9±2.0	33.3±1.7	0.330
OUES (mL.min^{-1}.logL^{-1})	1927±315	2140±274	0.306
$OUES_{AT}$ (mL.min^{-1}.logL^{-1})	2030±330*	2186±295	0.509
Borg score	5.2±0.4	6.2±0.4	0.001

FFM – Fat free mass; BSA – body surface area; VO_2/HR – oxygen pulse; RER – respiratory exchange ratio; V_E/VO_2 – ventilatory equivalent for oxygen; AT – anaerobic threshold; OUES – oxygen uptake efficiency slope; * - n=28.

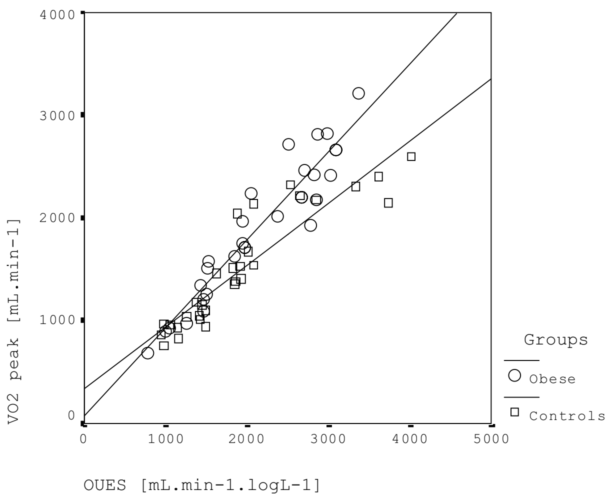

Fig. 1. Distribution of individual data for oxygen uptake efficiency slope (OUES), VO_2peak and respective regression lines in the two groups.

The duration of the exercise for the children in the obesity group was significantly shorter than controls (9.2±2.1 min vs. 10.4±1.2 min.; $p=0.010$). Twenty three controls and only 13 obese subjects reached the end point of the standard treadmill protocol applied. This difference was significant (Kendall's tau-b=0.005). The perception of exercise intensity of the children that finished the test was lower in comparison with the rest that were symptom-limited (Borg score 5.31±1.26 vs. 6.29±1.0; $p=0.001$).

Respiratory exchange ratio (RER) at peak exercise was higher in obese children ($p=0.006$) and surpasses the value of 1.0 in the earlier stages of exercise. In addition a trend was observed for maintaining higher values for this parameter in the recovery period (peak recovery RER = 1.30±0.07 vs. 1.22±0.11; $p=0.004$). Twenty seven children (9 controls and 18 obese children) achieved RER >1.10 – established measure for a maximal exercise test. This difference between groups was also significant (Kendall's tau-b=0.014). AT was not determined in 2 control children only.

Obese children rated perceived exertion (RPE) significantly higher than controls in the course of the standard workload applied (Borg score 6.2±1.2 vs. 5.2±1.1; $p=0.001$). There were no significant gender differences in perception of exercise of the children.

Very high correlation ($r = 0.906$) existed between OUES and VO_2 peak for all the participants in the study (n=60). The distribution of individual data for OUES vs. VO_2 peak and respective regression lines in the two groups is shown in Fig. 1. It is evident that regression line of children's OUES in the obesity group is steeper than that of controls. Strong correlations also exist between OUES and the oxygen pulse - VO_2/HR (r = 0.798).

Very high correlations were found between OUES and the basic anthropometric variables – height (r=0.880), BSA (r=0.857), FFM (r=0.861), age (r=0.825), weight (r=0.780) and BMI (r=0.478); $p<0.001$ for all coefficients.

Applying stepwise regression analysis to the factors that influence OUES for the whole population studied gave the following equation:

$$\text{OUES } (\text{mL.min}^{-1}.\log \text{L}^{-1}) = -3346.9 + 28.08 \times \text{Ht} + 794.2 \times \text{BSA}$$

$$R^2 = 0.793,\ \text{SEE} = 369,\ n = 60,$$

where SEE: standard error of estimate; BSA: body surface area in m^2, Ht: height in cm.

Extremely high correlation was found between OUES for the end of the exercise (100%) and OUES at AT - r=0.979; $p<0.001$. The distribution of these values and respective regression line are shown on Fig.2.

While oxygen uptake efficiency slope was only slightly and insignificantly higher in the obese group there was a significant difference in OUES between pooled boys and girls: 2335±875 $\text{mL.min}^{-1}.\log \text{L}^{-1}$ vs.1730±580 $\text{mL.min}^{-1}.\log \text{L}^{-1}$; p=0.003.

DISCUSSION

VO_2 peak is considered to be an expression of the integrated response of all systems to physical load. This trial confirms the well established finding that normalization of VO_2 to body mass reveals the "true" oxygen consumption by fat free tissues vs. the apparently higher values of this parameter in obese subjects. This issue is discussed by many authors (Wasserman et al., 1999, Armstrong et al., 1997).

It is well known that absolute VO_2 peak is strongly influenced by change in body size. For that reason the appropriate adjustment of this parameter for body size should help to explain the impact of other factors. VO_2/kg is most commonly used (Washington et al., 1994) and the easiest to calculate. The influence of body mass is not completely removed by this method thus penalizing heavier individuals (Loftin et al., 2001). The so-called allometric scaling technique was proposed as a better alternative of the conventionally used ratio method. The scaling exponent of 0.96 for VO_2 peak relative to mass in our children did not remove the differences in those parameters between obese and non-obese group probably due to the broader age span of the subjects. In that case Nevil (Nevil, 1997) recommends further covariates as height or age to be incorporated in the allometric model. However, it is not surprising that "standardizing" VO_2 peak by dividing it with BSA (it includes both weight and height in formula) removes differences between obese and non-obese group.

OUES derived from the absolute values for VO_2 and $\log V_E$ is slightly higher in the obesity group suggesting good ventilatory efficiency. The ability of obese children to perform physical work is reduced because the greater part of one's cardiovascular and respiratory reserve will be consumed to support the movement of the enlarged body. For both sexes an inverse relationship between fitness and fatness is found (Gutin et al., 1994). Our results showed that the standard exercise test applied was maximal in nature for the majority of the children in the obesity group. This fact was supported also by the finding that 56.7 % of them did not complete the test.

Many researchers support our point of view that submaximal exercise tests are more easily conducted thus more appropriate in childhood (Harris, 1999). True VO_2 max is difficult to reach, especially in pediatric population. A number of indices, reviewed in the literature, do not require maximal effort – anaerobic threshold (AT) determined by gas exchange (Beaver et al., 1986), V_E - VCO_2 slope relationship (Reindl & Kleber, 1996) and extrapolated maximal oxygen consumption (EMOC) (Buller & Poole-Wilson, 1988) were proposed. In 1996 R. Baba et al. (1996) introduced the OUES, an index that integrates the functional capacities of several systems, primarily cardiovascular, pulmonary and skeletal muscle. The transformed logarithmic regression is linear in almost all subjects and therefore the OUES does not require a maximal effort for its valid estimation. OUES has an excellent correlation with VO_2 even from 75% of exercise data (Baba et al., 1996; Hollenberg & Tager, 2000) and can be determined in all patients. Our results also support this hypothesis. From a practical point of view, it is very important to note the extremely high correlation between OUES calculated for the entire test (100% exercise duration) and

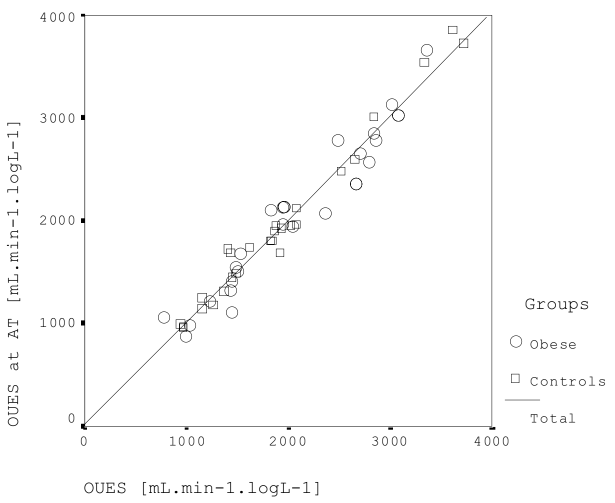

Fig.2. The distribution of OUES and OUES at AT and total regression line.

OUES at AT - r=0.979; p<0.001, allowing conclusions about the exercise tolerance in cases where no maximal effort is achieved. In addition, the OUES calculated up to the moment of emerging of AT differ only by 1.1% (1.7% in controls and 0.6% in obese subjects) from the OUES calculated at 100% of exercise data.

As seen from our regression equation the main determinants of OUES are height (Ht) and body surface area (BSA). The significant difference between pooled boys and girls regarding the OUES is obviously determined by the greater height in boys (height = 156±16 cm vs. 145±14 cm; p=0.010). To our knowledge, the dependency of OUES on anthropometric variables is not discussed anywhere and have to be further elucidated.

The higher values of the respiratory exchange ratio (RER) at peak exercise and higher rate of perceived exertion in the obesity group suggest the level of deconditioning associated with the lower physical activity of these children. This corresponds to the early and at the same time greater anaerobic supplement to energy generation producing excessive acid load.

This investigation is among the few ones exploring the application of rating scales for assessment of exercise perception in obese children. As expected, greater awareness of fatigue was found in the obese children (Ward & Bar-Or, 1990). The fact that they rate perceived exertion significantly higher and disconnect the test earlier can be explained by the higher aerobic cost of exercise as well as by the greater CO_2 turnover. At our laboratory we prefer the Category Ratio Borg scale - CT-10, especially when working with children. It is plain and better understood by the youngsters.

CONCLUSIONS

The absolute metabolic cost of exercise is higher in the obesity group compared to controls. Obese children have an increased awareness of fatigue that further limits their physical capacity. OUES is an objective measure of cardiopulmonary reserve that does not require a maximal effort, but is considerably dependent on anthropometric variables, which impedes its interpretation as exercise index in the course of childhood.

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