Validation of the new index OUES (slope ΔV02, VE) in the functional reserve assessment of cardiorespiratory system of children

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Abstract: The aim of this study was to determine the validity of the new index OUES for evaluating the performance of the cardiorespiratory system of Iranian children against the traditional index of VO2max with method of gas analyzers. The minimum time required to perform a submaximal test which will help to study, in the shortest time possible with the high sensitivity of exhaustive protocol, cardiorespiratory fitness in adolescent boys with high reliability. 72 healthy young males with a mean age (13.95 ± 1.84) and body mass index of 19.91±3.4$^{kg/m2}$ participated in an exhaustive test and VO2max test using gas analyzer (VE, VO2, VCO2) was measured. Then pattern of the predictor line between OUES and VO2max was measured. Results showed that with consideration of agreement diagram of Bland-altman, OUES index has high validity for evaluating the performance of children's cardiorespiratory functional reserve (R^2 = 0.90, SEE=292.2). A Significant relationship between the two indices QUES VO2max at different times of children`s GXT during maximal aerobic test (GXT) was obtained (R = 0.81-0.95). In studies of screening and clinical diagnosis of cardiovascular system, the protocol of OUES index during ergometry lower than lactate threshold is usable for Iranian healthy boys. Application of this sensitive index to compare the performance of the cardiorespiratory functional reserve of healthy children with counterpart patients can be also significant in submaximal exercise rather than exhaustive protocols.

[Farzad Nazem, Akbar Sazvar. **Validation of the new index OUES (slope ΔV02, VE) in the functional reserve assessment of cardiorespiratory system of children.** *Life Sci J* 2017;14(7):52-58]. ISSN: 1097-8135 (Print) / ISSN: 2372-613X (Online). http://www.lifesciencesite.com. 9. doi:10.7537/marslsj140717.09.

Key words: Oxygen Uptake Efficiency Slope (OUES), Vo2max, boys

Introduction:

Graded Exercise Testing (GXT) has been widely used for the purpose of screening studies and clinical evaluation of cardiovascular storage responses in normal subjects and in patients during standard physical activity. Maximal oxygen uptake (VO2max) is the highest volume of oxygen consumed by the slow- tension myofibrils during exhaustive exercise protocol (GXT) referred to as a gold standard of measuring the oxygen transport system (Kraemer and Fleck 2012).

According to scientific evidence, from theoretical view, VO2max the point at which oxygen consumption under workload is given to plateau or intracellular physio-metabolic level leading to a two-side balance of "the amount of oxygen required for oxidative metabolism from one hand and the amount of the consumed vo2 in chemical mitochondrial reactions " is established.

So that even with an increase in the intensity of work, Δ_{THR} and Δ_{VO2} do not changed. Of course, it is possible, in children and some adults, physiological phenomenon real plateau Δ_{VO2} during tests of (GXT) on a bicycle ergometer or a treadmill does not occur in that proportion with greater time of implementation, work efficiency (w/slope and speed) increases. Hence, researchers use VO2peak instead of VO2max (Mezzani 2009, Armstrong and Fawkner 2007, Vanhees et al 2005).

Maximal oxygen uptake during maximal aerobic tests measure is measurable dependent on the maximum effort of individuals and it is possible that subjects especially at children ages, with high motivation and maximum presentation of their ability don't participate in such tests or some patients with cardiovascular or respiratory failure, high blood pressure, kidney disease and diabetes, which are faced with certain restrictions, selection and implementation of the GXT test is not safe and may be associated with risks.

It appears that access to reliable physiological indicator that without the need to run the GXT, can measure safe levels of cardiorespiratory fitness (healthy or sick, young or adult) and also with the sensitivity to measure cardiorespiratory functional reserve performance at the submaximum level and below the lactate threshold ($VCO_2/VO_2 < 1$), will be of great importance. In this regard, a new method of oues has replaced traditional indicator (Baba et al 1996).

What is Oxygen Uptake Efficiency Slope (OUES)? OUES is a new index to assess cardiorespiratory fitness invented in 1996 by Japanese

Dr baba and opened its place in the scientific community (Baba et al 1996,1999,2000) so that in 2010, a review paper by Akkerman (2010) was published about the paper in 14 years. In 2014, Roselien Buys et al (2014) developed norm for OUES showing the importance of this new indicator.

In terms of terminology, OUES is the slope of the line formed between oxygen cost component VO2 and VE on the increasing ergometry situation, and it represents an incremental change in response to increased minute ventilation during exercise by the certain workload and is calculated from linear relationship □$_{□2}$ = □ □□□ □□ + □. In this formula, the slope of the line **a** is that called Oxygen Uptake Efficiency Slope (OUES). First, Dr BABA (1996) took logarithm to calculate OUES index from the minute ventilation, to make diagram changes of VE, V02 linear. Then, slope of the line formed between Log VE and VO2 could be calculated and introduced as a new index to measure cardiorespiratory reserve performance or Oxygen Uptake Efficiency Slope (Figure 1).

In this method, using a submaximal protocol, the correlation of OUES at ratios of 90% and 75% of the run time of an exhaustive test were obtained at R = 0.96 and R = 0.94.

This means that if a person performs a maximum 20-minute test run, we can replace the sub-maximum test run within 15 minute on standard GXT 20-minute. And thus the level of cardiorespiratory fitness with an emphasis on OUES in a shorter period will be assessed. In this study, a high correlation (R = 0.94) between the two indices of OUES and VO2max was achieved in 75% of the maximal exercise test (Baba et al 1996,1999).

Scientific evidence indicates that OUES is of great validity to assess cardiovascular system performance. In this regard, study of Gademan et al (2008) on heart patients showed the high validity of OUES index on cardiorespiratory fitness. Also, Akerman's (2010) study on healthy children aged 7-17 showed high correlation of R = 0.95 in both indices OUES and VO2max. Also, no significant difference in the pattern of OUES was not obtained when performing exhaustive and sub- maximum standard physical labor pattern.

On the other hand, Gruet (2010) reported correlation R^2= 0.83 between the two measures to assess cardiorespiratory fitness: VO2max and OUES in 80% standard GXT exhaustive test time for lung disease. Alessandro`s and et al (2009) clinical report on young patients who had undergone open heart surgery, revealed from physiological findings of subjects in the second half of the time GXT meaning in of 50% test ergometer protocol execution time, the evaluation of cardiac-respiratory function can be done. In this study, the correlation between the index VO2max and OUES was reported to be R = 0.71.

In this background, further scientific evidence on obese children (Alessandro`s and et al 2009, Marinov and Kostianev 2003) or healthy controls (Pichon et al 2002, Xing-Guo et al 2012) also shows that from OUES can be utilized to assess cardiorespiratory fitness levels at different ages. The advantage of this index is intended to track changes in systemic circulation parameters in response to controlled physical activity makes us free from full implementation of GXT exhaustive test.

Hence with a submaximal test in a shorter period, individual`s clinical responses can be measured with the same validity and sensitivity at maximum aerobics test, at the safety level from work intensity on patient, a middle-aged or children without risk of pathological symptoms or estimated from the health status of the individual and the talent athletes.

In the present study, we tried to study the validity of the new index OUES for evaluating the performance of the cardiorespiratory system of Iranian children against the traditional index of VO2max with method of gas analyzers. The minimum time required to perform a submaximal test which will help to study, in the shortest time possible with the high sensitivity of exhaustive protocol, cardiorespiratory fitness in adolescent boys with high reliability.

Material & Methods:

4 schools in education center from Hamedan city randomly selected and 72 healthy adolescent boys 11-17years old, with written permission from their parents, voluntary participate in this study. First parents of participants became familiar with the objectives of the project and after completing the questionnaire of Health PAR-Q Society for Sports Medicine America, anthropometric characteristics and percent of BMI (Guo et al 2000, Kuczmarski and Ogden 2002) using Diagram of Center for Disease control and prevention (CDC) and the percentage of two subcutaneous fat layers of brachial triceps and subscapular was determined according to slater (1988) equation (Dezenberg et al 1999). The ergometry intensity of each individual was estimated based on heart rate reserve (%HRR) during the incremental test of GXT from Karvonen formula (Myers 2010).

GXT protocol was performed on treadmill according to BABA 1996 method. This standard progressive exercise program for 10 minutes, which is designed for children, increases according to the time of exercise, and the increased speed and slope and the individual continues running beyond his lactate threshold on electrical treadmill equipped with automatic gas analyzers of respiratory gases (model

Ganshorn of Germany) to the time in terms of signs of:

A) respiratory efficiency more than unit (RER> 1.1) corresponding to changes of Δ_{VC02} / Δ_{V02} on screen of device.

B) a heart rate activity over □□□□□□□□□□□ > 185□□□

C) declaring individual`s intentional exhaustion (Akkerman 2010b, Hollenberg and Tager 2000).

In this protocol, Time for the first four steps of ergometry, 15 seconds and the next steps 5-7 three minutes is mentioned and finally the whole time of GXT protocol ended within 10 minutes (Baba et al 1999). To measure VO2max in direct method of gas analyzers, an average of ten seconds VCO2, VO2 measurement was recorded in the computer memory and physiology information in the final 20 seconds was used to determine the aerobic capacity. Exercise heart rate per second was measured by telemetry Polar T34 model made in Finland until the end of GXT protocol and was kept in device memory. OUES value was calculated from the linear relationship VO2 = aLogVE + b at 40, 60, 80 and 100% of the entire ergometry and also at the time subject got the lactate threshold (Baba et al 1996).

All cardiorespiratory variables were tested after 2 to 3 hours after lunch and abstinence from consumption of cocoa or coffee with light shirt and sport shoes at 4 pm to 6 pm on the treadmill. GXT test was performed under in physiology laboratory at the University of Bu-Ali Sina under temperature 19 to 21 degrees Celsius and relative humidity of 39 to 43 percent in 1860 meters above sea level.

Statistical methods:

The normal distribution of the absolute and relative values of the subject`s VO2max was found with Kolmogorov-Smirnov test (P = 0.2, Z = 0.09).

With the linear regression model, predicting the index OUES through direct measurement of individual practical capacity at different times of exhaustive protocol was evaluated.

Information of descriptive statistics of the variables were determined on the mean and standard deviation (Mean ± SD). significance level of P≤0.05 was selected for the analysis of statistical hypotheses.

Results:

Anthropometric and physiological characteristics of healthy adolescent boys are given In Table 1. With respect to the exercise heart rate (199.8 ± 4.6) beats per minute, percentage of heart rate reserve (94.68 ± 3.81) and respiratory exchange ratio (VCO2 / VO2: 1.26 ± 0.08), it can be said that the subjects have done maximal physical effort in the implementation of the Protocol GXT in BABA method. And the mean value of relative peak oxygen consumption (37.12±10 $mil.min^{-1}.kg^{-1}$) could indicate their actual maximum cardiovascular performance. As a result, this criterion can be used to predict children`s OUES in the different proportions of ergonomtry runtime. According to the results of the study, participants had reached lactate threshold in averagely 56% of the total time of the maximal test.

In Table and Figure 2, the high correlation can be seen between physiological indices of OUES and VO2max in 40, 60, 80 and 100% of maximal aerobic test execution time and the time to reach the lactate threshold (R^2=0.71, R^2=0.83, R^2=0.88, R^2=90, R^2=0.74).

Table 1. Anthropometric and physiological characteristics during Increasing ergometry test in adolescent boys

Variables	Mean	SD	SEM
Weight (kg)	51.64	13.15	1.55
Age (year)	13.95	1.8	0.21
RPE $_{(20)}$	18.6	0.9	0.1
% body fat	20.7	10.3	1.2
%BMI	40.7	2.55	3
$HR_{exercise}$ (bp/min)	199.8	4.6	0.55
%HRR: (work intensity index)	94.7	3.8	0.45
RER: V_{CO2} / V_{O2}	1.26	0.08	.009
$VO2_{max}$ ($ml\ min^{-1} \cdot kg^{-1}$)	37.12	10	1.18
OUES $_{max}$: ($VO2ml \cdot min^{-1}$) / $log_{10}VE$ ($L \cdot min^{-1}$)	1663.2	893.7	105.3

Table 2. Pattern of correlation between OUES and $VO2_{max}$ during different times exercise test

Physiological index: Practical capacity during ergometey		R^2	R	Sig	SEE	Regression equation
OUES $_{(Time\ 40\ \%)}$: 945	**$VO2_{max}$ ($L.min^{-1}$)**	0.71	0.84	0.000	449	$OUES_{40\ \%}$ =836.9 $VO2_{max}$ - 697.5
	$VO2_{max}$ ($ml{\cdot}min^{-1}{\cdot}kg^{-1}$)	0.61	0.78	0.000	516.1	$OUES_{40\ \%}$ = 64.48 $VO2_{max}$ – 1448.4
OUES $_{(Time\ 60\ \%)}$: 1353	**$VO2_{max}$ ($L.min^{-1}$)**	0.83	0.91	0.000	394.4	$OUES_{60\ \%}$ =1050 $VO2_{max}$ – 707.4
	$VO2_{max}$ ($ml{\cdot}min^{-1}{\cdot}kg^{-1}$)	0.69	0.83	0.000	538.3	$OUES_{60\ \%}$ =78.9 $VO2_{max}$ – 1575.8
OUES $_{(Time\ 80\ \%)}$: 1567	**$VO2_{max}$ ($L.min^{-1}$)**	0.88	0.94	0.000	319.9	$OUES_{80\ \%}$ = 1053.4 $VO2_{max}$ – 500.3
	$VO2_{max}$ ($ml{\cdot}min^{-1}{\cdot}kg^{-1}$)	0.67	0.82	0.000	533.1	$OUES_{80\ \%}$=76.2 $VO2_{max}$ – 1261.6
OUES $_{(Time\ 100\ \%)}$: 1663	**$VO2_{max}$ ($L.min^{-1}$)**	0.9	0.95	0.000	292.2	$OUES_{100\%}$ =1020.2 $VO2_{max}$ – 339.2
	$VO2_{max}$ ($ml{\cdot}min^{-1}{\cdot}kg^{-1}$)	0.65	0.81	0.000	529.5	$OUES_{100\%}$ =72.16 $VO2_{max}$ – 1015.5
OUES $_{in\ (AT)}$: 1289 or in Time $_{56\%}$	**$VO2_{max}$ ($L.min^{-1}$)**	0.74	0.86	0.000	449.1	$OUES_{in\ AT}$ = 909.2 $VO2_{max}$ – 494.7
	$VO2_{max}$ ($ml{\cdot}min^{-1}{\cdot}kg^{-1}$)	0.61	0.78	0.000	550.6	$OUES_{in\ AT}$ = 68.27 $VO2_{max}$ – 1244.4

Discussion:

In this applied research, the pattern of linear correlation between physiological criteria of OUES and VO2max in estimating cardiorespiratory reserve function in Iranian adolescent boys was reviewed with emphasis on validating new index OUES so that using it during submaximal ergometry and below the lactate threshold (Time 56%) OUES, children's capacity can be assessed with a high degree of accuracy and reliability.

Based on the findings in Table 2, the correlation index OUES is indicator of oxygen transfer system efficiency VO2max, in total runtime of exhaustive protocol, R^2 = 0.90, SEE=292.2 which is consistent with the result of a report of Japanese researcher presenting the correlation (R = 0.96) for both indices OUES and VO2max in Japanese healthy men and women aged 8-52 on treadmill in BABA method (Baba et al 1996).

Results of this study are consistent with the report of correlation between the two indices (R = 0.95) in the study of Akkerman (2010b) in ergometer test among 46 Dutch healthy children 7-17 years old. These scientific reports noted that the validity of OUES in determining the level of cardiorespiratory fitness among Iranian children follows the same model as their foreign counterparts.

In our study, after normalizing the VO2max index based on weight, level of correlation with index OUES reached lower at R = 0.81, which corresponds to the study of Xing-Guo Sun et al (2012). They reported the drop of correlation level of these two physiological variables after being normalized with the weight the healthy subjects 17-78 years from R=0.95 to R=0.76 that shows the influence of the components of body weight on OUES.

In clarifying the question of whether we can use OUES index under submaximal ergometry (VCO2 / VO2 < 1) in parallel with the maximal aerobic exhaustive test capability to determine the actual size of cardiorespiratory fitness? according to agreement plot Bland-Altman (figure 3), between the indexes of VO2max and OUES in Iranian boys at the moment of reaching the threshold Lactat) $OUES_{in\ (AT)}$), it was equivalent to 56% of the total time of exhaustive testing standard (R^2=0.61, SEE=449.1).

As well, the high correlation in the proportion time on a treadmill ergometer, including 40, 60, 80 and 100% of the total execution time, respectively R^2=0.71, R^2=0.83, R^2=0.88 and R^2=0.90, were obtained, respectively.

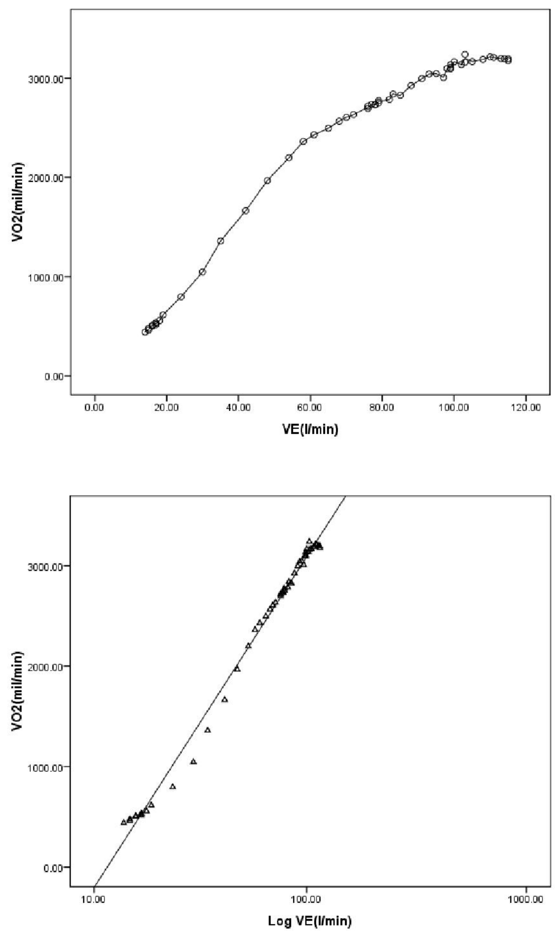

Figure 1: The relationship between VO2 and VE in a 16year-old boy during a maximal treadmill test. (On the left Diagram, the horizontal axis is logarithmic for OUES to be calculated)

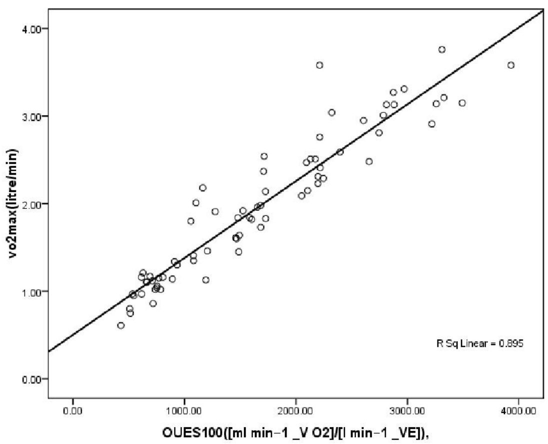

Figure 2. Dependence OUES regression model with VO2max index at the different time of maximal protocol (minutes) in Iranian children

It is suggested that for cardiovascular system performance measurement of boys, they do not need to to exercise as high as 100% of the time of exhaustive protocol, OUES $_{(Time100\%)}$. Because with gas analyzer physiological information on the maximal ergometery at 50% maximum, at hand, or the level of submaximal ergometer, with good accuracy and safety, cardiorespiratory fitness of the subjects can be studied to assess the epidemiological or clinical aim.

In this regard, Akkerman`s (2010b) study on healthy children 7-17 years, showed that the submaximal values of OUES and maximum values of OUES are not significantly difference but are highly correlated (R = 0.88) with VO2max so that OUES is stronger than VO2max even in estimating cardiorespiratory performance.

In research of Silvia Pogliaghi et al (2007) on the healthy elderly, There were obtained VO2max and OUES correlation in 60% of heart rate reserve at R^2=0.70. Alessandro et al (2009), studied the validity of the scale OUES from clinical aspects on heart disease patients and showed that the physiological data during exercise stress to measure the effectiveness of cardio respiratory system of these patients, is applicable at 50% of the total execution time of ergometry (R = 0.71).

In a similar study by Sophie (2012) on heart patients, a correlation between index OUES and VO2max at lactate threshold was reported to be R = 0.87. Bongers et al (2011) studying cardiac disease children with a mean age of 13.2 years, during ergometery at a moment of reaching the lactate threshold, reported VO2peak and OUES correlation at R = 0.55. But the low correlation, compared to the previous study and the present study, is probably due to heart disease in children with low cardiorespiratory reserve performance.

Conclusion: Based on the findings of our study and backgrounds available, it can be noted that the application of OUES as a new index of cardiorespiratory fitness levels in children is significant. On the other hand, this indicator is a valid and appropriate criterion for assessing the low performance of cardiorespiratory reserve in Iranian adolescent boys at the times lower than the maximum test so that our findings in 50% of the exercise stress test, with a high correlation showed the new index is used to determine the subjects' cardiovascular fitness.

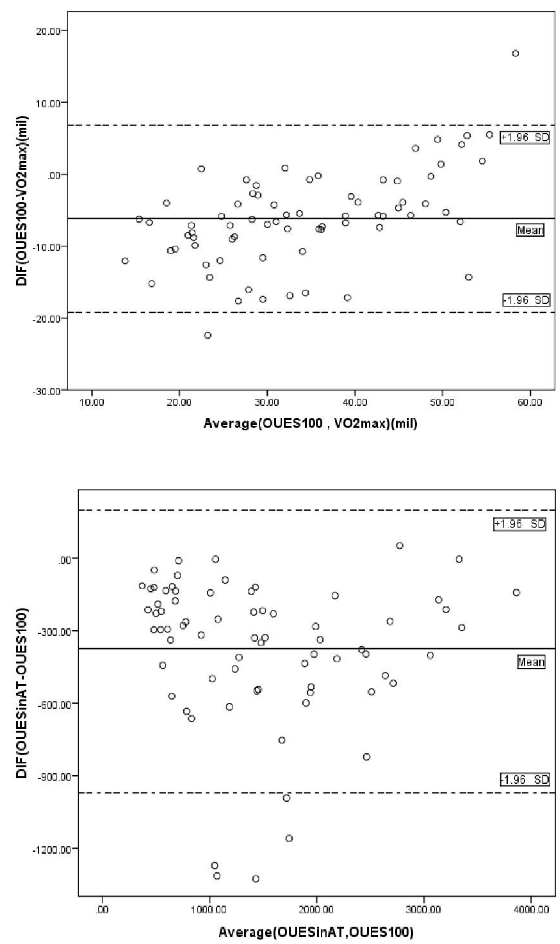

Figure 3: Diagram Bland-Altman agreement for OUES and VO2max in adolescent boys

This means the application of submaximal ergometer test (50% of the total time of maximum exhaustive test) for healthy and probable patient children in the age range of youth and adolescence without the ability or incentive to perform maximal standard tests which are usually performed in specialized centers of Cardiology would be beneficial.

Limitations of this study include the motivational level of children to run exhaustive protocols, lack of measurement of arterial blood oxygen saturation during ergometery and of the application of the method to determine the biomaturity of subjects, and the possibly the sample size studied.

Acknowledgement:

This article is adapted from Project of doctorate in Exercise physiology by fellowship funds (research deputy of Bu-Ali Sina University). The authors express their appreciation to the staff of the Department of Education, students, parents and school managers of Hamedan, who helped us in doing this research.

Running title:

Validation of new index OUES Against the VO2max

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7/25/2017