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Oxygen uptake efficiency slope calculations based on heart rate reserve endpoints in young, intellectually disabled individuals

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Abstract The validity of a new methodological approach, involving the use of exercise endpoints based on fractions of heart rate reserve (HR_{res}), to calculate oxygen uptake efficiency slopes (OUES) was tested. The study involved 48 young, intellectually disabled individuals (age range: 15–17 years) who performed an incremental cycling exercise to exhaustion. Furthermore, regarding the subjects who reached maximum efforts, the relationship between OUES and several exercise performance parameters was assessed. OUES was calculated using 75%, 90%, and 100% of the incremental exercise with data and data corresponding to 60% and 80% of the HR_{res} . Of the 48 participants, 12 subjects did not reach a peak RER of 1.09, and 36 subjects exceeded this value. Significant differences were not detected between the time-based calculations and those obtained using the HR_{res} -based measures of OUES. A Bland-Altman analysis did not reveal a bias that was significantly different from 0 (15.5 and 68.6 for OUES80% HR_{res} -OUES100 and OUES60% HR_{res} -OUES100, respectively), with precisions of 173.2 and 356.0 and 95% confidence limits from -296.8 to +327.8 and from -507.1 to +644.3 for OUES80% HR_{res} -OUES100 and OUES60% HR_{res} -OUES100 comparisons, respectively. High correlations were detected between peak oxygen uptake and OUES60% HR_{res} and OUES80% HR_{res} , and between VT and OUES60% HR_{res} and OUES80% HR_{res} . Thus, we found that OUES can be reliably calculated based on HR_{res} endpoints, during incremental cycling exercise, in young individuals with intellectual disabilities. Furthermore, the study confirms the validity of OUES as an indicator of aerobic exercise capability in this population.

Keywords : oxygen uptake efficiency slopes, heart rate reserve, intellectual disabilities

Introduction

In general, studies have reported that intellectually disabled (ID) individuals exhibit poor fitness levels on standard fitness tests, based on measures of cardiovascular endurance¹⁾. Because of their impaired capability to understand instructions and the difficulty associated with influencing their will to exercise, the results of their physical fitness tests are difficult to evaluate. The measurement of maximum oxygen uptake ($\dot{V}O_{2max}$), requiring maximal effort, is not as suitable of an assessment method for these disabled individuals as it is for non-impaired subjects.

To develop an objective, independent, and clinically useful submaximal measure of cardiorespiratory fitness, Baba et al. introduced the oxygen uptake efficiency slope (OUES), derived from the logarithmic relationship be-

tween oxygen uptake ($\dot{V}O_2$) and minute ventilation ($\dot{V}E$) during incremental exercise^{2,3)} (Fig. 1). The OUES has generally been calculated using all data points from truly-maximal exercises, and is often termed OUES100%. The OUES has also been shown to be reliably calculated based on shorter fractions of the same exercise⁴⁻⁶⁾. However, exercise time endpoints are of little prospective help when the exercise duration cannot be accurately predicted. Thus, it would be useful to anticipate appropriate endpoints for incremental tests in order to determine a reliable OUES, without putting ID individuals at unnecessary risk. Heart rate reserve (HR_{res} , calculated as the difference between the maximal and resting heart rates) is an index of relative exercise intensity that is commonly used in exercise prescriptions and monitoring⁷⁾, and is practical for use with ID subjects.

In this study, fractions of the theoretical HR_{res} (80% HR_{res} and 60% HR_{res}) are proposed as alternative exercise

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Fig. 1 Relationship between oxygen uptake ($\dot{V}O_2$) and minute ventilation ($\dot{V}E$) during incremental exercise in a healthy individual with intellectual disabilities. The constant for the logarithmic term of the curve-fitting equation (1074 for this subject) is defined as the oxygen uptake efficiency slope (OUES). The data are presented in the form of a linear (top) and semi-log plot of the x-axis (bottom)

endpoints for calculating the OUES in ID subjects. These measures were validated by examining the correlation of these measures with traditional calculations based on exercise duration (OUES75, OUES90, and OUES100) and with other indices of exercise capacity ($\dot{V}O_{2max}$ and ventilatory threshold (VT)).

Methods

Subjects. We studied 48 sedentary ID individuals who were of high school age (range of 15–17 years) and enrolled at a school for children with special needs. This study was approved by the Institutional Ethics Committee (IEC), and written informed consent was obtained from the parents or legal guardians of all of the participants. In the study cohort, the degree of the intellectual impairment was deemed to be mild (intelligence quotient of 50–70). Exclusion criteria for this study included a history of heart disorders, asthma, and extreme obesity (BMI > 25) (Table 1).

Study protocol. During the first laboratory visit, each individual's body mass and height was determined to the nearest 100 g and 0.1 cm, respectively, with the subject wearing only underwear and without shoes. During testing, subjects performed an incremental exercise test, until

Table 1. Mean and standard deviation (SD) values of the relevant physiological variables of subjects, separated by gender

Variable	Males (n = 24)		Females (n = 12)	
	Mean	SD	Mean	SD
Age (years)	16.2	0.8	16.1	0.9
Weight (kg)	56.4	10.4	50.6	6.2
Height (cm)	166.7	8.5	153.3**	8.3
BMI (kg/m ²)	20.1	2.0	21.5	2.2
W_{peak} (W)	133.3	38.5	96.3**	23.1
$\dot{V}O_{2peak}$ (mL/min)	2279.5	512.0	1436.4**	291.8
$\dot{V}O_{2peak}$ (mL/kg/min)	41.1	8.9	28.6**	5.8
VT (mL/kg/min)	26.3	5.6	17.2**	5.1
RER _{peak}	1.19	0.13	1.18	0.08
$\dot{V}E_{peak}$ (L/min)	84.3	29.9	54.5**	15.4
HR _{rest} (bpm)	88.4	13.2	88.4	12.2
HR _{peak} (bpm)	160.2	22.4	157.2	12.7

** indicates a significant difference ($P < 0.01$) compared to males. BMI, body mass index; W_{peak} , highest power output observed; $\dot{V}O_{2peak}$, peak oxygen consumption; VT, ventilatory threshold; RER_{peak}, peak respiration; $\dot{V}E_{peak}$, peak ventilation; HR_{rest}, heart rate at rest; HR_{peak}, peak heart rate.

exhaustion, on a bicycle ergometer (Well Bike BE-360, Fukuda Denshi, Tokyo, Japan) (CYC Test) 2–3 h after a light meal, under standardized environmental conditions. After a 5-min rest, followed by a 3-min warm-up (30 W), the workload was increased in a stepwise manner (10 W·min⁻¹)⁸. The subjects were asked to maintain a cadence of 60 revolutions/min (RPM) throughout the test, until they could no longer exercise. In consideration of the subjects' disabilities, all instructions were given in an identical manner by their regular classroom teacher. Each subject underwent a familiarization trial 1 week before the actual test.

Measurements and calculations. During the incremental testing, respiratory variables were measured, breath by breath, using an automated system (Oxycon Alpha, Mijnhard, The Netherlands) that was calibrated before each test, as indicated by the manufacturer. Resting values were calculated to reflect the mean over the last 30 s before the start of the exercise. The end point of exercise was defined if the following conditions were met: 1) Both 90% of the age-predicted maximal heart rate (220-age) and RER ≥ 1.09 were satisfied, 2) the work load was high enough that a cadence of 60 RPM could not be sustained.

The evaluation was performed as each subject reached

peak exercise intensity, as determined by the peak HR. The peak respiratory exchange ratio (peak RER) was also used because the likelihood of an appropriate heartbeat reply is less in ID subjects. Each index of exercise performance was examined for the subject group and resulted in the selection of a peak RER > 1.09 as the criterion indicating a maximal effort⁹. The highest power output observed was termed W_{peak} , whereas peak oxygen consumption ($\dot{V}O_{2\text{peak}}$), ventilation ($\dot{V}E_{\text{peak}}$), respiration (RER_{peak}), and heart rate (HR_{peak}) were estimated as averages over the last 10 s of exercise.

Individual $\dot{V}O_2$ ($\text{mL}\cdot\text{min}^{-1}$) data, relative to the incremental part of the exercise (excluding the initial 3-min warm-up), were plotted as a function of $\log_{10} \dot{V}E$ ($\text{L}\cdot\text{min}^{-1}$). The OUES was calculated as the slope of the linear relationship between $\dot{V}O_2$ and $\dot{V}E$ (Microsoft Excel 2007, Microsoft, Redmond, WA, USA), based on data corresponding to 75%, 90%, and 100% of the incremental exercise duration (OUES75, OUES90, and OUES100, respectively). Furthermore, OUES values were also estimated based on data corresponding to the attainment of 60% and 80% of the age-based HR_{res} ¹⁰. The times to reach 60% and 80% of the age-predicted HR_{res} , following the 3 min warm up, were also calculated. The ventilatory threshold (VT) was assessed using the V-slope method¹¹.

Statistical analysis. Means and standard deviations were used to describe the variables. Comparisons of the results obtained for males and females were performed using the Mann-Whitney U test. Differences between the different measures of OUES (OUES75, OUES90, OUES100, OUES60% HR_{res} , and OUES80% HR_{res}) were assessed by the Steel-Dwass test. Correlations between calculated variables were determined using Pearson's correlation coefficient. Agreement between the methods of measurement of OUES was assessed by means of Bland-Altman analysis. A significance level of $P < 0.05$ was set for all comparisons¹².

Results

Of the 48 participants, 12 subjects did not reach a peak RER of 1.09, and 36 subjects exceeded this value. Any participant with an RER value of greater than 1.1 was placed in the maximal effort group. However, none of the subjects within this group reached the predictive maximal heart rate ($220 - \text{age}$) (Table 1).

Differences were not detected between males and females with regard to their resting HR, HR_{peak} , or HR_{res} values. Males exercised for longer and showed a significantly higher aerobic exercise capacity (i.e., $\dot{V}O_{2\text{peak}}$) compared to females (~65% of that of males), for HR_{peak} and RER_{peak} .

All of the OUES values were significantly higher for males, compared to females (~75% of that of males) (Table 2). Significant differences were not detected be-

Table 2. Mean and standard deviation (SD) values for oxygen uptake efficiency slope (OUES), calculated from data from the entire exercise (OUES100), or fractions thereof (90% [OUES90] or 75% [OUES75]) and from data obtained upon reaching either 80% (OUES80% HR_{res}) or 60% (OUES60% HR_{res}) of the calculated heart rate reserve.

Variable	Males	SD	Females	SD
OUES100	2762.3	574.0	1701.3**	249.1
OUES90	2420.9	546.3	1505.1**	222.0
OUES75	2724.4	609.1	1723.5**	283.2
OUES80% HR_{res}	2723.9	611.2	1731.5**	332.9
OUES60% HR_{res}	2624.3	632.1	1771.5**	458.1

**indicated a significant difference ($P < 0.01$) compared to males

tween the different OUES measures, based on the entire exercise (OUES100) and fractions of the same exercise. Furthermore, significant differences were not detected between OUES100 and HR_{res} -based measures of OUES (OUES80% HR_{res} , $P = 0.6$; OUES60% HR_{res} , $P = 0.9$).

The results of the Bland-Altman analysis (Fig. 1) showed that the mean difference (bias) between the measures was 15.5 and 68.6 for OUES80% HR_{res} -OUES100 and OUES60% HR_{res} -OUES100, respectively; and neither was significantly different from 0. Furthermore, the standard deviation (precision) was 173.2 and 356.0, whereas the 95% limits of agreement ranged from -296.8 to +327.8 and from -507.1 to +644.3 for the OUES80% HR_{res} -OUES100 and OUES60% HR_{res} -OUES100 comparisons, respectively (Fig. 2). Individual values of OUES60% HR_{res} showed a good correlation and the values of OUES80% HR_{res} indicated an even higher correlation with $\dot{V}O_{2\text{peak}}$ ($r^2 = 0.58$ and 0.60 , respectively; the regression lines did not significantly differ) (Fig. 3). A good correlation was also found between the values of OUES60% HR_{res} and OUES80% HR_{res} and VT ($r^2 = 0.50$ and 0.51 , respectively; the regression lines did not significantly differ).

Discussion

The validity of a new methodological approach for the calculation of OUES was tested in ID individuals as an alternative to the traditional time-based calculations. These results met the 3 conditions that indicate that OUES is a reliable evaluation: 1) We showed a high correlation with $\dot{V}O_{2\text{peak}}$, a standard index of cardiorespirometry; 2) we also showed a correlation of $\dot{V}O_{2\text{peak}}$ being higher than VT, which is a submaximal index; and 3) There was little effect of the load intensity. Therefore, the main finding of this study was that OUES can be reliably calculated, based on HR_{res} endpoints, during incremental cycling exercise in young individuals with intellectual disabilities. Furthermore, this study confirms the validity of OUES as

Fig. 2 Bland-Altman plots showing the mean difference (bias) between measures of OUES80%HR_{res} and OUES100 (left), and OUES60%HR_{res} and OUES100 (right), as a function of the mean of the 2 measures. The value of the SD (precision) and 95% limits of agreement are also indicated on each graph.

Fig. 3 Individual values of OUES80%_{res} (left) and OUES60%_{res} (right) as a function of $\dot{V}O_{2peak}$ (mL·min⁻¹). Regression lines, equations, and correlation coefficients are indicated. The regression lines for OUES80%_{res} and OUES60%_{res} do not significantly differ.

an indicator of aerobic exercise capability in this population. Further, in agreement with previous studies^{4-6,13}, significant differences were not detected between OUES100 and OUES90 or OUES75. These similarities confirm that OUES can be reliably calculated using incremental exercise of submaximal intensity. OUES, an index obtained by analyzing $\dot{V}O_2$ and $\dot{V}E$ kinetics, is obtained by the mathematical analysis of the $\dot{V}E/\dot{V}O_2$ relationship. It is an attempt to combine $\dot{V}O_2$ with $\dot{V}E$ -related parameters. The advantage of the OUES is that it can be calculated from submaximal exercise test data.

OUES80%_{res} and OUES60%_{res} values, obtained in this study, were not significantly different from each other or from the traditional, time-based OUES calculations (Table 2). In addition, the present data indicate that OUES80%_{res} and OUES60%_{res} provide a non-biased and reliable measure of OUES100 (Fig. 1) in young ID individuals. These observations suggest that reliable measures of OUES can be obtained based on incremental exercises of relatively short duration and of submaximal intensity, provided that the subject reaches at least 60%HR_{res}. Increasing exercise duration to 80%HR_{res} might, however, increase the confidence of OUES determination (Fig. 1).

Certain studies^{5,6,11,14,15} have indicated that OUES80%_{res} and OUES60%_{res} are highly correlated with indices of aerobic exercise capability (i.e., $\dot{V}O_{2peak}$ and VT). This

suggests that OUES is a reliable index of aerobic exercise capacity, and that it can be determined through submaximal incremental exercise that elicits an HR_{res} of at least 60%. Increasing exercise duration to 80%HR_{res} further increases the reliability of OUES as an index aerobic exercise capacity ($r^2 = 0.60$ for $\dot{V}O_{2peak}$ and $r^2 = 0.51$ for VT). In the present study, as well as in previous works, the correlation of OUES with VT is lower, compared to the correlation with $\dot{V}O_{2peak}$ ^{5,6,15-18}. In the present case, this was speculated to be due to the wide variability and the relative inaccuracies associated with the determination of VT in young ID individuals (VT- $\dot{V}O_{2peak}$ correlation in this study was $r^2 = 0.51$). In previous studies^{15,17}, the lower correlation of OUES with VT, compared to $\dot{V}O_{2peak}$, might have also been due to the use of an exercise protocol that was suboptimal for VT determination¹⁹.

This study was limited by the small number of subjects recruited, the majority of whom exhibited mild intellectual disability; the outcomes may not be applicable to individuals with severe intellectual-disability. However, correct evaluations may be achieved by OUES if the heart rate can be raised by appropriate changes to the exercise method or protocol.

Conclusion

Our data indicate that fractions of the theoretical HR_{res} ($80\%HR_{res}$ and $60\%HR_{res}$) can be used as alternative exercise endpoints for reliable OUES calculations during incremental cycling exercise in young ID individuals. Furthermore, the study confirms the validity of OUES as a submaximal index of aerobic exercise capacity for this study population. In such a population, where maximal effort may be difficult to obtain and in which the time to exhaustion is highly variable, the use of reliable exercise endpoints, based on HR_{res} for OUES calculations, is of particular practical relevance. This study indicated that OUES is a suitable method for the evaluation of the fitness of an ID person, and facilitates the design of a safe, effective exercise program.

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