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Algorithm for interpretation of submaximal exercise tests in children

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Introduction. Assessment of exercise tolerance and physical capacity have always been a major issue in pediatric exercise physiology [1,2]. Due to ethical considerations [3] the use of maximal tests is restricted and the application of submaximal workloads is increasing recently [4]. The main problem with submaximal oxygen uptake data is that it does not have the capability to stratify the exercise tolerance of the children which completed the test protocol. Measurements of metabolic and subjective responses to submaximal exercise may assist in the decision making about children's physical fitness.

Aim: The aim of this study is to create an algorithm for interpretation of submaximal exercise tests evaluating physical capacity in children.

Materials and methods: Two hundred and thirty six healthy children (108 boys and 128 girls) in the age span 10-14 years took part in the study. The anthropometric parameters of boys and girls are as follows: height (cm) - 154±12.0 vs. 154±9.0, weight (kg) - 45.2 ± 11.7 vs. 44.6 ± 9.0, and BMI ($kg.m^{-2}$) – 18.7 ± 3.0 vs. 18.8 ± 2.7; ($p>0.05$ for all). All of them were in good health, generally physically active, taking no medications that would affect exercise performance. Prior to the test all the participants were subjected to comprehensive pulmonary function assessment, as well as complete anthropometric measurements, including stature, body mass, skinfold thickness and chest circumferences in full inspiration/expiration.

Exercise testing was performed in a laboratory compliant with the guidelines of the AHA [5] on a motor driven, electronically controlled treadmill (TrackMaster™, USA) using our modification of the Balke protocol [6,7] The test consists of nine one-minute-increments with constant velocity of 5.4 km/h starting from 6% elevation and increasing with 2% every minute.

Throughout the test gas exchange variables were determined with an on-line computerized system $CardiO_2$™ (Medical Graphics, MN, USA). The system was calibrated before each test. Pneumotachometer was used for recording of the tidal volume (V_T) and minute ventilation (V_E). 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), carbon dioxide output (VCO_2) and respiratory exchange ratio (RER). Heart rate was monitored electrocardiographically (Hellige, Germany) and the oxygen saturation was traced with pulseoxymeter Pulseox DP-8 (Minolta, Japan). At the end of each exercise increment and throughout the recovery period the children were asked to rate the perceived exertion using the Borg scale [8] depicting fatigue (dyspnea) from "not at all" to "maximal" by means of ten grades.

The **main principle** of the proposed algorithm is to use the estimate of the respiratory exchange ratio (RER) and the Borg score (subjective measure of the person's exercise tolerance) at peak exercise as predictors for the exercise tolerance. Borg scores above 5 are accepted as indicator of lower tolerance to the applied standard workload compared to Borg score ≤5. The RER has a value under 1 if there is a solely aerobic energy production and above 1 when a substantial anaerobic supplementation takes place. Thus four combinations, respectively four group can be defined as shown in **Table 1**:

Table 1. Main principle of the proposed algorithm and the corresponding groups (quadrants)

I main parameter	**II main arameter**	***Groups (quadrants)***
Borg ≤ 5	RER ≤ 1.0	Group 1
Borg ≤ 5	RER > 1.0	Group 2
Borg > 5	RER ≤ 1.0	Group 3
Borg > 5	RER > 1.0	Group 4

To verify the proposed algorithm, maximal exercise test with Bruce treadmill protocol [9] was conducted with 23 children randomized from the main group (age -13.2 ± 0.8; BMI - 18.7 ± 1.5 $kg.m^{-2}$) and 20 similarly aged children (13.5 ± 0.6; BMI -18.3 ± 1.8 $kg.m^{-2}$) actively training football and volleyball. The exercise results were grouped according to the algorithm based on the findings from the modified Balke treadmill test. Additional verification was ensured through applying the algorithm in the assessment of 17 children with obesity (BMI between 24.6 and 35.9 $kg.m^{-2}$; 29.2 ± 3.5, age -12 ± 2.2 years)

Multiple comparisons between groups were made by means of one way ANOVA with Bonferroni post-hoc correction (SPSS v. 6, Chicago, IL, USA). Values are expressed as mean ± SD.

Results: The results from the modified Balke test are presented in Table 2. In boys higher values of relative oxygen uptake (VO_2/kg) are observed, while in girls there are significantly greater values of ventilatory equivalents (VE/VO_2 è VE/VCO_2) and RER. Girls also show significantly higher perception of exercise assessed by means of Borg scale.

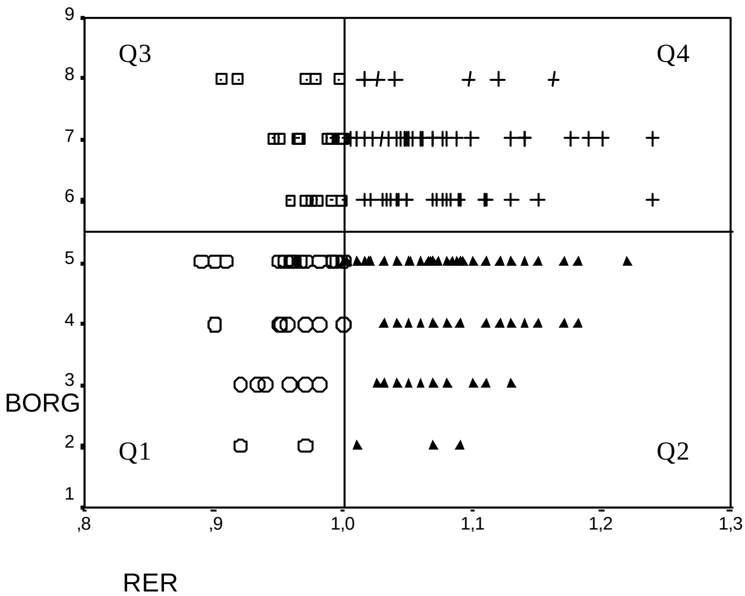
Table 2 – Basic parameters from the treadmill stress test for the studied groups

Parameters	Boys (n=108)	Girls (n=128)	P
Age years	11.8±1.4	12.1±1.4	NS*
BMI $kg.m^{-2}$	18.8±2.8	18.8±2.7	NS
VO_2 peak $mL.min^{-1}$	1746 ± 500	1656 ± 361	NS
VO_2/kg $mL.kg^{-1}.min^{-1}$	38.7 ± 4.4	37.2 ± 4.1	0.008
VE $L.min^{-1}$	50.1 ± 13.6	52.2 ± 1.7	NS
VE/VO_2	29.0 ± 3.2	31.7 ± 3.8	<0.001
RER	1.03 ± 0.06	1.06 ± .06	<0.001
Borg score	5.0 ± 1.4	5.4 ± 1.4	0.042

*NS – non significant

A diagram representing the distribution of the tested children in the constituted four groups (quadrants) is shown in **Fig. 1.** According to the principle - in quadrant 1 are grouped children with the highest presumed tolerance, in quadrant 4 with the lowest and in quadrants 3 and 4 reside children with intermediate physical capacity. In the first quadrant there are 16.1% of the studied children, in the second - 47%, in the third – 9.3% and in the fourth – 27.5%.

Fig. 1. Distribution of the studied children according to the algorithm in four groups (quadrants – Q)



No significant differences are found, concerning the mean peak (VO_2 peak) and relative oxygen consumption (VO_2/kg) in different quadrants. For example the children in the first quadrant (excellent fitness) have almost the same values compared to these in quadrant 4 (less fit): VO2/kg - 39.4 ± 4.3 vs. 37.8 ± 4.7 $mL.kg^{-1}.min^{-1}$; $p > 0.05$.

Table 3 is showing some basic anthropometric and functional parameters of the children studied with the Bruce protocol and grouped in the same four quadrants according to the principles derived from the submaximal Balke treadmill test. It is obvious that the group with the best exercise tolerance according to the algorithm (quadrant 1) reveals significantly greater values for the relative oxygen consumption (VO_2/kg) which decline significantly in the other groups reaching its lowest value in quadrant 4.

Table 3 – Basic parameters of the studied children with the Bruce protocol distributed according to the algorithm in four groups (quadrants - Q)

Parameters	Àge years	BMI $kg.m^{-2}$	VO_2/kg $mL.kg^{-1}.min^{-1}$	VE/VO_2	RER	Borg
Q#1; n=13	13.5±0.8	18.0±1.6	52.6±7.3	32.4±3.4	1.08±0.09	5.8±1.4
Q#2; n=20	13.5±0.6	18.8±1.7	47.4±6.0	33.8±3.7	1.16±0.07	5.5±1.4
Q#3; n=4	13.0±0.8	19.2±1.7	41.0±4.1	27.8±3.0	1.02±0.05	6.3±1.0
Q#4; n=6	12.8±0.8	18.1±1.6	36.4±3.7	34.8±2.2	1.17±0.06	6.7±0.5
Ð<0.05 Between the following groups			1/3; 1/4; 2/4		1/2; 2/3; 3/4	

Separating the children studied with Bruce protocol into two groups: actively training (n=20) and non training (n=23) displayed significant differences in oxygen uptake data (VO_2/kg = 51.8± 6.7 vs. 42.5 ±6.4 $mL.kg^{-1}.min^{-1}$; ð<0.001) and Borg score (5.3± 1.6 vs. 6.2± 0.9; ð=0.026). Actively training children have better aerobic parameters and go into the first (n=10; 50%) and second (n=10) quadrant. Non-training children are unevenly distributed in the four quadrants (n=3, 10, 4, 6 respectively) and only 13% reside in the first quadrant. The stated differences are statistically significant (Pearson Chi square = 0.003)

The ability of this algorithm to stratify the children's exercise tolerance on the basis of submaximal test performed with the modified Balke protocol was confirmed in the Obesity group. The children with obesity were distributed in quadrant 2 (n=7) and quadrant 4 (n=10).

Discussion: In the present paper an algorithm for interpretation of submaximal exercise tests evaluating physical capacity in pediatric age is proposed. We also prove its practical applicability verifying it by means of a maximal treadmill test and evaluating children with common pathological condition - obesity.

The problem with the submaximal exercise tests is that the measurement of oxygen consumption alone is not enough to indicate the exercise tolerance of children. That's why other physiological variables have to be analyzed to define the exercise tolerance of children [10,11]. Applying the Borg scale for grading fatigue (effort) is that baseline which allowed us to build an algorithm for interpretation. Our experience in exercise testing proves that after a careful preliminary instruction almost every child is able to rate the perceived exertion properly. We found that the combination of that index with the RER as a main indicator of the type of metabolism in the working muscle, independent of body weight (RER = VCO_2/VO_2), were forming a diagnostic algorithm for interpretation of submaximal exercise tests.

The validity of this approach is proved by the results obtained through the Bruce maximal exercise test**.** The children with the highest exercise tolerance according to the algorithm (quadrant 1) demonstrated significantly greater values for both peak and relative oxygen consumption in comparison to the other groups and especially to group 4 (bad tolerance quadrant). It is obvious that the combination defining quadrant 3 is very rare. It has to be clarified in the future whether it holds any discriminative significance. More important is that in group 4 reside 27.5% of all children e.g. every fourth child is with decreased exercise tolerance. This is a very alarming fact concerning the deconditioning of children and requires reevaluation of the physical education regime in schools. These data are confirmed by other authors as well [12].

Conclusion: The proposed algorithm for interpretation of submaximal exercise test based on the Borg score and the value of respiratory exchange ratio is a reliable diagnostic tool for evaluation of exercise tolerance in pediatric age.

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