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THE INFLUENCE OF AEROBIC AND ANAEROBIC CHARACTERISTICS OF CHILDREN OF DIFFERENT AGE ON ACHIEVEMENT OF VO_2 PLATEAU

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Abstract. VO_2max is a measurement of the maximal rate at which energy can be derived from oxidative processes. The plateau criterion has been considered the most important criterion when defining a VO_2max value. The purpose of this research was to compare subjects who achieve a plateau with those who do not and to determine which anthropometric and physiological factors and endurance performance influence the achievement of VO_2 plateau, and to find, whether the two groups differ in gender and age. The sample comprised 27 children (age 11.8±2.0 yrs, weight 49.7±14.0 kg, height 159.7±14.0 cm), 14 of them were boys and 13 were girls. The children exhibited average VO_2max values of 45.4±7.7 $ml \cdot min^{-1} \cdot kg^{-1}$ during the exercise. The criteria for achieving the plateau were respiratory exchange rate greater or equal 1.0, heart rate greater or equal 90% of predicted age-adjusted maximal heart rate and the change in VO_2 in the last minute of exercise less or equal 2 $ml \cdot min^{-1} \cdot kg^{-1}$ with an increase in workload. 56% of children met all three criteria for achieving the plateau in VO_2. Statistically significant differences between plateau achievers and non-achievers were found for gender, VO_2max, velocity at VO_2max, duration of the treadmill test, results on 2400 m and fat mass. In the other explanatory variables subjects showed no significant differences. This study demonstrates the plateau achievers are mostly girls, have worse results in tests of maximal aerobic power and endurance performance (velocity at VO_2max, duration of the treadmill, 2400 m run) and have more fat mass than non-achievers.

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Key words: VO_2 plateau – Children – Anthropometry - Physiological factors - Endurance performance

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Introduction

Oxygen uptake kinetics to a suddenly started exercise has been traditionally described as a single exponential function with a relatively steep increase at the beginning and a slower asymptotic approach to steady state level. Hamar *et al.* [9] described the VO_2 kinetics more accurately and analyzed three phases. The initial one immediately following the onset of exercise and characterized by a sudden increase of oxygen uptake in first or second breath with a subsequent plateau or rebound, takes some 20 to 25 s. At the transition into phase two the oxygen uptake does begin rise exponentially. The second phase culminates in phase three by settling at the level of steady state oxygen uptake or if exercise intensity exceeds the anaerobic threshold, by a slow upward drift of VO_2. The present study focuses primarily on the third phase, the plateau phase in oxygen consumption.

Many previous studies [1,2,3,8,11,13,16,19,20,21] investigated the achievement of a plateau in VO_2 in children and adolescents. They all found different percentage of those who reached the plateau in VO_2 and those who did not. For example, Armstrong *et al.* [1] discovered only 24% of children who reached the plateau in VO_2. On the other hand Mahon and Marsh [13] found 54% of children who reached the plateau in VO_2. Different objective and subjective criteria have been established to determine the attainment of a true VO_2. The plateau criterion has been considered the most important criterion when defining a VO_2max value. VO_2max is a measurement of the maximal rate at which energy can be derived from oxidative processes.

Researchers have used different methods and criteria for VO_2max in their studies, which could be the reason for different findings in these studies. To our knowledge all the studies had a common purpose: to determine, why some subjects achieve VO_2 plateau and others do not. Some authors ascertained there were no differences between plateau achievers and non-achievers [1,2,3,13,20,22]. Rivera-Brown *et al.* [20], for example compared pre-pubertal subjects who achieved a plateau with those who did not on maximal exercise variables and peak and mean anaerobic power and found no differences. On the other hand others reported significant differences [8,11,16,19]. Ritmeester *et al.* [19] discovered plateau achievers showed lower VO_2max than non-achievers. Later on Kemper and van Zundert [11], who focused mostly on anthropometric differences between young subjects that did and such that did not show a plateau in VO_2 during maximal treadmill exercise tests, reported that larger leg muscle mass would lead to a relatively higher VO_2max without a leveling-off in oxygen uptake. Niesen-Vertommen *et al.* [16] measured VO_2max, peak power and mean power on a cycle

ergometer in children and found a higher anaerobic power in the plateau achievers. Duncan [8] measured VO_2max in boys on a treadmill and found a higher test duration in plateau achievers.

There is no common answer on question what influences the achievement of VO_2 plateau in children. The purpose of this research was to compare subjects who achieve a plateau with those who do not and to determine which anthropometric and physiological factors and endurance performance influence the achievement of VO_2 plateau, and to find, whether the two groups differ in gender and age.

Material and Methods

Subjects: 27 healthy 10 to 14-year-old children were tested after parental written consent was obtained in accordance with National medicine ethical commission. All the subjects were moderately active and non-athletes.

Table 1
Basic characteristics of subjects

	Girls (n=13)	Boys (n=14)
Age (yrs)	11.6±2.2	12.0±1.8
Height (cm)	156.69±14.86	162.50±12.97
Weight (kg)	46.35±12.74	52.76±14.87
Maximal oxygen consumption ($ml \cdot min^{-1} \cdot kg^{-1}$)	39.6±4.7	50.8±5.9

Experimental session: The children were familiarized with the laboratory, testing procedures and instruments. They completed a trial on the treadmill and tensiometric platform. The experimental procedure consisted of four testing days. On the first day the anthropometric variables were measured and test of maximal velocity, explosive power and a 30 s Wingate anaerobic test were performed. On the second day the test of maximal aerobic power was measured. Between the first and the second period 3 to 5 days passed. On the third testing day the 600 m running test was carried out (5-7 days after maximal aerobic power test). On the last testing day the 2400 m running test was completed (7 days after the 600 m run).

Protocol: Maximal aerobic power test was measured with the subject running on a treadmill with increasing velocity and on a 5% slope [5]. Initial velocity was 8 km/h. The speed increased every minute by 1 km/h till voluntary exhaustion. Before the test the subjects warmed up for 11 min (3 min at 6 km/h and 4 min at 7 km/h at 0% slope and 4 min run at 0% slope at 8 km/h). After the test they walked 5 min to calm down. For completing the test the portable telemetric unit K4 Cosmed (Italy) was used to measure respiratory and gas exchange variables.

600 m and 2400 m running tests were carried out on a 400 m athletic track. Subject alone in assistance of experienced adult runner who encouraged the running rhythm completed maximal speed run. Each subject completed running test with portable telemetric unit K4B Cosmed (Italy), which was calibrated before each test. Heart rate was measured by a Polar electrocardiograph and telemetric unit (Oulu, Finland).

Blood lactate concentration (LA) was measured by Eppendorf Ebio lactate analyser (Germany). 20μl blood sample was taken from hyperemic earlobe. Measurement accuracy of blood lactate in fresh blood was $\pm 0.1 mmol \cdot l^{-1}$.

Muscle peak power (PP) and mean power (MP) were measured by the Wingate anaerobic test on a Monark cycle ergometer. The test is a 30 seconds "all – out" supramaximal task where, after a 3 to 4 min warm up, the subject pedals at a maximal rate against a high constant resistance (7.5% of body weight). PP was taken as the highest mechanical power output at any 1 s period. MP was the average power over the entire 30 seconds cycling with maximum intensity. Blood for lactate sampling after the cycling with maximum intensity was drawn from an earlobe. Blood from the earlobe was drawn five minutes post-exercise.

Maximal speed: the subject ran with maximal speed 20 m after 10 to 20 m of acceleration zone. Brower Timing System (USA) was used for measuring the 20 m time.

Heights in squat jumps and counter movement jump were measured with a tensiometric platform (Kistler, 9278, Winterthur, Switzerland) in a laboratory environment (equation 1). Take off power in squat jump (SJP) and in counter movement jump (CMJP) were calculated from equation 2. In the squat jump test the subject performs a vertical jump from a semi- squat position (knee- angle is 90°), with trunk as vertical as possible and hands on hips. Subject executes the test without the counter movement. In this test, subject started in erect position with hands on hips and executed a vertical jump after a downward counter movement (knee must be fixed at 90° at the end of the counter movement).

$$H = \frac{g\left(\frac{t_f}{2}\right)^2}{2} = \frac{gt_f^2}{8} \qquad \text{Equation 1}$$

Where:
H – jump height
t_f – flight time
g – gravity constant

$$P = \frac{W}{t_c} \qquad \text{Equation 2}$$

Where:

P – power at take-off
W – work at take-off
t_c – contact time

Anthropometric variables were measured with standard protocol according to EUROFIT (1983). Muscle and fat mass was estimated through anthropometry using modifying equation reported by Mateigka [14].

The criteria for achieving the plateau: The criteria for achieving the plateau were similar to those used by Rivera-Brown *et al.* [20], Nevill *et al.* [15], Karila *et al.* [10], Paterson *et al.* [18]:

1) RER≥1.0;
2) 2) HR≥90% of predicted age-adjusted maximal heart rate;
3) 3) the change in VO_2 in the last minute of exercise ≤2 $ml \cdot min^{-1} \cdot kg^{-1}$ with an increase in workload.

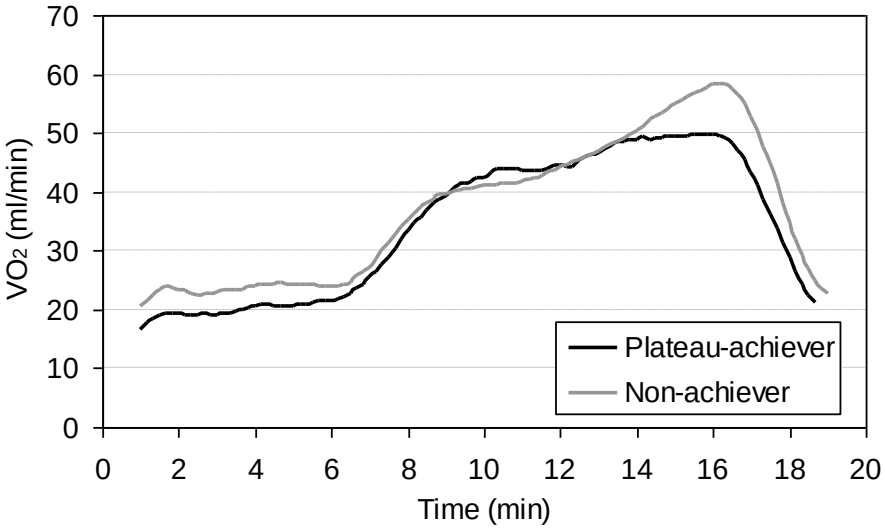

Fig. 1
VO_2 dynamics for a plateau-achiever and non-achiever

Statistical analysis: The percentages of children achieving each criterion for plateau as well as mean and standard deviations (SD) of all aerobic and anaerobic variables were calculated. An independent t-test and Pearson chi-square test[1] were used to compare plateau achievers and non-achievers on physical characteristics and peak exercise variables. An alpha level of $p<0.05$ was considered significant.

Results

Descriptive statistics: The mean ±SD of the age, weight, and height of the subjects were 11.8±2.0 yrs, 49.7±14.0 kg, and 159.7±14.0 cm, respectively. These children exhibited average VO_2max values of 45.4±7.7 $ml \cdot min^{-1} \cdot kg^{-1}$ during the exercise, which is typical for healthy untrained children [21].

Frequency of achievement of criteria for plateau: The criterion for RER≥1.0 was achieved by all of the subjects. The mean value of 1.19±0.14 is significantly higher than in the research of Rivera-Brown *et al.* [20]; but they also discovered

[1]For the nominal variable (*gender*)

that all the subjects met the criteria for RER. The criterion for HR ≥90% was met by 26 of the 27 children (96%). The third criterion was met by 15 out of 27 children (56%). For achieving the plateau in VO_2 all three criteria had to be met.

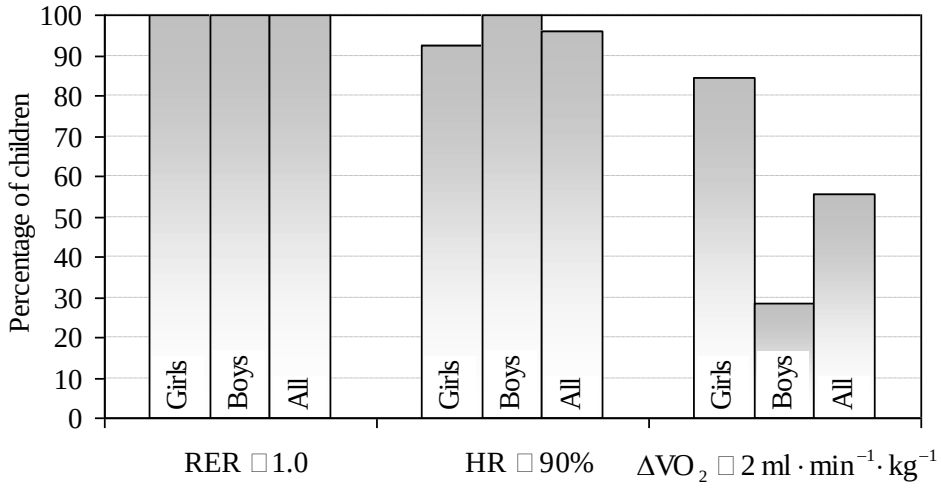

Fig. 2
Percentage of children achieving the criteria for plateau

Comparison between plateau achievers and non-achievers: Statistically significant differences ($P<0.05$) between plateau achievers and non-achievers were found for gender, VO_2max, velocity at VO_2max, duration of the treadmill test, results on 2400 m and fat mass. In the other explanatory variables subjects showed no significant differences. Among the plateau achievers almost 85% were girls, whereas among non-achievers the proportion of girls was only 29%.

Table 2
Maximal exercise values and other explanatory variables of children who achieved a plateau in oxygen consumption and those who did not

	Plateau (n=15)	No Plateau (n=12)	t-test (2 Sided Sig.)
Age (years)	12.1±2.1	11.4±1.8	0.37
Height (cm)	160.6±13.4	158.6±15.1	0.72
Weight (kg)	50.4±12.9	48.7±15.8	0.75
Fat mass (%)	17.4±5.5	12.3±4.2	0.01
Muscle mass (%)	46.6±2.9	46.8±2.8	0.89
Body mass index	19.3±2.4	18.9±3.2	0.73
Skin fold on upper arm (mm)	12.3±3.6	10.2±3.9	0.18
Maximal heart rate (bpm)	207.8±2.04	208.5±1.8	0.36
Maximal oxygen consumption ($ml \cdot min^{-1} \cdot kg^{-1}$)	41.53±6.2	50.3±6.7	0.02
Average absolute oxygen consumption ($ml \cdot min^{-1}$)	1367.0±412.8	1442.9±558.9	0.40
Maximal respiratory exchange rate	1.21±0.14	1.16±0.13	0.23
Average ventilation ($l \cdot min^{-1}$)	49.7±11.435	48.7±13.0	0.83
Velocity at VO_2max ($km \cdot h^{-1}$)	11.7±0.9	12.5±1.08	0.04
Duration of the treadmill test (min)	15.2±1.3	16.3±1.1	0.04
Results on 600 m (sec)	141.5±15.4	136.4±17.8	0.43
Blood lactate on 600 m	9.72±1.52	9.25±1.89	0.48
Results on 2400 m (sec)	777.2±92.7	693.2±81.6	0.03
Blood lactate on 2400 m	7.78±1.63	8.52±4.06	0.57
Peak power on Wingate test (W)	349.3±106.5	360.5±143.8	0.82
Relative peak power on Wingate test (W)	6.8±0.7	7.2±1.1	0.24
Maximal blood lactate on Wingate test	7.7±1.3	7.8±2.5	0.93
Vertical squat jump (cm)	23.7±4.2	22.6±4.1	0.53
Vertical counter movement jump (cm)	25.3±5.17	25.0±4.5	0.87
Sprint 20m (flying start) (sec)	3.00±0.28	3.03±0.36	0.81

Table 3 shows the distribution of plateau-achievers and non-achievers between girls and boys. With Pearson chi-square test statistically significant differences in achieving VO_2 plateau between girls and boys were confirmed.

Table 3
Distribution of plateau-achievers and non-achievers between girls and boys

			Plateau (n=15)	No Plateau (n=12)
Gender	Female	(n=13)	84.6%	28.6%
	Male	(n=14)	15.4%	71.4%
Total			100.0%	100.0%

Discussion

The purpose of this research was to compare subjects who achieve a plateau with those who do not and to determine which anthropometric and physiological factors and endurance performance influence the achievement of VO_2 plateau, and to find, whether the two groups differ in gender and age. The main findings were:

- 56% of children reached a plateau in VO_2,
- the plateau achievers were mostly girls (85%),
- the plateau achievers had worse results in tests of maximal aerobic power and endurance performance (velocity at VO_2max, duration of the treadmill test, 2400m run) and
- the plateau achievers had more fat mass than non-achievers.

The results of this study show that among 10 to 14-year-old children more girls (11 out of 13) than boys (4 out of 14) reached a plateau in O_2 uptake at the end of the maximal treadmill test. This finding agrees with Kemper and van Zundert [11] results, which studied the teenage period. They found that more girls (73%) than boys (53%) reach the VO_2 plateau at the end of maximal treadmill test. 5 years later, when the same population was 20 to 21-year-old the differences grew even larger.

Our study also confirmed that subjects who reached a plateau in O_2 uptake showed significantly smaller VO_2max than those who failed to display a plateau. Kemper and van Zundert [11] and Ritmeester *et al.* [19] confirmed this finding in their study, whereas Rivera-Brown *et al.* [20] study showed no differences in VO_2 plateau achievers and non-achievers.

The next two significant variables were velocity at VO_2max and duration of the treadmill test, which were lower for plateau achievers. The plateau achievers were exhausted sooner and consequently lasted less on the treadmill than non-achievers. This can be related to the result of the 2400 m run. The plateau achievers had significantly worse results in the 2400 m run than non-achievers. Leger and Boucher [12] showed that 2400 m run required great motivation and a knowledge of pacing. Our study clearly showed plateau achievers had lower endurance ability. Endurance ability depends among other factors also on motivation, which is important to overcome the physical effort. Lack of motivation could cause the children to complete the test earlier, which increases the probability to reach the plateau VO_2. Demarie *et al.* [6] showed that velocity at VO_2max combined VO_2max and economy into a single factor which explains differences in performance that VO_2max or running economy alone could not. Billat *et al.* [4] also suggested that vVO_2max was a good predictor of endurance performance. Noakes *et al.* [17] have shown that peak running velocity reached at exhaustion during the maximal treadmill test and maintained for 1 min, was a better predictor of running performance than VO_2max. All these findings confirm the fact that subjects who reached a plateau in O_2 uptake demonstrated worse results in endurance performance (2400 m run) and in the aerobic power test on a treadmill (velocity at VO_2max, VO_2max, duration of the treadmill test).

On the other hand no significant differences were found in anaerobic variables (peak power, relative peak power, maximal blood lactate on Wingate test and results in two vertical jumps). Niesen-Vertomen *et al.* [16] measured peak power and mean power on a cycle ergometer in a group of young subjects and found a higher anaerobic power in the plateau achievers. However Rivera-Brown *et al.* [20] was convinced that low anaerobic power has been proposed as a factor that may be limiting the achievement of a plateau in VO_2 of children who perform maximal power tests, but he discovered that no differences were found for peak power and mean power between prepubertal boys who achieved a plateau and those who had not.

Moreover, it has been shown that subjects with more fat mass reach a plateau in VO_2 more often. Kemper and van Zundert [11] also obtained this result. They were convinced the VO_2 difference between plateau achievers and non-achievers appeared to be related to certain anthropometric characteristics: muscle mass and lean leg volume. They also discovered that at the age of 20.5 females – who have comparatively smaller muscle mass and lean leg volume – attained the plateau criterion more often than males. They concluded these finding were probably caused by the peripheral metabolic and capillary capacity of the exercising muscles taxing central oxygen transport to a greater extent.

Girls are by nature weaker than boys. They have more redundant fat mass. Girls' relative VO_2max decreases with aging. Rowland [21] argues that fat mass lowers relative VO_2. Subjects with greater muscle mass are physically capable to run longer at VO_2max. Demarle *et al.* [7] explained that because the speeded HR response and the increased stroke volume, it was speculated that oxygen delivery to the active muscle could be improved at the onset of exercise. All these characteristics are reflected in the results of maximal performance tests. Our opinion is that subjects with greater fat mass and lower VO_2max (lower aerobic power) can display a plateau in O_2 uptake faster because fatigue occurs sooner. Plateau achievers were unable to sustain a required intensity and their time until exhaustion was shorter. Demarle *et al.* [7] concluded that decrease of oxygen deficit was related to increase of time until exhaustion in a severe run performed after a specific endurance training program. On the other hand, subjects with opposite characteristics (greater muscle mass, better oxygen delivery, higher VO_2max, longer time until exhaustion) could also display a plateau but they are not yet exhausted and can continue to exercise beyond a plateau level until they reach their real VO_2max.

This study demonstrates that the plateau achievers are mostly girls, have worse results in tests of maximal aerobic power and endurance performance (velocity at VO_2max, duration of the treadmill test, 2400m run) and have more fat mass than non-achievers.

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