

EFFECT OF THE CHRONOLOGICAL AGE AND SEXUAL MATURATION ON THE TIME TO EXHAUSTION AT MAXIMAL AEROBIC SPEED

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Abstract. The purposes of this study were: a) to verify the effect of chronological age and sexual maturation on the time to exhaustion at $VO_2\max$ (t_{lim}) and; b) to examine the reproducibility of t_{lim} in boys aged 10-15 years. Forty boys, divided into 4 groups, in accordance to the chronological age (G10-12 and G13-15) and sexual maturation (P1-P3 and P4-P5 levels for pubic hair), performed the following tests: 1) incremental test for determination of $VO_2\max$ and; 2) all-out exercise bout performed at $VO_2\max$ to determine the t_{lim} . There was no difference of t_{lim} (sec) between G10-12 and G13-15 (181.5 ± 96.3 vs. 199 ± 105.5). While the two measures of t_{lim} were moderately related ($r=0.78$), t_{lim} from the second test (226.6 ± 96.1 s) was higher than that of the first (191.3 ± 79.2 s). We can conclude that the t_{lim} is not influenced by chronological age and sexual maturation. Besides, t_{lim} presents a lower reproducibility in children and adolescents.

(Biol.Sport 24:21-30, 2007)

Key words: Maximal oxygen uptake – Running - Children.

Introduction

The effects of the chronological age and biological maturation on the maximal oxygen uptake ($VO_2\max$) and running economy (RE) in children and adolescents are well reported in the literature [19,22;27]. Many longitudinal studies have shown that the $VO_2\max$ expressed as absolute values ($l\cdot\min^{-1}$) increases about 11% per year, from 6 to 18 years old [1,23]. However, when $VO_2\max$ is expressed in ratio with body mass ($ml\cdot kg^{-1}\cdot\min^{-1}$), it has been shown to remain unchanged with maturation in both sexes. RE, defined as the aerobic demand (VO_2) of submaximal running [12], also is influenced by the chronological age. Longitudinal [19] and cross-sectional [3] studies have verified that RE increases according to the chronological age, regardless of the physical training.

Another index associated to the aerobic performance, which have been widely studied in adults, is the running speed associated with $VO_2\max$ ($vVO_2\max$). As the

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vVO₂max combines the maximal aerobic power (VO₂max) and RE into a single factor, many studies performed in highly trained athletes, have verified that the vVO₂max is more sensitive to the aerobic training effects [11] and more valid to explain individual differences in the aerobic performance, than VO₂max or RE alone [12]. In children and adolescents, few studies have analyzed the factors that can influence the vVO₂max. Billat *et al.* [8] verified that the VO₂max and vVO₂max were significantly higher in boys (49.4 ml·kg⁻¹·min⁻¹ and 12.6 km/h) than girls (40.4 ml·kg⁻¹·min⁻¹ and 11.2 km/h) with the same age group (10 to 12 years old). Beside the higher VO₂max, boys also present a better RE. To our knowledge no study has analyzed the effects of the chronological age and biological maturation on the vVO₂max.

The maximal endurance time or time to exhaustion (t_{lim}), obtained at the intensity corresponding to the vVO₂max has been also widely investigated in adults [6,7,17]). In athletes, t_{lim} at vVO₂max has been used as an index of anaerobic capacity, to prescribe, in an individualized manner, the duration of stimuli during interval training, and to predict performance [10,14]. Although in homogeneous groups the VO₂max and vVO₂max have a lower coefficient of variation (5-8%), t_{lim} presents a higher interindividual variability (20-45%). Part of this variability can be explained by the aerobic characteristic of the athletes. Studies performed in endurance runners have verified an inverse relationship of t_{lim} with VO₂max [9] and vVO₂max [6,7]. In children and adolescents, t_{lim} has been used to determine the training effects [4] and critical speed [5]. However, the factors that can influence the t_{lim} as well its reproducibility in this population have not been investigated.

Therefore, the purposes of this study were: a) to verify the effect of the chronological age and sexual maturation on the VO₂max, vVO₂max and t_{lim} at vVO₂max in boys of 10-15 years old; to analyze the relationship between t_{lim} at vVO₂max and the VO₂max, vVO₂max, chronological age, sexual maturation and anthropometrics characteristics and; c) to examine the reproducibility of the t_{lim} at vVO₂max in children and adolescents.

Materials and Methods

Subjects: Participated of this study 40 boys aged 10-15 years, divided into 4 groups, in accordance to the chronological age (10-12 years - G10-12, and; 13-15 years - G13-15) and sexual maturation (P1-P3 and P4-P5 levels for pubic hair). Subjects were not presently undertaking any regular exercise training. Age was computed from date of birth and date of examination. Sexual maturity was visually assessed by an experienced physical education professor using the pubic hair index



developed by Tanner [24]. All participants and their parents gave their informed consent and the study was approved by the university's ethics committee. Table 1 shows the main physical characteristics of the subjects.

Anthropometrics characteristics: Height, body mass, and skinfold thickness over the triceps (TR) and subscapular (SE) region were measured according to the techniques described by Guedes [16]. The body fat (%G) was estimated according to the equation of Lohman [20]: $\%G = 1.35 (\sum TR + SE) - 0.012 (\sum TR + SE)^2 - C$, where C is a constant depending on chronological age.

Experimental protocols: Before data collection, subjects became accustomed to treadmill running and mouth-piece breathing. This process consisted in an initial period of walking followed by slow jogging that normally lasted 5 min.

Day 1: $VO_2\max$ and determination of the velocity at maximal oxygen uptake occurs ($vVO_2\max$)

The tests were carried out on a motorized treadmill (INBRAMED Super ATL, Porto Alegre, Brazil) using a discontinuous, incremental protocol, starting with stages of 3 min at 7 km/h and speed increments of 1 km/h. All stages were followed by a 30-s period of rest. Subjects ran until they felt unable to continue the exercise. Oxygen consumption was continuously monitored (Aerosport Teem 100 Metabolic Analysis System) during the initial resting period (VO_{2rest} , measured with the subject standing on the treadmill) and throughout the tests until exhaustion. The equipment was calibrated before each test according to the manufacturer's instructions. This analyzer has previously been validated over a wide range of exercise intensities [21,29]. Heart rate (HR) was also continuously recorded throughout the tests (Polar, Kempele, Finland). The $VO_2\max$ was defined as the highest 20-s VO_2 value reached during the incremental test. The main criterion for attaining $VO_2\max$ was an increase of less than $2 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ in spite of an increase in the workload as suggested by Taylor *et al.* [25]. HR levelling and R values at 1.0 or higher were used as secondary criteria.

The velocity associated to $VO_2\max$ ($vVO_2\max$) was calculated according to the equation of di Prampero [13]: $vVO_2\max = (VO_2\max - VO_2\text{rest}) \cdot CR^{-1}$, where CR ($\text{ml O}_2/\text{kg}^{-1} \cdot \text{min}^{-1}$) is the oxygen cost of running per unit of body mass at a given velocity (v) and was calculated by the formula: $CR = (VO_{2v} - VO_2\text{rest}) \cdot v^{-1}$ and CR was calculated for the velocity associated with 75% $VO_2\max$.

Day 2: Determination of the maximal endurance time (t_{lim}) at $vVO_2\max$

The purpose of this session was to determine the individual t_{lim} at $vVO_2\max$. After a 15-min warm-up at 60% $vVO_2\max$, the treadmill speed was quickly increased (in less than 10 s) to the individual $vVO_2\max$. Tests were terminated



when the participants placed his hands back on the railing, signifying volitional fatigue. T_{lim} was measured to the nearest second.

Statistical analysis: Data are presented as mean \pm SD. Non parametric Mann-Whitney's U-test was used to test differences between mean values. Intraclass correlation coefficient was used to analyze the reproducibility of the t_{lim} at vVO_{2max} . Correlations between t_{lim} at vVO_{2max} and the VO_{2max} , vVO_{2max} and anthropometrics characteristics were evaluated using stepwise multiple regression analysis. Statistical significance was set at $P \leq 0.05$.

Results

Table 1 shows the anthropometrics characteristics of the subjects divided by chronological (G10-12 and G13-15) and sexual maturation (P1-P3 and P4-P5). The chronological age, body mass and height were significant different between groups. However, there was no significant difference in body fat between groups.

Table 1

Means values \pm SD of physical characteristics of the subjects divided by chronological G10-12 (10-12 years) and G13-15 (13-15 years), and sexual maturation P1-3 (P1-P3) and P4-5 (P4-P5)

Variables	G10-12 (n=20)	G13-15 (n=20)	P1-3 (n=20)	P4-5 (n=20)
Age (years)	11.4 \pm 0.6	14.1 \pm 0.6*	11.6 \pm 0.9	13.9 \pm 0.8**
Body mass (kg)	38.8 \pm 8.6	55.9 \pm 14.2*	37.9 \pm 7.7	56.9 \pm 13.4**
Height (cm)	143.6 \pm 8.2	163.3 \pm 10.2*	142.8 \pm 7.2	164.2 \pm 9.1**
Body fat (%G)	15.5 \pm 9.8	14.9 \pm 5.7	16.0 \pm 9.4	14.4 \pm 6.2

* $p < 0.05$ in relation to G10-12

** $p < 0.05$ in relation to P1-3

VO_{2max} , vVO_{2max} and t_{lim} at vVO_{2max} values are presented in Table 2. VO_{2max} (l/min) and vVO_{2max} were significant higher in G13-15 and P4-P5 groups than G10-12 and P1-P3, respectively. There were no differences in VO_{2max} (ml/kg/min) and t_{lim} at vVO_{2max} between groups.



Table 2

Mean values \pm SD of maximal oxygen uptake (VO_{2max}), velocity at VO_{2max} (vVO_{2max}), and time limit at vVO_{2max} (t_{lim}) of the subjects divided by chronological age G10-12 (10-12 years) and G13-15 (13-15 years), and sexual maturation P1-3 (P1-P3) and P4-5 (P4-P5)

Variables	G10-12 (n=20)	G13-15 (n=20)	P1-3 (n=20)	P4-5 (n=20)
VO_{2max} (l/min)	1.84 \pm 0.4	2.81 \pm 0.6*	1.80 \pm 0.3	2.87 \pm 0.5**
VO_{2max} (ml/kg/min)	47.9 \pm 6.8	50.4 \pm 5.5	47.9 \pm 6.8	50.3 \pm 5.5
V VO_{2max} (km/h)	11.8 \pm 1.2	12.6 \pm 1.23*	12.1 \pm 1.2	12.9 \pm 1.1**
t_{lim} (seg)	181.5 \pm 96.3	199 \pm 105.5	183.9 \pm 96.0	196.5 \pm 106.1

* $p < 0.05$ in relation to G10-12

** $p < 0.05$ in relation to P1-3

Day 3: Reproducibility of the t_{lim} at vVO_{2max}

Eleven of the subjects carried out an additional t_{lim} at vVO_{2max} within 1 wk of the first test.

Table 3

Multiple correlation coefficients of aerobic and anthropometric characteristics with t_{lim} at vVO_{2max} . N=40

Variables	R^2
%G	0.37*
V VO_{2max} (km/h)	0.59**

V VO_{2max} = aerobic maximal velocity; %G = body fat

* $p < 0.05$

** $p < 0.01$

Table 3 provides data from a stepwise multiple regression analysis, which selects the best combination of predictors of t_{lim} at vVO_{2max} . For the 40 boys



analyzed, body fat and $v\text{VO}_2\text{max}$ explain 59% of the variance in the t_{lim} at $v\text{VO}_2\text{max}$.

While the two measures of t_{lim} at $v\text{VO}_2\text{max}$ were moderately related ($r=0.78$; $p<0.05$), t_{lim} at $v\text{VO}_2\text{max}$ from the second test (226.6 ± 96.1 s) was significantly higher than that of the first (191.3 ± 79.2 s). The intra-individual difference between these tests averaged 35 ± 54 s, with a CV value of 22% (Fig. 1).

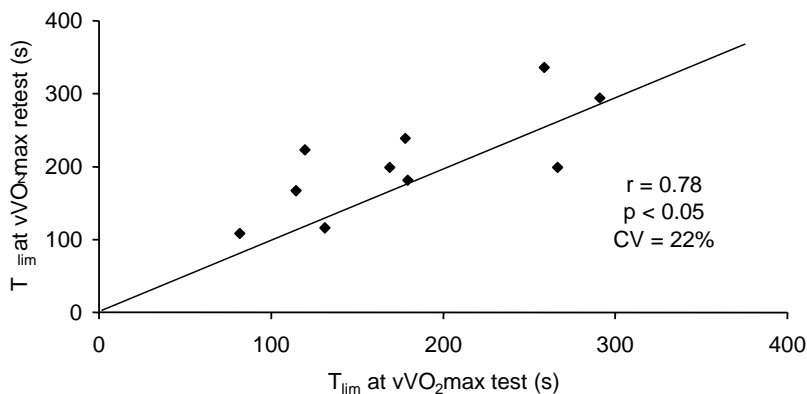


Fig. 1

Test-retest reproducibility of the t_{lim} at $v\text{VO}_2\text{max}$. Dashed line is the identity line ($x=y$)

Discussion

The main finding of the present study was that the t_{lim} at $v\text{VO}_2\text{max}$ is not influenced by the chronological age and sexual maturation, and significantly related to the body fat and $v\text{VO}_2\text{max}$. Besides, the t_{lim} at $v\text{VO}_2\text{max}$ presents a lower reproducibility in children and adolescents.

The analysis of the effects of the chronological age and sexual maturation on the aerobic power (VO_2max and $v\text{VO}_2\text{max}$) and t_{lim} at $v\text{VO}_2\text{max}$, requires at first a discussion about the validity of the VO_2max values in children and adolescents. The conventional criterion for the attainment of VO_2max during an exercise test is a leveling off or plateau in VO_2 ($\text{VO}_{2\text{plateau}}$) despite an increase in exercise intensity [18]. Some studies have shown that just 30% of the children present the $\text{VO}_{2\text{plateau}}$ during the incremental test [1,2], while in adults, this phenomenon is found in 50% of the tests [18]. However, Armstrong *et al.* [2] did not verify hemodynamic

(maximal heart rate), metabolic (R and blood lactate) and anthropometric (height and body mass) differences among children and adolescents that exhibited or not the $VO_{2\text{plateau}}$. Besides, when performed supramaximal efforts, children who did not presented $VO_{2\text{plateau}}$, did not exhibited any increase in the VO_2 , even though they have shown an increase in the indices (R and blood lactate) that suggest an increase of the anaerobic contribution in these conditions [2]. The lower $VO_{2\text{plateau}}$ incidence in children has been explained by the lower anaerobic capacity, motivation and concentration in relation to adults [18,22].

The values and the effects of the chronological age on the $VO_{2\text{max}}$ (l/min and ml/kg/min) found in our study are in accordance with those reported in previous studies in similar age groups. Longitudinal studies with European, Japanese, American and Canadian children and adolescents have verified an increase on absolute values (l/min) and maintenance of the relative values (ml/kg/min) of $VO_{2\text{max}}$ among 8 to 18 years old [1,23].

Although the $VO_{2\text{max}}$ expressed in ratio with body mass ($\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) was not different, we verified that the $vVO_{2\text{max}}$ was significantly higher in the oldest group. It is important to note that the $vVO_{2\text{max}}$ in our study was determined in accordance to di Prampero [13], which has represented exercise intensities that could be maintained aerobically with no anaerobic contribution. Therefore, the increase of the anaerobic capacity that occurs during the adolescence [28], probably had not contributed to the increase of the $vVO_{2\text{max}}$ in the groups G13-15 and P4-5. This phenomenon suggests an improvement of RE with the maturation, even in individuals that were not involved in a regular physical training program. Many studies (longitudinal and cross-sectional) have verified an improvement in RE with age increase [2,19]. This improvement has been attributed to the decrease of the oxygen ventilatory equivalent (VE/VO_2), reducing the energetic cost of respiratory muscles [22] and/or to the increase of the lower limbs, allowing higher amplitude and lower stride frequency [27].

T_{lim} at 100% $vVO_{2\text{max}}$ has been used as an index of the anaerobic capacity, to prescribe, in an individualized manner, the duration of stimuli during interval training, and to predict performance in athletes [10,14]. However, t_{lim} values have shown wide intra- and inter-study variability, preventing a possible comparison between studies [6,7,10].

In our study, it was also observed a higher interindividual variability in the t_{lim} , in both studied groups ($CV=52-54\%$). Part of this variability (59%) can be explained by body fat and $vVO_{2\text{max}}$. Previous studies performed in adult runners also have found an inverse relationship between the t_{lim} and $vVO_{2\text{max}}$ [6,7]. At first, these data suggest that the performance at $vVO_{2\text{max}}$ is higher as lower is the



vVO₂max (index that reflects the aerobic fitness). However, these inverse correlations have not been found in other studies realized in the same laboratory [6,10].

To our knowledge, no studies have analyzed the effects of the chronological age and maturation on the t_{lim} at vVO₂max. In adults t_{lim} at vVO₂max is moderately correlated to anaerobic capacity [14]. As the chronological age determines the increase of this capacity [28], t_{lim} at vVO₂max could also be higher with the maturation process. However, in our study t_{lim} at vVO₂max was not influenced by chronological age and sexual maturation. Once again, it is important to note that the vVO₂max was determined according to di Prampero [13] that, as previously discussed, represented exercise intensities that could be maintained aerobically with no anaerobic contribution. So, the possible influence of the anaerobic capacity on the t_{lim} at vVO₂max was not probably eliminated during the determination of the vVO₂max. The first hypothesis that could explain these similar values of the t_{lim} at vVO₂max among children and adolescents is that the improvement of the anaerobic capacity can be balanced in some way by the increase of vVO₂max. The second hypothesis is that the t_{lim} at vVO₂max in children and adolescents cannot have a higher dependence of the anaerobic capacity. Anyway, the significance of the t_{lim} at vVO₂max still needs consideration. In fact, it is not clear whether the large interindividual differences are caused by a higher aerobic power, or as suggested by several researchers, by individual differences in anaerobic capacity [14].

In relation to the reproducibility of the t_{lim} at vVO₂max, Billat *et al.* [7] verified in adult endurance runners that the values obtained in the test (404±101 s) and re-test (402±113 s) were not different and moderately correlated (r=0.86). The average absolute difference was 44 s or approximately 10% of the value of t_{lim}. In the present study, the two measures of t_{lim} at vVO₂max were moderately related (r=0.78; p<0.05), but the value from the second test (226.6±96.1 s) was significantly higher than that of the first (191.3±79.2s). The intra-individual difference between these tests averaged 35±54 s, with a CV value of 22%. Previous studies performed in adults during cycling [15] and upper body exercise [26] have also found a lower reproducibility of the t_{lim} at vVO₂max. So, the use of the t_{lim} at vVO₂max in children and adolescents should be done carefully, mainly when the objective is to determine the extent to which pre–post changes can be attributed to a particular intervention.

We can conclude that the chronological age and sexual maturation determine the increase of the vVO₂max without modifying the VO₂max (ml·kg⁻¹·min⁻¹), possibly by an improvement of RE in this age group. The t_{lim} at vVO₂max is not influenced by chronological age and sexual maturation, and is significantly



correlated to body fat and $v\text{VO}_2\text{max}$. Besides, t_{lim} at $v\text{VO}_2\text{max}$ presents a lower reproducibility in children and adolescents.

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Accepted for publication 27.01. 2006

