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MAXIMAL OXYGEN UPTAKE AND MATURATION IN 12-YEAR-OLD MALE ROWERS

MAKSIMALNI PRIMITAK KISIKA I BIOLOŠKA DOB KOD 12-GODIŠNJIH VESLAČA

Pavle Mikulić, Lana Ružić, Goran Leko

Faculty of Kinesiology, University of Zagreb, Croatia

SUMMARY

This study was designed to examine the differences in VO_2max between 47 rowers of the same chronological age (12-year-olds; mean ± SD 12,5 ± 0,3), but of varying levels of physical maturity. VO_2max was expressed in absolute units (L/min), as the ratio standard mass-related units (mL/kg/min) and using the allometric model specific to the data set. Sexual maturity was visually assessed using indices of pubic hair developed by Tanner. The subjects were classified in pre-pubertal (Tanner stage 1), early-pubertal (Tanner stage 2), and mid-pubertal (Tanner stages 3 and 4) groups. They completed an incremental maximal treadmill test. Differences were compared using a one-way ANOVA.

VO_2max (L/min) in 12-year-old rowers proved to be greater in the mid-pubertal group than in both the early-pubertal (+19,7%) and pre-pubertal (+24,8%) groups. When expressed as a ratio standard (i.e. in mL/kg/min), VO_2max was +12,1% greater in the mid- and pre-pubertals than in the earlypubertals. However, when compared using the appropriate scaling procedure, the VO_2max in mid-pubertal rowers was +14.5% greater than in the early-pubertals, and +9,1% greater than in pre-pubertals. This suggests that factors other than body mass explain the greater aerobic power (as assessed by VO_2max) in more physically mature individuals of the same chronological age. Allometric scaling of VO_2max in the present study yielded a scaling coefficient for body mass of 0,68 (95% CI = 0,51-0,87). This finding reinforces the view that, in children, VO_2max increases relative to body mass raised to the power of 0,67 rather than in direct proportion with body mass (i.e. mass^{1,0}).

In conclusion, using a log-linear scaling model to adequately control for body mass, we have demonstrated significant differences in VO_2max among 12-year-old rowers of varying stages of puberty and, consequently, varying levels of maturity. Further research is needed in order to further explain the above-mentioned differences among groups of rowers exhibiting differing levels of maturity independent of body mass.

Key words: VO_2max, physical maturity, young rowers, allometric scaling

SAŽETAK

Ova studija provedena je sa ciljem ispitivanja razlika u maksimalnom primitku kisika (VO_2max) između 47 veslača iste kronološke dobi (12-godišnjaci, AS±SD = 12,5±0,3), ali različite biološke dobi. VO_2max je izražen u apsolutnim jedinicama (L/min), u omjeru prema tjelesnoj masi (mL/kg/min) kao i uz upotrebu nelinearnog modela specifičnog za uzorak ispitanika. Biološka zrelost procjenjivana je vizualno korištenjem klasifikacije faza spolne zrelosti prema Tanneru. Ispitanici-veslači podijeljeni su u grupu veslača u pred-pubertetu (faza 1 po Tanneru), ranom pubertetu (faza 2 po Tanneru) i srednjem pubertetu (faze 3 i 4 po Tanneru). Mladi veslači podvrgnuti su progresivnom maksimalnom testu opterećenja na pokretnom sagu, a razlike su uspoređene upotrebom ANOVE.

VO_2max (L/min) u 12-godišnjih veslača pokazao se većim u veslača u srednjem pubertetu u odnosu i na one u ranom pubertetu (+19,7%), i posebno na one u pred-pubertetu (+24,8%). Izražen u odnosu na tjelesnu masu (mL/kg/min), VO_2max je bio +12,1% veći u veslača u srednjem i pred-pubertetu u odnosu na one u ranom pubertetu. Međutim, kada su rezultati uspoređeni upotrebom adekvatnog postupka normalizacije rezultata, VO_2max u veslača u srednjem pubertetu bio je +14.5% veći u odnosu na one u ranom pubertetu i +9,1% veći u odnosu na one u pred-pubertetu. Takvi rezultati sugeriraju da neki drugi čimbenici pored veće tjelesne mase objašnjavaju veću aerobnu snagu (procijenjenu sa VO_2max) kod biološki starijih pojedinaca iste kronološke dobi. Upotreba nelinearnog modela za pokazatelj VO_2max u ovoj studiji ukazala je na koeficijent skaliranja (eksponent) za tjelesnu masu 0,68 (95% CI = 0,51-0,87). Ovo otkriće pojačava pretpostavku da se, kod djece, VO_2max povećava u odnosu na tjelesnu masu sa eksponentom 0,67, a ne u direktnom odnosu sa tjelesnom masom (tj. masa^{1,0}).

Zaključno, korištenjem nelinearnog modela u svrhu adekvatne kontrole tjelesne mase dokazali smo značajne razlike u VO_2max između 12-godišnjih veslača različitih po biološkoj dobi. Daljnja istraživanja su neophodna u svrhu detaljnijeg objašnjenja gore spomenutih razlika između grupa veslača različite biološke dobi neovisno o tjelesnoj masi.

Ključne riječi: VO_2max, biološka zrelost, mladi veslači, normalizacija rezultata

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INTRODUCTION

Children and adolescents function in a society that puts great emphasis on chronological age, especially for youth sports. When children and adolescents within the same chronological age are grouped into categories that contrast differing levels of physical maturity, available data illustrate clear maturity gradients (12). From 10 to 16 years of age, this variable relationship between biological age and chronological age is especially pronounced (15). The influence of the maturation process upon physiological responses to exercise is an important issue in the field of pediatric exercise science; therefore, both biological and chronological age (5) should perhaps be taken into account when assessing the physical responses of young athletes.

In rowing, high levels of both aerobic and anaerobic capacities are required for successful performance, and during a 2000 m race both energy capacities are stressed to their maximum (19,22). Aerobic energy capacity is particularly important in rowing since it has been found to contribute a total of 70-80% of the energy demand of a 2000 m race (18). The ability to perform aerobic exercise is associated with the individual's maximal oxygen uptake (VO_2max), which is widely recognized as the best single index of aerobic fitness (6). Some recent studies aimed at detecting the most important parameters used to predict rowing performance (8,10,16,26), either on a rowing ergometer or “on water,” yielded data that demonstrate the crucial importance of aerobic capacity (as measured by VO_2max or power output at VO_2max) for successful rowing performance. For the purposes of talent identification and selection in rowing, it is important early on to recognize individuals who demonstrate the necessary prerequisites for high-level competition rowing.

Traditionally, VO_2 is expressed as an absolute value (i.e. in L/min) and as a ratio standard, or per kilogram of body mass (i.e. in mL/kg/min). By expressing VO_2 as a ratio standard, it is assumed that VO_2 is “normalized” and the influence of body mass is removed. Although the theoretical and statistical limitations of the ratio standard have been widely addressed, they have also been largely ignored. A number of studies have demonstrated that the expression of performance variables as a simple ratio with body mass does not adequately normalize data for body size (3,9,13,14). Allometric scaling models have been shown to be more appropriate for partitioning out the effects of body size in both children and adults (12,25). Therefore, in our study, comparisons of VO_2max independent of body mass were also made using allometric scaling procedures.

Because the impact of maturation upon physiological responses to exercise is a vital issue in the field of pediatric exercise science, this study was designed to examine the differences in VO_2max between rowers of the same chronological age (12-year-olds), but of varying levels of physical maturity. Body mass was controlled using both the conventional ratio standard and the allometric relationship specific to the data set.

METHODS

Subjects

All 12-year-old members of so-called “rowing schools” affiliated with five different rowing clubs in Zagreb, Croatia were invited to participate in the study. Sixty-one members volunteered, representing 87% of the total number of eligible rowers (according to official rowing club records). The prerequisites for inclusion in this study were the following: (1) they participated in rowing training for at least six months prior to their visit to the Human Performance Laboratory; (2) they reported regular attendance (>75% of the total number of practices within the past six months), and (3) they reported no medical problems. All these data were checked with the participants' coaches as well and verified using each young rower's medical and attendance records. The sample for this study eventually comprised 47 rowers aged 12,5 ± 0,3 years (mean ± SD; range: 12,0 12,9 years). While in rowing school, young rowers typically train three times per week for 75-90 min per training session. The training is a combination of rowing-specific training, which includes “on-water,” ergometer, and tank rowing, and cross-training, which mainly includes running various distances, playing ball games, swimming and strength training. The subjects participated in no additional physical training other than mandatory physical education classes in their elementary schools twice per week (2x45 min).

Due to the age of the subjects and the nature of the testing procedures, each subject's parents (or legal guardians) and coaches were asked to give their consent following an explanation of the nature and purpose of the experiment and of the risks associated with participation. This explanation was in compliance with the Declaration of Helsinki. All experimental procedures were approved by the Ethics Committee of the School of Kinesiology at the University of Zagreb. We instructed the coaches not to engage the subjects in any strenuous activity the day before they visited the Human Performance Laboratory. We also told the subjects to consume their last light meal no less than two hours prior to testing.

Laboratory data collection

The age of the subjects was computed from date of birth and date of examination and rounded to the nearest decimal. Sexual maturity was visually assessed using indices of pubic hair developed by Tanner (23). All observations were made by the same medical doctor, a specialist pediatrician. The subjects were classified in three categories based on their pubertal stage: one pre-pubertal group (subjects classified into Tanner stage 1), one early-pubertal group (subjects classified into Tanner stage 2), and one mid-pubertal group (subjects classified into Tanner stages 3 and 4). The determination of pubertal groups follows the divisions described in Malina et al. (12). In accordance with the recommendations of the International Biological Program (24), body height, body mass, triceps and calf skinfolds (using the Harpenden caliper) were measured. The percentage of body fat was estimated using the two measured skinfolds according to the method developed by Slaughter et al. (21) for children and adolescents aged 8-17. Lean body mass was calculated by subtracting estimated body fat from total body mass.

After the anthropometrical measurements were taken, the rowers completed an incremental maximal treadmill test (Runrace Competition HC1200, Technogym, Italy). Although we usually tested the athletes using sport-specific equipment, the pilot study proved that the majority of subjects were not able to perform the incremental maximal test satisfactorily on a rowing ergometer (i.e. they were not able to adequately row at the demanded wattage levels). Thus, we opted for a treadmill test. The test began with three minutes of walking at 3 km/h. The treadmill speed was increased by 1 km/h each minute (running started at 7 km/h) until the point of voluntary exhaustion. A constant inclination of 1,5owas used. The expired air was collected and analyzed using a breath-by-breath gas exchange system (COSMED Quark b^2, Italy) equipped with Quark b^2 6.0 PC software support. The heart rate of each subject was monitored using a short-range radio telemetry system (Polar Electro, Finland). Cardio-respiratory parameters were calculated automatically and printed every 30 seconds. The highest values were calculated as the arithmetic means of the two consecutive highest 30-second values. The subjects' rate of perceived exertion was monitored each minute using the Borg's rating of perceived exertion scale. We observed the following criteria to ensure that the young rowers had given their best effort (12): heart rate = 220 - age, respiratory quotient = 1.05 or higher, rating of perceived exertion ≥18 on the Borg scale. We assumed that maximal effort had been given if at least two of these three criteria had been satisfied. A plateau criterion was not used since it has been established that only a minority of children demonstrate a true VO_2max plateau in spite of exercising to exhaustion (4). To determine maximal blood lactate levels, the "Lactate Pro" blood lactate test meter (Arkray Factory Inc., Japan) was used. A capillary blood sample was obtained using a finger stick procedure two minutes after the point of voluntary exhaustion on the treadmill.

Data analysis

We used the *SPSS 11.5 for Windows* (Chicago, Illinois) statistical package in order to process and report the data, which are reported as mean±SD. Differences in anthropometric characteristics, as well as in parameters of maximal aerobic exercise among the three age groups (i.e. the pre-pubertal, early-pubertal and mid-pubertal groups), were compared using a one-way ANOVA. Peak oxygen uptake was expressed in absolute units (L/min), as well as the ratio standard mass-related units (mL/kg/min). In addition, comparisons of VO_2max independent of body mass were made using the allometric model. More specifically, the following equations were used to determine a common exponent for the relationship between VO_2max and body mass:

$$VO_2max = a \cdot \text{body mass}^k \qquad \text{(Eq. 1)}$$

where a is the mass coefficient, and *k* is the reduced exponent, the numerical value of which can be obtained from the log-log plot of the experimental data, as the logarithmic expression is a straight line:

$$\log(VO_2max) = \log a + k \cdot \log(\text{body mass}) \qquad \text{(Eq. 2)}$$

Thus, VO_2max is estimated after having adequately controlled for differences in body size (body mass in this example).

RESULTS

The 12-yr-old rowers' physical characteristics are presented in Table 1, while their peak exercise data are displayed in Table 2. Tables 3 and 4 present the descriptive data for the rowers classified according to pubertal stage.

Table 1. Age, rowing experience, and physical characteristics of 12-year-old rowers (n=47)
Tablica 1. Dob, staž bavljenja veslanjem i fizičke karakteristike 12-godišnjih veslača (n=47)

Variable	Mean±SD	Range
Age (yrs)	12,5± 0,3	12,0-12,9
Rowing experience (mths)	17,1±13,6	17,1-13,6
Body height (cm)	160,9± 8,2	141,0-179,8
Body mass (kg)	52,3± 9,9	33,0-70,3
Lean body mass (kg)	41,1± 7,3	25,9-57,9
Percent fat (%)	21,0± 5,3	11,4-32,9

Table 2. Maximal responses to progressive treadmill test of 12-year-old rowers (n=47)
Tablica 2. Pokazatelji pri maksimalnom opterećenju za izvođenja progresivnog testa opterećenja na pokretnom sagu kod 12-godišnjih veslača (n=47)

Variable	Mean±SD	Range
VO_2max (L/min)	2,56± 0,44	1,80-3,67
VO_2max (mL/kg/min)	49,5 ± 6,0	39,4-61,9
VO_2max (mL/kg^{0,67}/min)	180,4 ±18,9	148,7-224,2
HRmax (beats/min)	202,7 ± 7,7	188-216
RQmax	1,18± 0,07	1,03-1,33
Maximal blood lactate (mmol/L)	8,7 ± 2,2	4,8-13,8

The one-way ANOVA revealed a significant main effect in all measured anthropometric variables (body height, body mass and lean body mass) among the pre-, early-, and mid-pubertal groups. The exception is percent body fat in which no significant main effect was observed. The Bonferroni *post-hoc* tests identified higher values for both early- and mid-pubertal rowers than for their pre-pubertal counterparts (p<0,01). No differences with respect to body height were observed between early- and mid-pubertal rowers. In terms of body mass, both early- (p<0,05) and mid-pubertal (p<0,01) rowers were heavier than pre-pubertal athletes, with no significant difference between early- and mid- pubertal rowers (p>0,05). In terms of lean body mass, mid-pubertal rowers were superior to both early- and pre-pubertal athletes (p<0,01), with the early-pubertals being superior to the pre-pubertals ($p<0,05$).

Table 3. Age, rowing experience, and physical characteristics of 12-year-old rowers by puberty stage
Tabica 3. Dob, staž bavljenja veslanjem i fizičke karakteristike 12-godišnjih veslača promatrano prema fazi puberteta

Variable	Group by puberty stage		
	Pre-pub. (n=14)	Early-pub. (n=15)	Mid-pub. (n=18)
Age (yrs)	12,4±0,3	12,4±0,3	12,6±0,3
Rowing experience (mths)	21,9±7,7	16,1±14,2	14,2±7,8
Body height (cm)	153,4±6,2	160,5±5,3	167,5±7,0
Body mass (kg)	44,1±9,0	51,8±7,3	59,8±7,4
Lean body mass (kg)	34,6±6,2	40,0±3,6	48,0±5,5
Percent fat (%)	21,1±4,5	22,2±6,0	19,6±5,1

Table 4. Maximal responses to progressive treadmill test of 12-yr-old rowers by puberty stage
Tablica 4. Pokazatelji pri maksimalnom opterećenju za izvođenja progresivnog testa opterećenja na pokretnom sagu kod 12-godišnjih veslača - promatrano prema fazi puberteta

Variable	Group by puberty stage		
	Pre-pub. (n=14)	Early-pub. (n=15)	Mid-pub. (n=18)
VO_2max (L/min)	2,21±0,26	2,41±0,28	3,02±0,29
VO_2max (mL/kg/min)	51,3±7,0	46,9±5,4	50,9±5,1
VO_2max (mL/kg^{0,67}/min)	176,7±16,7	166,3±13,0	194,4±14,7
HRpeak (beats/min)	204,7±6,5	202,7±7,0	200,9±9,4
RQpeak	1,18±0,07	1,20±0,09	1,16±0,06
Max. blood lactate (mmol/L)	8,5±2,8	8,9±2,1	8,7±2,0

The achieved values for maximal RQ, maximal blood lactate levels, and maximal heart rate (Table 1) suggest that young rowers satisfied the criteria established to ensure that their best efforts had been given (see *Laboratory data collection* in Methods). Allometric scaling procedures identified a mass exponent of k=0,68 (95% CI = 0,51-0,87). This exponent does not differ significantly from the theoretical k exponent of 0.67 (as predicted by theory of geometric similarity, see Astrand (6) for details); therefore, we compared VO_2max, expressed as mL/kg^{0,67}/min, in subjects exhibiting varying levels of physical maturity.

The One-way ANOVA revealed a significant main effect in VO_2max ($p<0,01$), VO_2max in ratio with body mass ($p<0,01$), and VO_2max expressed as mL/kg^{0,67}/min ($p<0,01$) among the pre-, early-, and mid-pubertal groups. The Bonferroni *post-hoc* tests identified the mid-pubertal group as having significantly greater VO_2max ($p<0,01$) values than the early- and pre-pubertal groups, while the differences between the pre- and early-pubertal groups were not significant ($p>0,05$). In addition, VO_2max in ratio with body mass was significantly greater ($p>0,05$) in the pre- and late-pubertal groups than in the early-pubertal group. No differences were observed between the pre- and late-pubertal groups ($p<0,05$). When VO_2max, expressed as mL/kg^{0,67}/min is observed, significant differences are noted between the pre- and mid-pubertal groups ($p<0,05$) and between the early- and mid-pubertal groups ($p<0,01$). No significant main effects ($p>0,05$) among the groups were revealed regarding maximal heart rate, maximal respiratory exchange ratio or maximal blood lactate levels.

DISCUSSION

Few studies allow for possible comparisons of VO_2max values; in a similar study conducted by Armstrong et al. (4) 12-year-old boys produced VO_2max values somewhat below those of our subjects. The difference may be explained by the fact that the study examined the general population of 12-year-old boys, as opposed to our sample, which consisted only of young athletes.

Maximal oxygen uptake in 12-year-old rowers is greater in the mid-pubertal group than in both the early-pubertal (+19,7%) and pre-pubertal (+24,8%) groups. When expressed as a ratio standard (i.e. in mL/kg/min), VO_2max is +12,1% greater in the mid- and pre-pubertals than in the early pubertals. However, when compared using the appropriate scaling procedure, the VO_2max in mid-pubertal rowers is +14.5% greater than in the early-pubertals, and +9,1% greater than in pre-pubertals. This suggests that factors other than body mass explain the greater aerobic power (as assessed by VO_2max) in more physically mature individuals of the same chronological age. Of course, cross-sectional studies can only indicate differences among the respective groups, whereas the changes are inferred (12).

Allometric scaling of VO_2max in the present study yielded a scaling coefficient for body mass of 0,68 (95% CI = 0,51-0,87). The dimensional scaling of geometrically similar individuals suggests that VO_2max, which is primarily limited by maximal cardiac output, should be proportional to body mass raised to the power of 0,67 (6). Our findings are clearly in line with that theoretical exponent and also with earlier studies (1,14). This finding reinforces the view that, in children, VO_2max increases relative to body mass raised to the power of 0,67 rather than in direct proportion with body mass (i.e. mass^{1,0}). Mass exponents other than 0,67 have previously been reported in children (17,20), but may be attributed to the modeling of small sample groups. According to Weslman (25), the factor contributing most to diversity in the obtained mass exponents in previous studies using children appears to be sample size. It has been suggested that meaningful exponents can only be obtained when modeling large groups, where the range of body mass is extensive.

The present scaling procedure is the classical scaling approach for comparing metabolic rate in subjects of varying body weights. The approach, which is based on basic principles of geometry, physics and biology, offers a general unifying explanation for scaling, which is used extensively in biology. Relatively few studies have examined the relationship between VO_2max and the maturation process, but the available data indicate that, in boys, VO_2max increases with greater levels of physical maturity. Among factors that may contribute to the more mature boys' higher VO_2max, Armstrong et al. (4) state that higher hemoglobin concentrations are found in more mature individuals. In the exercise sciences, maturity is usually assessed using one or more indicators of somatic, sexual or skeletal maturity (4). Although no single indicator can provide a complete description of growth and maturation rates, there is a high level of concordance among the various indicators (7). Data on the relationship of VO_2max to maturity are sparse, probably due to the complex ethics and logistics of maturity assessment.

It should be noted that the approach used for the present study is limited by the fact that stages of puberty (as assessed using Tanner's indices of pubic hair) were used as indicators of maturity. Sexual maturation is a continuous process, and the use of only five discrete pubertal stages suggests an incomplete approach, implying that some important information may be lacking (12). We admit that a more continuously distributed indicator of physical maturity (skeletal age, time before and after peak height velocity) would have provided additional information on the young rowers' levels of physical maturity, thus permitting a more thorough analysis.

VO_2max has been shown to be closely related to the maturation process, as indicated by skeletal age (11). Sexual maturity as assessed by indices of pubic hair have been shown by previous studies to be related to VO_2max, with more mature boys demonstrating higher VO_2max values than those of less mature boys. In accordance with the results of the present study, VO_2max in ratio with body mass has been shown to remain unchanged with maturation (2). Few studies (4) have investigated VO_2max in relation to maturation using alternate statistical approaches for accounting for body size differences. Armstrong (4) states that imposing the ratio standard on data sets, instead of deriving the appropriate exponent from statistical modeling, probably clouds the interpretation of the development of VO_2max in relation to body size during maturation.

In conclusion, using a log-linear scaling model to adequately control for body mass, we have demonstrated significant differences in VO_2max among 12-year-old rowers of varying stages of puberty and, consequently, varying levels of maturity. In previous studies, these differences may have been masked by the inappropriate use of VO_2max in ratio with body mass (mL/kg/min). Further research is needed in order to further explain the above-mentioned differences among groups of rowers exhibiting differing levels of maturity independent of body mass.

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