Effect of biological maturation on maximal oxygen uptake and ventilatory thresholds in soccer players: An allometric approach

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Effect of biological maturation on maximal oxygen uptake and ventilatory thresholds in soccer players: An allometric approach

GIOVANI CUNHA, THIAGO LORENZI, KATIUCE SAPATA, ANDRE LUIZ LOPES, ADROALDO CEZAR GAYA, & ÁLVARO OLIVEIRA

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Abstract

In this study, we investigated the effect of biological maturation on maximal oxygen uptake ($\dot{V}O_2\text{max}$) and ventilatory thresholds (VT1, VT2) in 110 young soccer players separated into pubescent and post-pubescent groups. Maximal oxygen uptake and $\dot{V}O_2$ corresponding to VT1, VT2, and $\dot{V}O_2\text{max}$ were expressed as absolute values, ratio standards, theoretical exponents, and experimentally observed exponents. Absolute $\dot{V}O_2$ was different between groups for VT1, VT2, and $\dot{V}O_2\text{max}$. Ratio standards for VT1, VT2, and $\dot{V}O_2\text{max}$ were not significantly different between groups. Theoretical exponents for VT1, VT2, and $\dot{V}O_2\text{max}$ were not properly adjusted for the body mass effects on VT1, VT2, and $\dot{V}O_2\text{max}$. When the data were correctly adjusted using experimentally observed exponents, VT1 and VT2 were not different between groups. The experimentally observed exponent for $\dot{V}O_2\text{max}$ was different between groups ($P=0.048$), however, this difference could not be attributed to biological maturation. In conclusion, biological maturation had no effect on VT1, VT2, or $\dot{V}O_2\text{max}$ when the effect of body mass was adjusted by experimentally observed exponents. Thus, when evaluating the physiological performance of young soccer players, allometric scaling needs to be taken into account instead of using theoretical approaches.

Keywords: Soccer, children, maximal oxygen uptake, ventilatory threshold, allometry

Introduction

Soccer performance is composed of technical, tactical, physical, physiological, and psychological factors (Stolen, Chamari, Castagna, & Wisloff, 2005). Running is the predominant activity, with players covering an average of approximately 8–12 km during a single soccer match (Hoff & Helgerud, 2004; Stolen et al., 2005). Aerobic metabolism is estimated to contribute approximately 90% of energetic demand (Bangsbo, 1994). Thus, maximal oxygen uptake ($\dot{V}O_2\text{max}$) and the lactate threshold can help to determine the performance and training regime of soccer players. Maximal oxygen uptake is considered the best index of aerobic power in heterogeneous populations and in soccer players (Armstrong & Welsman, 2000; Hoff & Helgerud, 2004), while the lactate threshold is often used to characterize changes in aerobic fitness in response to training (Hoff & Helgerud, 2004; McMillan, Helgerud, Macdonald, & Hoff, 2005).

Exercise physiologists are faced with the challenge of determining whether changes in physiological performance variables are part of normal development or occur as a result of training. Comparisons between groups or between individuals’ performance relative to their peers are confounded by body size differences (Welsman, Armstrong, Nevill, Winter, & Kirby, 1996). An understanding of changes in $\dot{V}O_2\text{max}$ between childhood and adulthood is confounded by variability in body size and body composition (Tolfrey et al., 2006).

It has been shown that aerobic power, strength, and explosive power increase progressively from 8 to 18 years of age (De Ste Croix, Deighan, & Armstrong, 2003; Nedeljkovic, Mirkov, Kukolj, Ugarkovic, & Jarić, 2007; Rowland, 2005; Van Praagh & Doré, 2002). For this reason, adolescent soccer players are often categorized by age. Such categorization is aimed at giving players equal participation and training opportunities. Similarly, many studies have used categorization by age to...
investigate differences in the performance and metabolism of soccer players (Coelho e Silva et al., 2010; Figueiredo, Gonçalves, Coelho e Silva, & Malina, 2009; Hirose, 2009; Nedeljkovic et al., 2007; Vaeyens et al., 2006). Structured talent identification and development programmes for soccer are less clearly delineated. However, it is essential to understand the key elements of talent identification and the development process.

Recently, attention has been drawn to the independent effects of biological maturation (biological age) on $V'O_{2\text{max}}$, the lactate threshold, strength, speed, and other sport-specific skills (Armstrong & Welsman, 2000, 2001; Armstrong, Welsman, Nevill, & Kirby, 1999; Beunen et al., 2002; Cunha, Célia, Ribeiro, & Oliveira, 2008; Eisenmann, Pivarnik, & Malina, 2001; Malina, Eisenmann, Cumming, Ribeiro, & Aroso, 2004; Malina, Ribeiro, Aroso, & Cumming, 2007).

Biological maturation, which can be defined as progress towards the adult state, varies in timing and tempo (Baxter-Jones, Eisenmann, & Sherar, 2005). Many positive effects have been attributed to biological maturation, including increases in muscle mass, strength, power, type II muscle fibres, muscle glycogen concentration, and glycolytic metabolism (Boisseau & Delamarche, 2000; Nedeljkovic et al., 2007; Rowland, 2005; Van Praagh & Doreé, 2002).

Published data on the effects of biological maturation on $V'O_{2\text{max}}$ and ventilatory thresholds are limited and conflicting. Ventilatory threshold is defined as the exercise intensity at which the increase in ventilation becomes disproportional to the increase in power output or speed of locomotion during an incremental exercise test (Svedahl & MacIntosh, 2003). The ventilatory thresholds might be used as a non-invasive alternative to the determination of the lactate threshold (Wasserman & McIlroy, 1964). There is some evidence that biological maturation may affect $V'O_{2\max}$ (Armstrong & Welsman, 2000, 2001; Armstrong et al., 1999; Beunen et al., 2002; Eisenmann et al., 2001; Malina et al., 2004) and ventilatory thresholds (Cunha et al., 2008), but there is no consensus regarding how biological maturation affects the relationship between $V'O_{2\max}$ and ventilatory thresholds (Reilly, Bangsbo, & Franks, 2000).

An effective exercise and training programme during each maturational stage is important for performance. Therefore, biological maturation should be considered when selecting adolescent soccer players. Soccer players who are more biologically mature often have greater strength, explosive power, speed, sport-specific skills, and aerobic power than their less mature peers (Coelho e Silva et al., 2010; Hirose, 2009; Malina et al., 2000, 2004, 2007; Philippaerts et al., 2006; Vaeyens et al., 2006).

Important advances have been made regarding the interpretation of traditional $V'O_{2\max}$ measurements (absolute values, ml min$^{-1}$; ratio standard, ml kg$^{-1}$ min$^{-1}$). With ratio standard analysis, it is assumed that $V'O_{2\max}$ is normalized for the influences of body mass. However, there are many theoretical and statistical limitations to the ratio standard used to express $V'O_{2\max}$ data (Armstrong & Welsman, 2000; Armstrong et al., 1999; Rowland, 2005; Welsman et al., 1996). For instance, aerobic power is often overestimated in individuals with a low body mass and underestimated in individuals with a high body mass (Chamari et al., 2005; Cunha et al., 2008; Rowland, 2005).

In an attempt to allow comparisons between soccer players of different body sizes, many authors have expressed $V'O_{2\max}$ using allometric scaling (Cunha et al., 2008; Helgerud, Engen, Wisloff, & Hoff, 2001; Hoff, Wisloff, Engen, Kemi, & Helgerud, 2002; Wisloff, Castagna, Helgerud, Jones, & Hoff, 2004). The use of allometric methods has been proposed to adjust for the effects of body mass on $V'O_{2\max}$ strength, torque, and movement performance, since allometric modelling provides the independent indices of body size for each one of the above variables (Armstrong & Welsman, 2001; Jaric, 2002; Markovic & Jaric, 2004; Rowland, 2005; Wisloff et al., 2004). In addition, alternative statistical models have been used to create tests of independence for $V'O_{2\max}$ and body mass (Eisenmann et al., 2001). Studies have shown that the relationship between growth and $V'O_{2\max}$ in young athletes is dependent on the $V'O_{2}$ expression model or the statistical analysis applied (Armstrong & Welsman, 2001; Armstrong et al., 1999; Eisenmann et al., 2001; Malina et al., 2004; Nevill, Rowland, Goff, Martel, & Ferrone, 2004b; Welsman et al., 1996).

The present study had two main objectives: (1) to examine the influence of biological maturation on ventilatory thresholds and $V'O_{2\max}$ in young soccer players, and (2) to evaluate methods used for adjusting the physiological data to compensate for body size in young soccer players.

**Methods**

**Participants**

The sample consisted of 110 First Division amateur male players from the Brazilian Soccer League. All participants had trained 3–5 times per week for at least one year. They had also participated in a weekly official game. Consent forms were reviewed and signed by the athletes and their parents in accordance with the Declaration of Helsinki. This study was approved by the University Ethics Committee (CEP 2006575).
**Procedures**

Soccer players were separated into two maturational groups according to their pubertal status, pubescent (n = 52) and post-pubescent (n = 58). Pubertal status was assessed visually based on Tanner’s indices for pubic hair development (Tanner, 1962). The pubescent group consisted of pubertal stages 2 (n = 12), 3 (n = 20), and 4 (n = 20), while the post-pubescent group consisted of pubertal stage 5 (n = 58).

The assessment was conducted in two phases. During the first phase, individuals were given information about the nature of the research and the tests to be carried out, and they signed informed consent. They also underwent assessment of height, body mass, age, years of training, and biological maturation. Subsequently, the participants were familiarized with the maximal test protocol. In the second phase, after a freely chosen warm-up, the maximal exercise tests were initiated at a speed of 7 km·h⁻¹ on a treadmill (Quinton, Seattle, WA). Workload was then increased by 0.5 km·h⁻¹ every 30 s until exhaustion. All athletes were verbally encouraged to achieve their best performance during the maximal exercise test. The criteria used to verify maximal effort included a respiratory gas exchange ratio (RER) ≥ 1.15, a final peak heart rate ≥ 95% of age-predicted maximum (220 – age), and/or a plateau in $\dot{V}O_2$ due to the systematic increases in workload (Dekerle, Baron, Dupont, Vanvelcenaher, & Pelayo, 2003; Midgley, McNaughton, Polman, & Marchant, 2007).

**Aerobic power**

Pulmonary gas exchange ($\dot{V}O_2$ and carbon dioxide production, $\dot{V}CO_2$) and expired minute ventilation were measured breath by breath during exercise using an automated metabolic cart (CPX-D, MGC USA). The equipment was calibrated before each exercise test according to the manufacturer’s instructions. The $O_2$ and $CO_2$ analysers were calibrated using gas standards of known concentrations before each exercise test.

The lactate threshold was determined using the ventilatory thresholds. Maximal oxygen uptake and ventilatory thresholds were determined based on plots of ventilation ($\dot{V}E$) and the ventilatory equivalents ($\dot{V}E/\dot{V}O_2$ and $\dot{V}E/\dot{V}CO_2$) as a function of oxygen uptake and time. The criteria to determine ventilatory thresholds (VT₁ and VT₂) and $\dot{V}O_{2\text{max}}$ were as follows:

1. VT₁ was considered the lowest workload at which $\dot{V}E/\dot{V}O_2$ showed a systematic increase without a concomitant increase in $\dot{V}E/\dot{V}CO_2$ (Dekerle et al., 2003; Wasserman & McIlroy, 1964).
2. VT₂ was considered the lowest workload at which $\dot{V}E/\dot{V}O_2$ showed an increase with a concomitant increase in $\dot{VE}/\dot{V}CO_2$ (Dekerle et al., 2003; Wasserman & McIlroy, 1964).
3. VT₁ and VT₂ were the workloads linked to the first and second non-linear increases in the $\dot{VE}$ plot (Dekerle et al., 2003).
4. $\dot{V}O_{2\text{max}}$ was defined as the minimum exercise intensity at which a plateau in $\dot{V}O_2$ was observed. A plateau of $\dot{V}O_2$ in the $\dot{V}O_2$–exercise intensity relationship was defined as an increase in $\dot{V}O_2$ of less than 1.5 ml·kg⁻¹·min⁻¹ with a corresponding increase in exercise intensity. When a plateau in $\dot{V}O_2$ could not be detected, peak $\dot{V}O_2$ ($\dot{V}O_{2\text{peak}}$) was used (Dekerle et al., 2003; Midgley et al., 2007).

Three independent observers blindly detected VT₁ and VT₂ using the above criteria. A heart rate monitor (Polar, S610 USA) was used to record heart rates during the test. Body mass and height were registered using a platform scale (Filizola, Brazil).

**Allometric scaling**

An initial homogeneity test of regression slopes between groups was performed to determine if a common scaling exponent could be used for $\dot{V}O_{2\text{max}}$ for the group as a whole. This process included entering group (pubescent and post-pubescent) and the group $\times$ log body mass interaction term as covariates in the analyses: $\log \dot{V}O_{2\text{max}} = a + b \log$ body mass $+ c \times$ group (dummy coded pubescent = 1 and post-pubescent = 2). The same procedure was repeated for VT₁ and VT₂.

Initial analysis showed that the interaction term did not significantly affect variance in VT₁ ($P = 0.127$), VT₂ ($P = 0.501$) or $\dot{V}O_{2\text{max}}$ ($P = 0.735$). The allometric relationship between body size, VT₁, VT₂, and $\dot{V}O_{2\text{max}}$ was based on the general allometric equation ($y = ax^b$), where $y$ can take the absolute value of VT₁, VT₂, and $\dot{V}O_{2\text{max}}$, $x$ is body mass (kg), $a$ is the proportionality constant, and $b$ is the exponent for body mass. This can be described by the following equation: $\log y = \log a + b \log x$.

**Statistical analysis**

We used the Statistical Package for the Social Sciences (SPSS v.16.0). The data are expressed as means ± standard deviations (±). To check normality of data, the Kolmogorov-Smirnov test and skewness and kurtosis calculations were applied.
The Levene test was used to check the data for homogeneity of variance. Independent t-tests were used to identify differences between groups with in relation to age, height, body mass, years of formal training, VT1, VT2, and VT02max. One-way analysis of variance (ANOVA) with Bonferroni post-hoc tests were used to evaluate differences between pubertal stages and chronological age.

Analysis of covariance (ANCOVA) was applied to determine whether the interaction term exerted any effect on the variance in VT1, VT2, and VT02max. Multiple linear regression analysis identified the relative contributions of height, body mass, chronological age, years of formal training in soccer, and biological maturation to the variance of cardiopulmonary variables (VT1, VT2, and VT02max). The regression protocol allowed all variables to be entered into the equation and sequential removal of variables that met the criteria for elimination. Statistical significance was set at P < 0.05.

**Results**

The participants’ anthropometric characteristics and years of training classified by maturational stage are shown in Table I. Differences in body mass between the groups justified the use of the allometric model.

Exponents calculated through linear regression analysis after application of the logarithms of the power function equation are shown in Table II. It should be noted that the 95% confidence interval for the experimentally observed, body mass-related exponents, VT1 (b = 0.94), VT2 (b = 0.95) and VT02max (b = 0.90), did not include the theoretical values of the exponents, b = 0.67 or b = 0.75.

Figures 1, 2, and 3 show the power ratio independence tests for VT1, VT2, and VT02max after application of different scaling exponents.

Test of independence for VT02max and body mass (kg) expressed in absolute terms (A) and as a ratio standard (B), after applying theoretical exponents b = 0.67 (C) and b = 0.75 (D), as well as the experimentally observed exponent for soccer players b = 0.90 (E), are shown in Figure 1.

Test of independence for VT2 and body mass (kg) expressed in absolute terms (A) and as a ratio standard (B), after applying theoretical exponents b = 0.67 (C) and b = 0.75 (D), as well as the experimentally observed exponent for soccer players b = 0.94 (E), are shown in Figure 2.

Based on the data shown in Figures 1, 2, and 3, the experimentally observed exponents were superior to the theoretical exponents and the ratio standards by adjusting for the effects of body mass on VT1, VT2, and VT02max.

The VT1, VT2, and VT02max values, expressed using different scales for the pubescent and post-pubescent groups, are shown in Table III.

Table IV shows VT1, VT2, and VT02max after adjustment for experimentally observed exponents. The data are organized by pubertal stage, based on Tanner’s index of pubic hair. When the effect of body mass was appropriately adjusted for using experimentally observed exponents, the VT1, VT2, and VT02max responses did not increase proportional to biological maturation levels, but rather displayed a relatively constant behaviour throughout the maturation process.

Table V shows VT1, VT2, and VT02max values after adjustment for experimentally observed exponents. The data are organized by age. The VT2 values differed between the 12–13 and 14–15 year groups; however, this difference could not be attributed to any single variable, as shown in Table VI.

### Table I. Anthropometric characteristics and years of training experience of young soccer players grouped by maturational stage (mean ± SD).

<table>
<thead>
<tr>
<th></th>
<th>Pubescent (n = 52)</th>
<th>Post-pubescent (n = 58)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chronological age (years)</td>
<td>13.4 ± 1.0</td>
<td>17.0 ± 1.4 *</td>
</tr>
<tr>
<td>Body mass (kg)</td>
<td>62.5 ± 9.9</td>
<td>73.9 ± 6.6 *</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.69 ± 0.08</td>
<td>1.78 ± 0.07 *</td>
</tr>
<tr>
<td>Years of training</td>
<td>5.6 ± 2.0</td>
<td>7.1 ± 2.8 *</td>
</tr>
</tbody>
</table>

*Significantly different from pubescent group (P < 0.05).

### Table II. Allometric exponents for VT02max and ventilatory thresholds in relation to body mass in soccer players.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Group</th>
<th>b</th>
<th>95% CI</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>VT02max</td>
<td>Pubescent</td>
<td>0.83</td>
<td>0.69 to 0.95</td>
<td>0.77</td>
</tr>
<tr>
<td></td>
<td>Post-pubescent</td>
<td>0.80</td>
<td>0.56 to 1.03</td>
<td>0.44</td>
</tr>
<tr>
<td></td>
<td>Combined</td>
<td>0.90</td>
<td>0.80 to 0.99</td>
<td>0.76</td>
</tr>
<tr>
<td>VT2</td>
<td>Pubescent</td>
<td>0.90</td>
<td>0.76 to 1.02</td>
<td>0.79</td>
</tr>
<tr>
<td></td>
<td>Post-pubescent</td>
<td>1.00</td>
<td>0.79 to 1.22</td>
<td>0.60</td>
</tr>
<tr>
<td></td>
<td>Combined</td>
<td>0.95</td>
<td>0.86 to 1.03</td>
<td>0.80</td>
</tr>
<tr>
<td>VT1</td>
<td>Pubescent</td>
<td>0.93</td>
<td>0.74 to 1.12</td>
<td>0.65</td>
</tr>
<tr>
<td></td>
<td>Post-pubescent</td>
<td>1.18</td>
<td>0.86 to 1.50</td>
<td>0.48</td>
</tr>
<tr>
<td></td>
<td>Combined</td>
<td>0.94</td>
<td>0.81 to 1.07</td>
<td>0.64</td>
</tr>
</tbody>
</table>

*Note: Independent group model: y = ax^b (for pubescent and post-pubescent); combined group model: y = ax^b · exp(c), where b is the scaling exponent derived from the regression model. y took the values of log VT02max, log VT2, and log VT1 (ml · min⁻¹), x took the values of log body mass (kg). 95% CI = 95% confidence intervals for b; R² is the adjusted coefficient of determination.
Figure 1. Test of independence for \( \dot{V}O_{2\text{max}} \) and body mass (kg) expressed as absolute values (A) and ratio standards (B), after applying theoretical exponents \( b = 0.67 \) (C) and \( b = 0.75 \) (D), as well as the experimentally observed exponent for soccer players \( b = 0.90 \) (E).

Figure 2. Test of independence for \( VT_2 \) and body mass (kg) expressed as absolute values (A) and ratio standards (B), after applying theoretical exponents \( b = 0.67 \) (C) and \( b = 0.75 \) (D), as well as the experimentally observed exponent for soccer players \( b = 0.95 \) (E).
After verification of the essential estimated variables, the results of multiple linear regression to compare the relative contributions of chronological age, body mass, biological maturation, height, and years of formal training in soccer to the variance of the five forms of expression of VT1, VT2, and \( VO_2_{\text{max}} \) are summarized in Table VI. After adjusting for the effects of body mass using the experimentally observed exponents, biological maturation and age had no effect on VT1, VT2 or \( VO_2_{\text{max}} \).

Discussion

To our knowledge, this is the first study to show that biological maturation does not affect the VT1, VT2 or \( VO_2_{\text{max}} \) values of young soccer players when proper scaling procedures are used. These findings also illustrate that it is inappropriate to assume that scaling to either the traditional ratio standard (ml \cdot kg^{-1} \cdot min^{-1}) or to one of the theoretical exponents (ml \cdot kg^{-0.67} \cdot min^{-1} and ml \cdot kg^{-0.75} \cdot min^{-1}) will control adequately for body size differences in young soccer players.

The beneficial effects of biological maturation on athletic performance have been thoroughly described previously (Boisseau & Delamarche, 2000; Nedeljkovic et al., 2007; Rowland, 2005; Van Praagh & Doré, 2002). Typically, soccer players who are more mature are taller, heavier, and more powerful than players who are less mature (Coelho e Silva et al., 2010; Hirose, 2009; Malina et al., 2000, 2004; Philippaerts et al., 2006; Vaeyens et al., 2006). Consequently, recent studies have suggested that young soccer players who mature physically earlier may be preferentially selected, while those who mature later are systematically unselected (Coelho e Silva et al., 2010; Hirose, 2009; Malina et al., 2000; Philippaerts et al., 2006; Vaeyens et al., 2006). For this reason, biological maturation is a very important variable in the detection and selection of soccer talent.

Some authors (e.g. De Ste Croix et al., 2003; Malina, 2006) state that the effects of biological maturation on performance must be interpreted with caution, because many studies have estimated maturation based only on age, without determining the maturation stage of the participants or without the use of a proper method to adjust or control for the effects of body mass (Nevill, Bate, & Holder, 2005).

When the above criteria are used, biological maturation has a positive effect on \( VO_2_{\text{max}} \) (Armstrong & Welsman, 2000, 2001; Armstrong et al., 1999; Beunen et al., 2002; Cunha et al., 2008; Eisenmann et al., 2001; Malina et al., 2004; Welsman et al., 1996). This finding suggests that the interpretation of results is dependent on data normalization and correct selection of statistical analysis.
Table III. Maximal oxygen uptake and ventilatory thresholds in young soccer players expressed using different scalings (mean ± s).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Pubescent (n = 52)</th>
<th>Post-pubescent (n = 58)</th>
</tr>
</thead>
<tbody>
<tr>
<td>VO2max (ml · min⁻¹)</td>
<td>3715.3 ± 536.3</td>
<td>4445.4 ± 470.9*</td>
</tr>
<tr>
<td>VO2max (ml · kg⁻¹ · min⁻¹)</td>
<td>59.6 ± 4.3</td>
<td>60.1 ± 4.9</td>
</tr>
<tr>
<td>VO2max (ml · kg⁻₀.₆₇ · min⁻¹)</td>
<td>232.5 ± 17.2</td>
<td>248.7 ± 19.9*</td>
</tr>
<tr>
<td>VO2max (ml · kg⁻₀.₇₅ · min⁻¹)</td>
<td>167.1 ± 11.8</td>
<td>176.3 ± 14*</td>
</tr>
<tr>
<td>VO2max (ml · kg⁻₀.₉₀ · min⁻¹)</td>
<td>93.8 ± 6.5</td>
<td>96.6 ± 7.7*</td>
</tr>
<tr>
<td>VT₂ (ml · min⁻¹)</td>
<td>2748.3 ± 419.8</td>
<td>3261.4 ± 374.4*</td>
</tr>
<tr>
<td>VT₂ (ml · kg⁻¹ · min⁻¹)</td>
<td>44.0 ± 3.2</td>
<td>44.1 ± 3.1</td>
</tr>
<tr>
<td>VT₂ (ml · kg⁻₀.₆₇ · min⁻¹)</td>
<td>171.8 ± 13.4</td>
<td>182.3 ± 14.1*</td>
</tr>
<tr>
<td>VT₂ (ml · kg⁻₀.₇₅ · min⁻¹)</td>
<td>123.6 ± 9.0</td>
<td>129.2 ± 9.7*</td>
</tr>
<tr>
<td>VT₂ (ml · kg⁻₀.₉₅ · min⁻¹)</td>
<td>54.1 ± 3.8</td>
<td>54.6 ± 3.9</td>
</tr>
<tr>
<td>VT₁ (ml · min⁻¹)</td>
<td>1799.4 ± 319.9</td>
<td>2071.0 ± 304.5*</td>
</tr>
<tr>
<td>VT₁ (ml · kg⁻¹ · min⁻¹)</td>
<td>28.7 ± 3.0</td>
<td>27.8 ± 3.1</td>
</tr>
<tr>
<td>VT₁ (ml · kg⁻₀.₆₇ · min⁻¹)</td>
<td>112.4 ± 12.6</td>
<td>115.6 ± 13.2</td>
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<tr>
<td>VT₁ (ml · kg⁻₀.₇₅ · min⁻¹)</td>
<td>81.0 ± 8.8</td>
<td>81.9 ± 9.1</td>
</tr>
<tr>
<td>VT₁ (ml · kg⁻₀.₉₄ · min⁻¹)</td>
<td>36.8 ± 3.8</td>
<td>36.2 ± 3.9</td>
</tr>
</tbody>
</table>

*Significantly different from pubescent group (P < 0.05).

Table IV. Maximal oxygen uptake and ventilatory thresholds after adjustment for allometric scaling grouped by stage of pubic hair (mean ± s).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Tanner stage of pubic hair development</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2 (n = 12)</td>
</tr>
<tr>
<td>VO2max (ml · kg⁻₀.₉₀ · min⁻¹)</td>
<td>92.4 ± 6.1</td>
</tr>
<tr>
<td>VT₂ (ml · kg⁻₀.₉₅ · min⁻¹)</td>
<td>52.5 ± 3.7</td>
</tr>
<tr>
<td>VT₁ (ml · kg⁻₀.₉₄ · min⁻¹)</td>
<td>35.7 ± 2.6</td>
</tr>
</tbody>
</table>

*Significantly different with respect to stage of pubic hair development (P < 0.05).

Table V. Maximal oxygen uptake and ventilatory thresholds after adjustment for experimentally observed exponents grouped by chronological age (mean ± s).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Chronological age (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>12–13 (n = 26)</td>
</tr>
<tr>
<td>VO2max (ml · kg⁻₀.₉₀ · min⁻¹)</td>
<td>93.0 ± 6.4</td>
</tr>
<tr>
<td>VT₂ (ml · kg⁻₀.₉₅ · min⁻¹)</td>
<td>52.8 ± 3.9</td>
</tr>
<tr>
<td>VT₁ (ml · kg⁻₀.₉₄ · min⁻¹)</td>
<td>36.5 ± 4.1</td>
</tr>
</tbody>
</table>

*Significantly different with respect to 12–13 year age group (P < 0.05).

Increases in absolute VO₂max are strongly correlated with increases in body mass, which, among other factors, are connected to changes to the lungs, heart, and skeletal muscle during puberty (Rowland, 2005). Consequently, absolute VO₂max values increase proportionally with biological development.

The ratio standard (ml · kg⁻¹ · min⁻¹) is used extensively in the literature to adjust VO₂max values to body size. In contrast to absolute values, ratio standard VO₂max responses do not increase proportionally with biological maturation, displaying a relatively constant pattern throughout the maturational process (Armstrong et al., 1999; Cunha et al., 2008; Rowland, 2005; Welsman et al., 1996). However, traditional ratio standard analysis methods are rarely criticized when they do not adequately highlight body mass effects on VO₂max responses (Armstrong & Welsman, 2001; Armstrong et al., 1999; Chamari et al., 2005; Cunha et al., 2008; Eisenmann et al., 2001; Nevill & Holder, 1995;
Nevill et al., 2004b, 2005; Welsman et al., 1996; Wisloff et al., 2004). Our results agree with the literature, which shows that the ratio standard assessment was in confidence interval for the body mass combined exponent did not include $b = 0.67$ or $b = 0.75$ (see Table II). Moreover, the multiple linear regression analysis demonstrated that biological maturation was the predictive variable for variance in $V_{O2max}$ (ml · kg$^{-0.67}$ · min$^{-1}$: 17.8%; ml · kg$^{-0.75}$ · min$^{-1}$: 11.4%). These results clearly show how inappropriate scaling can influence $V_{O2max}$ responses, and demonstrate the importance of calculating an experimentally observed exponent for each specific sample.

Welsman and colleagues (1996) used both the ratio standard and the allometric form to adjust the effect of body size on $V_{O2max}$ of three different groups: prepubescents ($n = 24$), pubescents ($n = 26$), and adults ($n = 16$). The ratio standard assessment was in accordance with the literature. In contrast, the allometric analysis (ml · kg$^{-0.80}$ · min$^{-1}$) showed a gradual increase in $V_{O2max}$ between groups. Soccer players' $V_{O2max}$ results have previously been
reported (Cunha et al., 2008); however, these findings could affect the conventional interpretations of $V'\text{O}_2\text{max}$ during children’s growth and biological maturation, which cannot be supported by the present study.

Malina and colleagues (2004) examined the impact of experience, body size, and maturational changes on the functional capacities of soccer players aged 13–15 years. They found that biological maturation and training experience explained 21% of the aerobic resistance. Moreover, Armstrong and colleagues (1999) noted that sex, growth, and biological maturation influenced $V'\text{O}_2\text{peak}$ in children aged 11–13 years. Furthermore, it was shown that biological maturation affected $V'\text{O}_2\text{peak}$ in children without training, after normalization to their body sizes. We found that the experimentally observed exponent $b = 0.90$ provided a better fit, statistically, than the other $V'\text{O}_2\text{max}$ expression forms. A significant difference was detected between the pubescent and post-pubescent groups when $V'\text{O}_2\text{max}$ was properly expressed (ml $\cdot$ kg$^{-0.90} \cdot$ min$^{-1}$). Nevertheless, these differences could not be attributed to biological maturation or any other variable in the multiple linear regression analysis.

Cross-sectional studies have suggested that VT$_2$ could decrease as biological maturation progresses (Cooper, Weiler-Ravell, Whipp, & Wasserman, 1984; Kanaley & Boileau, 1988; Reybrouck, Weymans, Stijns, Knops, & van der Hauwaert, 1985), contrary to a longitudinal study, which reported decreases as biological maturation progresses (Cooper, Weiler-Ravell, Whipp, & Wasserman, 1987). Cunha and colleagues (2008) demonstrated that pre-pubescent, pubescent, and post-pubescent individuals presented similar VT$_2$ values expressed as %$V'\text{O}_2\text{max}$.

In soccer, VT$_2$ analysis is especially important because this intensity coincides with the intensity displayed during a match (Helgerud et al., 2001; Stroyer, Hansen, & Klausen, 2004). Soccer players have presented VT$_2$ values between 80 and 90% of maximum heart rate (Cunha et al., 2008; Helgerud et al., 2001; Stroyer et al., 2004) and 75–90% when VT$_2$ was expressed as a percentage of $V'\text{O}_2\text{max}$ (Chamari et al., 2005; Cunha et al., 2008; Helgerud et al., 2001; Hoff et al., 2002).

Adjustments related to body mass effects on VT$_2$ are important because they allow correct comparisons between distinct maturational groups. For instance, when VT$_2$ was expressed as a function of ratio standard $V'\text{O}_2$ (ml $\cdot$ kg$^{-0.95} \cdot$ min$^{-1}$), there were no differences observed between the pubescent and post-pubescent groups. Curiously, the multiple linear regression analysis showed proper body mass effect adjustments to VT$_2$ by the ratio standard. Similar to the $V'\text{O}_2\text{max}$ findings, our results showed that the use of theoretical exponents did not properly adjust for possible effects of body mass on VT$_2$ values.

When allometric procedures were carried out, we found an experimentally observed exponent ($b = 0.95$) with a statistical fit that is superior to the other VT$_2$ forms of expression. When VT$_2$ was expressed properly (ml $\cdot$ kg$^{-0.95} \cdot$ min$^{-1}$), there were no significant differences between the pubescent and post-pubescent groups. Multiple linear regression analysis did not highlight any influence of biological maturation on VT$_2$.

The ratio standard was properly adjusted for the effects of body mass on VT$_1$. However, an experimentally observed exponent calculated for VT$_1$ ($b = 0.94$) resulted in clearer VT$_1$ values than those obtained with the other expression forms, fitting correctly with body mass influences on VT$_1$. This analysis also indicates that VT$_1$ remains stable during the maturational process.

Drawing any conclusions on the effects of biological maturation on the ventilatory thresholds or lactate threshold is difficult because few studies have used appropriate methods to normalize data and adjust body mass effects. Therefore, more studies with better methodology are required to obtain clearer evidence regarding this topic.

The theoretical exponents do not properly fit body mass effects on VT$_1$, VT$_2$, and $V'\text{O}_2\text{max}$. Nevill and colleagues’ (2004a) assumption that muscular enlargement exists in professional soccer players was confirmed. The fitted mass exponents for the calf and thigh muscle girths were $b = 0.43$ and $b = 0.39$ respectively, providing strong evidence that leg muscle mass increased at a greater rate than that predicted by geometric similarity ($b = 0.33$). Another explanation is given by Batterham and Jackson (2003), who demonstrated the need to calculate an experimentally observed exponent for $V'\text{O}_2\text{max}$ and $V'\text{O}_2\text{submax}$.

Overall, it is recommended to identify experimentally observed exponents for maximal and submaximal exercises because slight variations in these exponents could lead to confusing interpretations of body mass, biological maturation, and age effects on VT$_1$, VT$_2$, and $V'\text{O}_2\text{max}$. Although calculating experimentally observed exponents places additional
demands on routine test procedures and could complicate inter-study comparisons, it may assist in clarifying the effects of biological maturation on $\dot{V}O_{2\text{max}}$ and associated variables.

From a practical point of view, routine testing of performance is easier when it is based on age. Unavoidably, players who are older have higher strength, power, endurance, and sport-specific skills than younger individuals; however, these differences in athletic performance should be analysed carefully because individuals of the same age may show large variations in biological maturation, which can confound the process of talent identification.

**Conclusions**

Biological maturation does not affect $V_T_1$, $V_T_2$, and $\dot{V}O_{2\text{max}}$ responses when expressed using appropriate allometric scaling. Experimentally observed exponents were the best means of adjusting for the effects of body mass on $V_T_1$, $V_T_2$, and $\dot{V}O_{2\text{max}}$. Which and how physiological variables affect these responses during growth and biological maturation in soccer players remains unclear. Nevertheless, in order to evaluate the physiological performance in young soccer players, the allometric scaling needs to be taken into account instead of using theoretical approaches.

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**References**


