Aerobic Fitness, Maturation, and Training Experience in Youth Basketball

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Relationships among chronological age (CA), maturation, training experience, and body dimensions with peak oxygen uptake (VO\textsubscript{2max}) were considered in male basketball players 14–16 y of age. Data for all players included maturity status estimated as percentage of predicted adult height attained at the time of the study (Khamis-Roche protocol), years of training, body dimensions, and VO\textsubscript{2max} (incremental maximal test on a treadmill). Proportional allometric models derived from stepwise regressions were used to incorporate either CA or maturity status and to incorporate years of formal training in basketball. Estimates for size exponents (95% CI) from the separate allometric models for VO\textsubscript{2max} were height 2.16 (1.23–3.09), body mass 0.65 (0.37–0.93), and fat-free mass 0.73 (0.46–1.02). Body dimensions explained 39% to 44% of variance. The independent variables in the proportional allometric models explained 47% to 60% of variance in VO\textsubscript{2max}. Estimated maturity status (11–16% of explained variance) and training experience (7–11% of explained variance) were significant predictors with either body mass or estimated fat-free mass (\(P \leq 0.01\)) but not with height. Biological maturity status and training experience in basketball had a significant contribution to VO\textsubscript{2max} via body mass and fat-free fat mass and also had an independent positive relation with aerobic performance. The results highlight the importance of considering variation associated with biological maturation in aerobic performance of late-adolescent boys.

Keywords: percentage of mature height, adolescent, allometric scaling, young athletes

Many activities in basketball are performed at near-maximal intensities and tax anaerobic capacities.\(^1\) However, most game-related activities are of low (~40%) and medium (50%) intensities and along with recovery are accomplished via aerobic-energy pathways.\(^1\) Aerobic fitness may have more importance in the recovery during repeated bouts of high-intensity intermittent exercise, rather than in providing a direct performance benefit.\(^2\) Although the aerobic contribution to a single, short-duration sprint is relatively small, the aerobic contribution increases with repeated sprints.\(^3\) In addition, morphological characteristics play an important role in determining roles of individual players\(^4\) and are often central to the selection process for young players.\(^5\) Nevertheless, interindividual variability in functional and morphological characteristics is considerable among youth\(^6,7\) and adult\(^8\) basketball players.

The issue of aerobic fitness is of interest to researchers in sport science. Peak oxygen uptake (VO\textsubscript{2max}), as an indicator of aerobic fitness, is routinely expressed as a ratio standard (eg, mL ∙ min\(^{-1}\) ∙ kg\(^{-1}\)), despite theoretical and statistical limitations.\(^9\) Allometric models are also effective for partitioning body-size effects in physiological variables or performances, in particular VO\textsubscript{2max}.\(^9\) Alternative statistical models using linear regression and allometric scaling (log-linear regression) have been recommended to provide a “size-free” expression of VO\textsubscript{2max}.\(^9\) Allometric models may also be used to accommodate potentially confounding variables to explain interindividual variability on the dependent variable.\(^9\)

The majority of data dealing with aerobic fitness in children and adolescents are based on individuals who were not regularly involved in intensive training programs.\(^10–12\) On the other hand, intensive training programs and high-level competitions are experienced by many young athletes. Adolescent athletes within a sport tend to be relatively homogeneous in training history, functional capacity, and sport-specific skills, but variation in size and maturity status may be considerable.\(^5\) The influence of accumulated training stimulus on VO\textsubscript{2max} in young athletes engaged in organized training programs has not been clearly addressed. In addition to confounding effects of body dimensions on VO\textsubscript{2max}, the potential influence of interindividual differences in the timing and tempo of biological maturation on physiological performance of adolescents, both athletes and nonathletes, needs consideration. In this context, the purpose of this
study was to evaluate the extent that chronological age (CA), biological maturity status, training experience, and body-dimension characteristics account for the interindividual variation in VO2\textsubscript{max} in adolescent male basketball players. Given the trend toward intensive training in youth sports at relatively young ages, examining the relationships of CA, morphology, maturation, and training with VO2\textsubscript{max} in young athletes engaged in sport-specific training merits further study.

Methods

Sample

The sample included 37 male adolescent basketball players (15.3 ± 0.6 y, 14.0–16.3). All players were of Portuguese ancestry with the exception of 2 who were of African ancestry. All participants were volunteers and were classified as under 16 years by the Federação Portuguesa de Basquetebol (Portuguese Basketball Federation). At the time of study, all players trained regularly (4–6 sessions/wk; ~360–510 min/wk) and typically played 1 or 2 games/wk over a 10-month season (mid-September to June). Participants were engaged in clubs participating in under-16 national-level competition. All participants had been in formal training and competition for at least 2 years, with a mean of 6.4 ± 2.6 years. Number of years of training was obtained by interview.

The study was approved by the Portuguese Foundation for Science and Technology and also by the Scientific Committee of the University of Coimbra. Participants were informed about the nature of the study and that participation was voluntary and they could withdraw from the study at any time. Players and their parents or legal guardians provided informed written consent.

Anthropometry and Body Composition

All measurements were taken by a single experienced observer. Height was measured with a portable stadiometer (Harpenden model 98.603, Holtain Ltd, Crosswell, UK) to the nearest 0.1 cm. Reliability estimates are reported elsewhere. Body mass was assessed to the nearest 0.01 kg with participants wearing a bathing suit without shoes on an electronic scale connected to the plethysmograph computer (Bod Pod Composition System, model Bod Pod 2006, Life Measurement, Inc, Concord, CA, USA). Air-displacement plethysmography (compartment volume without subject minus volume with the subject) was used to estimate body volume and, in turn, composition. The unit was calibrated using a 2-point calibration method based on the manufacturer’s instructions. Before each trial, the Bod Pod was calibrated using a 50.255-L cylinder. All participants were tested while wearing Lycra underwear and a swim cap as recommended by the manufacturer. Two trials were performed for each subject. Participants sat quietly in the chamber while the raw body volume was measured consecutively until 2 values within 150 mL were obtained. If more than 3 raw body volumes were necessary, 2 to 3 additional measurements were obtained after recalibrating the Bod Pod. Average volume of air in the lungs and thorax during normal tidal breathing (thoracic gas volume) was measured for each subject and used in the computation of body volume. Body density (body mass/body volume) was calculated and used to estimate percentage fat using the age- and sex-specific constants. Percentage fat was in turn converted to fat mass (FM); fat-free mass (FFM) was estimated by subtraction.

Age and Maturity Status

CA was calculated to the nearest 0.1 year as birth date minus testing date. CA, height, and body mass of the player and midparent height were used to predict mature (adult) height with the Khamis–Roche protocol. Current height of each player was then expressed as a percentage of predicted mature height to provide an estimate of biological maturity status. Individuals who are closer (eg, 94%) to mature height are more advanced in maturity status than individuals who are farther (eg, 89%) from mature height.

VO2\textsubscript{max}

VO2\textsubscript{max} was determined using an incremental running test on a motorized treadmill (Quasar, HP Cosmos, Germany). Participants started with 3 minutes at 8 km/h, with subsequent increments of 2 km/h every 3 minutes until 14 km/h. Exercise intensity was subsequently increased through increasing the treadmill elevation by 2.5% after 12 minutes and every 3 minutes until exhaustion, which was reached in 8 to 12 minutes. Attainment of VO2\textsubscript{max} was confirmed if the athlete met any 2 of the following criteria: volitional exhaustion, respiratory-exchange rate ≥1.10, heart rate reaching a value within 10% of the age-predicted maximal heart rate, and a plateau in oxygen consumption despite increased exercise intensity. Expiratory O2 and CO2 concentrations and flow were measured every 10 seconds using a gas analyzer (MetaMax System, Cortex Biophysik GmbH, Leipzig, Germany). Calibration and ambient air measurements were conducted before each testing session according to the manufacturer’s guidelines. Before each test, flow and volume were calibrated using a 3-L-capacity syringe (Hans Rudolph, Kansas City, MO). CO2 and O2 sensors were calibrated using a calibration kit (Cosmed, UN1956, 560L, 2200 psig, 70°F) with known concentrations of CO2 and O2 (5% CO2, 16% O2, balance N2). Heart rate was measured throughout exercise with a commercially available heart-rate monitor (Polar, Finland).

Analysis

Descriptive statistics were calculated for the total sample. Pearson correlation coefficients were initially calculated to examine the linearity between body dimensions (height, body mass, FFM) and VO2\textsubscript{max} expressed in
allometric models. The models incorporated CA or log-transformation of variables based on proportional size was conducted using the linearized equation with tors (ie, log height, log body mass, and log FFM).

Values of $a$ (intercept) and $k$ (slope of the line) were solved by applying standard least-squares linear regression to the logarithmic-transformed data in the form of

$$\log y = \log a + k \times \log x + \log \epsilon$$  \hspace{1cm} (Eq 2)

where $y$ was the dependent variable of VO$_{2\text{max}}$ (natural logarithms, ie, log VO$_{2\text{max}}$) and body-dimension descriptors (ie, log height, log body mass, and log FFM).

Subsequently, multiple stepwise-regression analysis was conducted using the linearized equation with log-transformation of variables based on proportional allometric models. The models incorporated CA or percentage of predicted mature height and years of training experience as exponential terms in addition to 1 of the morphological dimensions (height, body mass, or FFM) as follows:

$$\text{VO}_{2\text{max}} = \text{size descriptor}^{a+b} \times (\text{age or } \% \text{ mature height}) + c \times (\text{years of training}) \times \epsilon$$ \hspace{1cm} (Eq 3)

This model can be linearized with a log transformation, and stepwise multiple linear-regression analysis was used to fit the unknown parameters. The log-transformed version of the preceding equation is

$$\log \text{VO}_{2\text{max}} = k_1 \log(\text{size descriptor} + a + b) \times (\text{age or } \% \text{ mature height}) + c \times (\text{years of training}) + \log \epsilon$$ \hspace{1cm} (Eq 4)

Validation of the allometric models was determined by examining the association between the residuals of each model. The respective scaling denominators were then calculated using Pearson product–moment correlations to check the assumptions of scaled VO$_{2\text{max}}$ independency of the participants’ age or maturity status, years of training experience, and body dimensions, as well as homoscedasticity of residuals in the log-linear regressions. If the allometric model was successful in partitioning out the influence of CA or maturation, training experience, and body dimensions, the correlation between the residuals and each independent variable in the model, separately, should approach zero, which indicates there is little or no residual size correlation. Correlation coefficients that do not approach zero, regardless of whether they are statistically significant, suggest that the proportional allometric model has not been completely successful in rendering VO$_{2\text{max}}$ independent of CA or biological maturation, training experience, and body dimensions. The coefficient of determination ($R^2$) provides an indication of the variance explained by the independent variables in each proportional allometric model. Statistical analyses were performed using SPSS version 17.0 software (SPSS, Chicago, IL).

**Results**

Characteristics of the total sample are summarized in Table 1. Percentage of predicted mature height attained at the time of study (15.3 ± 0.6 y) was 97.5% ± 2.3%. The estimate was in advance of that for the sample on which the height-prediction protocol was developed, 96.0% ± 1.3% at 15.0 years (participants were measured within 1 mo of their birthdays). By inference, the sample of basketball players was somewhat advanced in biological maturity status for CA. Mean height and body mass approximated age-specific 90th percentiles of the US reference for males.

Estimates for body-dimension exponents (95% CI) from the separate allometric models for VO$_{2\text{max}}$ were height 2.16 (1.23–3.09), body mass 0.65 (0.37–0.93), and FFM 0.73 (0.46–1.02). The body dimensions explained 39% to 44% of variance in the VO$_{2\text{max}}$. The residuals of the simple allometric models presented no residual correlation with the respective body-dimension variables, indicating that they can be used to derive VO$_{2\text{max}}$ “size free scores” for each of the size variables. However, substantial residual size correlations were apparent when residuals were correlated with other size variables (eg, residuals of VO$_{2\text{max}}$ modeled for height against body mass). The correlations (.10 < $r$ < .23) indicated that height, body mass, or FFM individually did not completely partition out the influence of body dimensions in VO$_{2\text{max}}$.

Results of the multiple stepwise regressions for allometric models are summarized in Table 2. The independent variables explained 47% to 60% of the variance in the VO$_{2\text{max}}$. CA was not a significant predictor once training experience and body-size variables were accounted for in the regressions (models 1, 2, and 3). In contrast, percentage of mature height was a significant predictor with training experience and separately with body mass and FFM (models 5 and 6, $P \leq .01$) but not with height (model 4).

| Table 1 Descriptive Statistics for the Total Sample (N = 37) |
| --- | --- | --- |
| Chronological age, y | 15.32 | 0.64 | 14.01–16.32 |
| Percentage of predicted mature height, % | 97.5 | 2.3 | 90.5–100.9 |
| Years of training | 6.38 | 2.60 | 2.00–11.00 |
| Height, cm | 181.7 | 7.6 | 165.5–195.6 |
| Body mass, kg | 73.3 | 10.3 | 55.8–98.9 |
| Fat-free mass, kg | 64.0 | 8.5 | 49.8–85.0 |
| Percentage of fat mass | 12.5 | 6.8 | 1.7–38.3 |
| Maximum O$_2$ consumption, L/min | 4.65 | 0.66 | 3.20–6.49 |
As expected, all independent variables entering the final models had a positive association with VO_{2\text{max}}. In all models the body-size variables were the first predictors identified. Introduction of training experience as a significant predictor (\(P \leq .01\)) in the models contributed 11% to 16% to the explained variance. For the final models, the explained variance added by percentage of adult height as a significant predictor (\(P \leq .01\)) was 11% for the model including training experience and body mass and 7% for the model including training experience and FFM. The estimated body-size exponents derived from multiple stepwise regression increased the contribution of each body dimension’s descriptor in the models incorporating CA and training experience. In contrast, when CA was replaced by the estimate of maturity status, size exponents decreased for body mass and FFM but did not differ for height.

### Discussion

The contributions of years of sport-specific training, CA, somatic maturity status (percent of mature height attained), height, body mass, and FFM to VO_{2\text{max}} among adolescent basketball players were evaluated. The allometric models identified body dimensions and training experience as significant predictors of VO_{2\text{max}}. Advanced biological maturity status, training experience, and either body mass or FFM were among significant predictors of VO_{2\text{max}}. The models were consistent in identifying height and training experience as significant predictors, whereas both CA and estimated maturity status were removed. The independent variables incorporated in the allometric models explained 47% to 60% of variance in VO_{2\text{max}}, emphasizing the importance of the interrelationships among muscle mass,
accumulated training experience, and biological matura-
tion to maximal aerobic performance in this sample of
late adolescent basketball players.

The growth characteristics of this sample of Por-
tuguese adolescent basketball players were consistent
with other reports for young male basketball players.6,7
Variation in body dimensions was considerable (Table 1)
and probably reflected position-specific characteristics,
consistent with the importance of body dimensions in
basketball selection.4 Mean heights and body masses of
the basketball players approximated age-specific 90th
percentiles for US reference males.17 The larger size
reflected in part the selective demands of basketball
and also advanced maturity status. Mean percentage of
predicted mature height attained at the time of the study
(15.3 ± 0.6 y) was 97.5% ± 2.3% (Table 1), which was
in advance of longitudinal samples in the Fels Growth
Study, on which the height-prediction protocol was
developed, 96.0% ± 1.3% at 15.0 years (participants
were measured within 1 mo of their birthdays),18 and
and in the Berkeley Guidance Study, 96.0% ± 3.3% at 15.5
years.18 Observations for estimated maturity status were
consistent with assessments of skeletal age (Fels method)
in Portuguese youth basketball players.7 Skeletal maturity
assessments in other samples of youth basketball players
are apparently not available, although a sample of active
boys that included primarily basketball players followed
longitudinally through adolescence was advanced in
skeletal age at CAs of 14 to 16 years.19,20

Current height expressed as a percentage of predicted
mature height is based on size attained and is the result
of variation in tempo of growth; it is not an indicator of
the time of maximal growth during the adolescent spurt
(age at peak height velocity).21 The protocol is useful
in distinguishing youngsters who are tall at a given age
because they are genetically tall or who are tall because
they are advanced in maturation compared with peers.21
The method for predicting mature height was based on
current CA, height, and body mass of the player and
midparent height.14 The method was modified from an
earlier protocol that also included skeletal age among
predictors.22 Differences between the 2 protocols with
and without skeletal age among predictors were relatively
small.23 Percentage of predicted adult height attained
at a given age (without skeletal age) showed moder-
ate concordance with maturity classifications based on
skeletal age in samples of American football players 9
to 14 years24 and soccer players 11 to 13 years of age.25
Nevertheless, there is a need for further refinement and
validation of noninvasive methods for the estimation of
biological maturity status.

\( \text{VO}_{2\text{max}} \) of the adolescent basketball players (Table 1) was higher than previously reported for a similar age
range in the general population.11,26 Most available data
for \( \text{VO}_{2\text{max}} \) in basketball players are reported as ratio
standards to control for the effects of body mass. Poten-
tial misinterpretations associated with this approach
have been noted. Nevertheless, allowing for statisti-
cal limitations and sampling, there was considerable
variability in \( \text{VO}_{2\text{max}} \) among male basketball players
13 to 18 years of age.27–29 Although basketball is not an
endurance sport per se, high values for cardiopulmonary
functions are often viewed as important for the mainte-
nance of a high level of activity during an entire game8
and for effective recovery from high-intensity, short
bursts of movement.28 Higher levels of aerobic fitness
among basketball players may also have a potentially
important role in the prevention of performance decre-
ments throughout a season.8

It is expected that absolute \( \text{VO}_{2\text{max}} \) increases as a
function of body dimensions during childhood and ado-
lescence, whether or not youth are engaged in organized
sports and other physical activities. Longitudinal data
based on Canadian and Belgian boys indicated, on aver-
age, coincident occurrence of peak velocity of growth
in height and \( \text{VO}_{2\text{max}} \).11,30 Studies using multilevel modeling
also demonstrated a size-independent effect of biological
maturity on \( \text{VO}_{2\text{max}} \).10,26 \( \text{VO}_{2\text{max}} \) adjusted for age and
body dimensions increased with pubertal status in male
athletes in the Training of Young Athletes study.12 In
general, age-related increases in \( \text{VO}_{2\text{max}} \) appeared to be
mediated largely by changes in size dimensions; however,
year-to-year changes in body mass and \( \text{VO}_{2\text{max}} \) may also
be masked by individual differences in the timing and
tempo of biological maturation.31

Although interest in the development of \( \text{VO}_{2\text{max}} \) in
youth is considerable, few studies have addressed the
topic in children and adolescents engaged in highly struc-
tured training regimens. Interpretation of the relationship
between body dimensions and \( \text{VO}_{2\text{max}} \) may be influenced
by growth and maturation per se and by a potential influ-
ence of training on FFM. Moreover, limited longitudinal
data for estimates of FFM (lean-tissue mass and bone
mineral content via DXA, muscle via radiography) show
a peak velocity of growth during adolescence that occurs,
on average, after age at peak height velocity.21

As noted, expression of \( \text{VO}_{2\text{max}} \) as a ratio standard
presents theoretical and statistical limitations.9 Allometric
scaling (log-linear regression) was adopted in the current
study. Initially, it was used as a power function to relate
\( \text{VO}_{2\text{max}} \) to body dimensions. Since important inter-
dividual variability in body dimensions occurs during
pubertal development and growth spurt,21 proportional
allometric models were used.15 Two exponential terms
were added to the size term: The first incorporated either
CA or maturity status and the second incorporated years
of formal training. The nonlinear allometric modeling
procedures were statistically appropriate to account for
differences in body dimensions. The null correlation
between the residuals of the power-function models
and their respective body-dimension variables indicated
that power functions can be used to derive \( \text{VO}_{2\text{max}} \) “size
free scores” for each of the adopted size variables. The
proportional allometric models derived from stepwise
regressions were also adjusted to fit the \( \text{VO}_{2\text{max}} \) data, as
absolute residuals from each of the models were uncor-
related with the log-transformed independent variables
in each of the models. These results were consistent with
application of similar allometric models for partitioning body-size effects from physiological variables or performances, in particular VO$_{2\text{max}}$ in youth and adult team-sport athletes.

The size exponents derived from the allometric model (Eq 1) are consistent with observation in the literature that the relationship between body dimensions and VO$_{2\text{max}}$ is not proportional. Exponents derived from the models for height, body mass, and FFM were reasonably consistent with the theory of geometrical similarity. Humans are not geometrically similar, and athletes in particular have greater muscle development. It might be expected, therefore, to have inflated size exponents indicating greater growth in VO$_{2}$ per body mass. The point exponents for body mass presented in this study were lower than those for male adolescents in a similar age range but not engaged in sports and also in studies of young athletes. The results may be explained by higher mean weights in the sample of basketball players than young athletes from other sports (eg, long-distance runners and soccer). Hence, generalizations from the current sample to other youth populations in general and to youth participants in other sports should be made with caution. The lack of geometric similarity among physiques also indicates potential dangers of using body-mass power functions to model VO$_{2\text{max}}$.

**Practical Applications and Conclusions**

Large portions of the variance in VO$_{2\text{max}}$ of adolescent basketball players are accounted for by biological maturation, years of training experience, and body dimensions. Biological maturation and training experience had an indirect effect via body mass and FFM but an independent positive relationship with aerobic performance. Thus, researchers and coaches should consider the variability associated with biological maturation on aerobic performance of adolescent athletes, even in individuals beyond the interval of maximum growth when rates of change in body dimensions, body composition, and various bodily systems tend to be lower as physical and physiological maturity is approached. The accumulation of basketball-specific training loads through the years also appears to have a positive independent effect on the development of aerobic-energy pathways in late adolescence.

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