UNIVERSIDADE DE COIMBRA
Faculdade de Ciências do Desporto e Educação Física

CONSUMO MÁXIMO DE OXIGÉNIO EM JOVENS BASQUETEBOLISTAS MASCULINOS:

contribuição do tamanho corporal, maturação e treino utilizando modelos alométricos

Dissertação apresentada com vista à obtenção do grau de mestrado em treino desportivo para crianças e jovens pela Faculdade de Ciências do Desporto e Educação Física da Universidade de Coimbra sob orientação do Prof. Doutor Manuel João Cerdeira Coelho e Silva

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À minha família,
que sempre me ajudou e me apoiou incondicionalmente.
Obrigado por tudo.

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RESUMO

O presente estudo examinou a inter-associação entre idade maturação, anos de treino, tamanho corporal e o consumo máximo de oxigénio ($VO_{2máx}$), em jovens basquetebolistas masculinos dos 14.0 aos 16.3 anos de idade. A bateria de dados incluiu para todos os atletas (n=37) a determinação da maturação somática determinada pela estatura matura predita (protocolo Khamis-Roche), anos de prática desportiva competitiva federada de basquetebol, estatura, massa corporal, massa isenta de gordura determinada por pletismografia de ar deslocado. A determinação da potência aeróbia foi obtida através de um teste direto, máximo, contínuo e por patamares de carga progressiva, no *treadmill*. A análise de dados considerou a estatística descritiva. Adicionalmente, foram explorados modelos alométricos obtidos pela técnica de regressão linear simples considerando a transformação logarítmica das duas medidas de tamanho corporal (massa corporal, massa isenta de gordura), como variáveis independentes, e a transformação logarítmica do $VO_{2máx}$ como variável dependente. Subsequentemente, foram explorados modelos multiplicativos, com recurso à técnica de regressão linear múltipla, considerando, para além das medidas utilizados nos modelos simples, também os anos de treino e a maturação somática. Os expoentes alométricos para o tamanho corporal foram 0.649 e 0.731, respectivamente para a massa corporal e para a massa isenta de gordura. Os modelos multiplicativos acrescentaram variância explicada relativamente aos modelos mais simples, sugerindo um efeito independente do treino e da maturação sobre o consumo máximo de oxigénio.

Palavras-chave: Percentagem de estatura matura; Desporto infanto-juvenil; Modelação alométrica; Jovem atleta.

ABSTRACT

Relationships among maturation, training experience and body dimensions with maximal oxygen uptake (VO_{2max}) were considered in male basketball players aged 14.0-16.3 years. Data also included for all players maturity status estimated as percentage of predicted adult stature attained at the time of the study (Khamis-Roche protocol), years of training, body dimensions and and VO_{2max} (incremental maximal test on a treadmill). Proportional allometric models derived from stepwise regressions were used, the first to incorporate either CA or maturity status, and the second to incorporate years of formal training in basketball. Estimates for size exponents from the separate allometric models for VO_{2max} were 0.649 and 0.731 for body mass and fat-free mass. Estimated maturity status and training experience were significant predictors with either body mass or estimated fat-free mass. Biological maturity status and training experience in basketball had a significant contribution to VO_{2max} via body mass and fat-free fat mass, and interestingly, also had an independent positive relation with aerobic performance.

Keywords: percentage of mature stature, youth sports, allometric scaling, young athletes.

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PARTE I

CONSUMO MÁXIMO DE OXIGÉNIO EM JOVENS BASQUETEBOLISTAS MASCULINOS: contribuição do tamanho corporal, maturação e treino utilizando modelação alométrica

1. INTRODUÇÃO

A aptidão aeróbia associa-se positivamente com a capacidade de recuperação durante episódios repetidos de esforço em regimes intermitentes de elevada intensidade. Por conseguinte, a aptidão aeróbia estabelece uma associação importante com a natureza do esforço no basquetebol, caraterizado por um elevado número de *sprints* repetidos (Castagna et al., 2007). Os valores médios de consumo máximo de oxigénio ($VO_{2máx}$) em jovens basquetebolistas jovens e adultos jovens estão razoavelmente descritos na literatura (Apostolidis, Nassis, Bolatoglou, & Geladas, 2004; Castagna, Chaouachi, Rampinini, Chamari, & Impellizzeri, 2009; Castagna, Impellizzeri, Rampinini, D'Ottavio, & Manzi, 2008; Castagna et al., 2007).

Adicionalmente, as características morfológicas parecem desempenhar um papel importante na especialização dos jogadores por posição (Drinkwater, Pyne, & McKenna, 2008), sendo um aspeto central no processo de identificação e seleção de jovens jogadores (Coelho e Silva, Figueiredo, Carvalho, & Malina, 2008; Malina, 1994).

A maioria dos dados relativos à aptidão aeróbia em crianças e jovens é resultante de trabalhos com amostras que não estão envolvidos em programas de treino intensivo (Armstrong & Welsman, 2001; Beunen et al., 2002; Geithner et al., 2004). O treino é responsável por adaptações dos sistemas biológicos que determinam o $VO_{2máx}$, estando associado a melhorias no perfil oxidativo dos músculos esqueléticos (Holloszy, Rennie, Hickson, Conlee, & Hagberg, 1977).

O $VO_{2máx}$ é frequentemente expresso como uma rácio (ex., $ml \cdot min^{-1} \cdot kg^{-1}$), apesar das limitações teóricas e estatísticas (Nevill, Ramsbottom & Williams, 1992; Tanner, 1949). A modelação alométrica configura-se como uma alternativa válida para obter expressões de variáveis fisiológicas e de desempenho, independentes do tamanho corporal (Nevill et al., 1992). A técnica corresponde à utilização de regressões lineares recorrendo a transformações logarítmicas das variáveis independentes e dependentes, obtendo-se expoentes superiores ou inferiores à unidade (Armstrong & Welsman, 1994; Nevill et al., 1992).

Os atletas adolescentes, no seio de uma única modalidade desportiva, tendem a apresentar-se como um grupo relativamente homogéneo no que diz respeito à história de treino, volume anual, nível de desempenho em capacidades funcionais e até metodologias predominantes, apesar da considerável e substancial variabilidade inter-individual no tamanho corporal e maturação biológica (Malina, 1994).

O presente estudo pretende examinar o contributo da idade cronológica (IC), maturação biológica, experiência de treino e tamanho corporal, para explicar a variabilidade no $VO_{2máx}$ em basquetebolistas adolescentes masculinos.

2. METODOLOGIA

2.1. Amostra

Esta investigação contou com a participação de 37 jovens jogadores de basquetebol do sexo masculino (15.3±0.6 anos, 14.0–16.3 anos). Todos os atletas são de descendência Portuguesa, com a exceção de dois deles de descendência africana. Os atletas foram classificados como Sub-16 pela *Federação Portuguesa de Basquetebol*.

No momento de realização do estudo, todos os atletas treinavam regularmente (4-6 sessões$\cdot$semana^{-1}; ~360-510 minutos$\cdot$semana^{-1}) e jogavam, normalmente, um a dois jogos por semana durante a época competitiva de 10 meses (Setembro a Junho).

Todos os participantes estavam envolvidos no processo formal de treino e competição pelo menos à dois anos (média: 6.4±2.6 anos). Os anos de prática desportiva foram obtidos por entrevista tendo sido confirmados na base de dados *on-line* da *Federação Portuguesa de Basquetebol* (FPB, 2009).

O estudo foi aprovado pela *Fundação Portuguesa para a Ciência e Tecnologia* e pelo *Conselho Científico* da *Faculdade de Ciências do Desporto e Educação Física* da *Universidade de Coimbra*. O estudo foi conduzido de acordo com padrões éticos reconhecidos internacionalmente (Harris & Atkinson, 2009).

Todos os atletas foram informados acerca da natureza voluntária de participação no estudo, podendo esta ser interrompida em qualquer momento.

2.2. Antropometria e composição corporal

Todas as medições antropométricas foram efetuadas por um único e experiente observador, seguindo procedimentos antropométricos estandardizados (Lohman, Roche, & Martorell, 1988). A estatura foi medida através de um estadiómetro portátil (Harpenden model 98.603, Holtain Ltd, Crosswell, UK), até aos 0.1 cm. A massa corporal foi medida com recurso a uma balança eletrónica interligada ao computador do pletismógrafo (Bod Pod Composition System, model Bod Pod 2006, Life Measurement, Inc., Concord, CA, USA), até aos 0.01 kg.

A avaliação da composição corporal foi realizada por pletismografia (Bod Pod Composition System, model Bod Pod 2006, Life Measurement, Inc., Concord, CA, USA). O volume corporal foi medido de acordo com os procedimentos da aplicação informática do Bod Pod (versão 3.2.5; DLL, 2.40; versão de controlo 5.90). Os procedimentos para a determinação do volume corporal por pletismografia com subsequente estimação da composição corporal são os descritos por Dempster & Aitkens (1995) e por McCrory, Gomez, Bernauer & Mole (1995). Todos os participantes, no momento da avaliação, usaram apenas roupa interior de licra e uma touca de natação tal como é recomendado pelo fabricante. Protocolarmente, solicitou-se ao participante que se mantivesse sentado e imóvel dentro da câmara. O participante foi ainda informando da necessidade da normalização dos movimentos respiratórios. Este procedimento foi realizado por duas vezes consecutivas a fim de encontrar uma consistência de resultados que não fosse variável em mais de 150 mL. Se fossem necessárias mais de três avaliações, o Bod Pod era recalibrado e eram efetuadas mais duas a três avaliações. O volume de gás torácico foi calculado pela própria aplicação do dispositivo, com base na estatura, idade e sexo. A densidade corporal (massa corporal/volume corporal) foi calculada para estimar a percentagem de gordura corporal utilizando as fórmulas específicas para a idade e sexo, sugeridas por Lohman (1986). A percentagem de massa gorda foi posteriormente convertida em massa gorda (MG). A massa isenta de gordura (MIG) foi obtida por subtração.

2.3. Idade e maturação

A IC foi calculada até aos 0.1 anos através da subtração da data de nascimento à data de realização do estudo. A IC, a estatura atual, a massa corporal de cada atleta e a estatura média parental, foram utilizadas para o cálculo da estatura matura predita através do protocolo Khamis–Roche (Khamis & Roche, 1994). A estatura atual de cada atleta foi posteriormente expressa como uma percentagem da estatura matura predita e utilizada como um indicador de estatuto maturacional. Um individuo que está mais próximo (ex., 94%) da estatura matura está mais avançado no estatuto maturacional do que um indivíduo que está mais afastado (ex., 89%) da estatura matura (Malina, Bouchard, & Bar-Or, 2004).

2.4. Consumo máximo de oxigénio

A determinação do $VO_{2máx}$ foi obtida através de um teste de corrida progressiva num ergómetro *treadmill* motorizado (Quasar, HP Cosmos, Germany). Os participantes iniciaram o teste a 8 $km \cdot h^{-1}$ durante 3 min com incrementos subsequentes de 2 $km \cdot h^{-1}$ a cada 3 min até aos 14 $km \cdot h^{-1}$. A intensidade do exercício aumentou-se, subsequentemente, através do incremento de inclinação do *treadmill* em 2.5% após os 12 min e a cada 3 min até à exaustão, que foi atingida em 8-12 min.

A obtenção do $VO_{2máx}$ era confirmada sempre que se verificasse dois dos seguintes critérios: exaustão volitiva; coeficiente respiratório igual ou superior a 1.10; frequência cardíaca nivelada em torno de um valor compreendido entre os 10% da frequência cardíaca máxima predita para a idade; ou um *plateau* no consumo de oxigénio, apesar do aumento da intensidade do exercício (Gore, 2000).

As concentrações de O_2 e CO_2 expirado foram medidas a cada 10 segundos utilizando um analisador de gases (MetaMax System, Cortex Biophysik GmbH, Leipzig, Germany). A calibração e as medições do ar ambiente, foram conduzidas antes de cada teste de acordo com as indicações do fabricante. A calibração do sensor de volume foi realizada antes do início de cada um dos testes. Para isso, utilizou-se uma seringa 3L (*Hans Rudolph, inc, Series 5530, Kansas city, USA*) com a qual se executaram 5 injeções de ar. No caso do volume ejetado corresponder ao medido, a calibração era aceite. Este processo era realizado duas vezes consecutivas. Os sensores de CO_2 e O_2 foram calibrados utilizando o *kit* de calibração (Cosmed, UN1956, 560L, 2200 psig, 70º F) com concentrações de CO_2 e O_2 (5% CO_2, 16% O_2, BAL. N2). A frequência cardíaca foi registada batimento a batimento durante a totalidade do teste, com um monitor *Polar* (Polar, Finland).

2.5. Tratamento estatístico

Inicialmente produziu-se a caracterização da amostra através da estatística descritiva, nomeadamente, através de parâmetros de tendência central (média) e de dispersão (desvio padrão e amplitude). Foram calculadas correlações para examinar a linearidade entre as dimensões corporais (massa corporal, MIG) e o $VO_{2máx}$ expresso em termos absolutos ($L \cdot min^{-1}$). Os modelos alométricos simples foram utilizados para examinar as relações entre as dimensões corporais e o $VO_{2máx}$:

$$Y = a \cdot X^k \cdot \varepsilon$$

[Equação 1]

em que *a* representa o valor de interceção da linha de tendência da regressão linear no eixo do Y e *k* o declive da linha de tendência da regressão linear. Os valores de *a* e *k* foram obtidos a partir de regressões lineares das transformações logarítmicas na forma de:

$$\text{Log Y} = \text{Log a} + \text{k} \cdot \text{Log X} + \text{Log } \varepsilon,$$

[Equação 2]

em que Y é a variável dependente $VO_{2máx}$ (Log $VO_{2máx}$) e X os descritores das dimensões corporais (Log massa corporal e Log MIG).

Subsequentemente, foram executadas regressões lineares múltiplas utilizando a equação com variáveis transformadas logaritmicamente, tendo por base modelos alométricos proporcionais (Nevill & Holder, 1994). Os modelos incorporam os anos de treino e, depois, anos de treino mais % de estatura matura predita, como termos exponenciais para além das dimensões morfológicas (massa corporal ou MIG):

$$VO_{2máx} = \text{descritor de tamanho corporal}^{k} \cdot \exp\,[a + b \cdot (\%\ \text{estatura matura predita}) + c \cdot (\text{anos de treino})] \cdot \varepsilon$$

[Equação 3]

Este modelo pode ser linearizado com uma transformação logarítmica, utilizando-se subsequentemente regressões lineares múltiplas para ajustar os parâmetros desconhecidos. A versão da equação anterior transformada logaritmicamente passa a:

$$\text{Log}\,(VO_{2máx}) = k \cdot \text{Log (descritor de tamanho corporal)} + a + b \cdot (\%\ \text{estatura matura predita}) + c \cdot (\text{anos de treino}) + \text{Log}\ \varepsilon$$

[Equação 4]

Os coeficientes de determinação (R^2) providenciam uma indicação da variância explicada pelas variáveis independentes em cada modelo alométrico. As correlações foram consideradas triviais ($r < 0.1$), baixas ($0.1 < r < 0.3$) moderadas ($0.3 < r < 0.5$), moderadamente elevadas ($0.5 < r < 0.7$), elevadas ($0.7 < r < 0.9$) ou quase perfeitas ($r > 0.9$) (Hopkins, 2002).

3. RESULTADOS

As características da amostra total estão sumariadas na Tabela 1. As associações entre o $VO_{2máx}$ e as variáveis de tamanho corporal (dados transformados logaritmicamente) são apresentadas na Tabela 2. Os expoentes alométricos para o tamanho corporal foram 0.649 e 0.731, respectivamente para a massa corporal e para a massa isenta de gordura.

Tabela 1. Estatística descritiva para a totalidade da amostra (*n* = 37).

	Média	Desvio Padrão	Amplitude
Idade cronológica, anos	15.3	0.6	14.0 – 16.3
Percentagem da estatura matura predita, %	97.5	2.3	90.5 – 100.9
Anos de treino, anos	6.38	2.60	2.00 – 11.00
Estatura, cm	181.7	7.6	165.5 – 195.6
Massa corporal, kg	73.3	10.3	55.8 – 98.9
Massa isenta de gordura, kg	64.0	8.5	49.8 – 85.0
Percentagem de massa gorda, %	12.5	6.8	1.7 -38.3
Consumo máximo de O_2, L/min	4.65	0.66	3.20 – 6.49

Tabela 2. Expoentes alométricos (valor de *k*) obtidos através da equação 1 para dois descritores de tamanho corporal (massa corporal e massa isenta de gordura).

Preditores	Expoente alométrico (*k*)	*95% IC*
Log – massa corporal	0.649	(0.372 - 0.926)
Log – massa isenta de gordura	0.731	(0.446 - 1.016)

Os resultados das regressões múltiplas para os modelos alométricos são apresentados nas Tabelas 3a-d. As variáveis independentes explicam entre 47.0% a 60.3% da variância (Tabela 4).

A IC não se revelou um preditor significativo nas regressões múltiplas, após se controlar para os anos de treino e para as variáveis de tamanho corporal. A percentagem de estatura matura predita revelou-se um preditor significativo quando considerada com os anos de treino e a massa corporal ou massa isenta de gordura (Modelos 2 e 4, respetivamente na Tabela 3b e Tabela 3d).

Tal como era esperado, todas as variáveis independentes que se assumiram como preditores significativos, mostraram uma associação positiva com o $VO_{2máx}$. Em todos os modelos alométricos, as variáveis de tamanho corporal mostraram-se como os preditores que explicaram maior porção de variância inter-individual.

A percentagem de variância explicada por cada descritor de tamanho corporal aumentou quando, nas regressões múltiplas, se adicionou os anos de treino e a maturação somática, como termos exponenciais.

Tabela 3a. Modelação alométrica do consumo máximo de oxigénio considerando a massa corporal e os anos de prática desportiva em basquetebolistas de 14-16 anos de idade (Modelo 1).

Predictores	Expoente alométrico	*P*	*Correlações parciais*
Log – massa corporal	0.732	0.000	0.707
Anos de treino	0.019	0.011	0.337

Tabela 3b. Modelação alométrica do consumo máximo de oxigénio considerando a massa isenta de gordura e os anos de prática desportiva em basquetebolistas de 14-16 anos de idade (Modelo 2).

Predictores	Expoente alométrico	*P*	*Correlações parciais*
Log – massa isenta de gordura	0.840	0.000	0.759
Anos de treino	0.021	0.003	0.370

Table 3c. Modelação alométrica do consumo máximo de oxigénio considerando a massa corporal, os anos de prática desportiva e maturação somática em basquetebolistas de 14-16 anos de idade (Modelo 3).

Predictores	Expoente alométrico	*P*	*Correlações parciais*
Log – massa corporal	0.578	0.000	0.558
Anos de treino	0.022	0.002	0.399
% de estatura matura predita	0.022	0.012	0.345

Table 3d. Modelação alométrica do consumo máximo de oxigénio considerando a massa isenta de gordura, os anos de prática desportiva e maturação somática em basquetebolistas de 14-16 anos de idade (Modelo 4).

Predictores	Expoente alométrico	*P*	*Correlações parciais*
Log – massa isenta de gordura	0.686	0.000	0.620
Anos de treino	0.024	0.001	0.421
% de estatura matura predita	0.020	0.015	0.314

Tabela 4. Resumo dos modelos alométricos apresentados nas Tabelas 3a-d.

	R (coeficiente da regressão múltipla)	*R^2* (variância explicada)	*R^2 ajustado* (variância explicada ajustada)
Modelo 1	0.707	50.0%	47.0%
Modelo 2	0.751	56.4%	53.8%
Modelo 3	0.767	58.9%	55.1%
Modelo 4	0.798	63.6%	60.3%

4. DISCUSSÃO

Foram examinadas as contribuições dos anos de treino na modalidade, IC, maturação somática (% de estatura matura predita), massa corporal e MIG para explicar a variância inter-individual no $VO_{2máx}$ de jovens basquetebolistas. A modelação alométrica identificou os descritores de tamanho corporal e os anos de prática como preditores significativos do $VO_{2máx}$.

A maturação biológica, os anos de prática e a massa corporal ou a MIG mostram-se preditores significativos do $VO_{2máx}$. As variáveis independentes incorporadas nos modelos alométricos, explicaram entre 47.0 a 60.3% na variância no $VO_{2máx}$, reforçando a importância das inter-relações entre massa muscular, experiência de treino acumulada e maturação biológica com a potência aeróbia, nesta amostra de basquetebolistas adolescentes.

A variação na estatura, massa corporal e MIG foi considerável (Tabela 1) e provavelmente reflete as características específicas por posição. Isto é consistente com a importância das dimensões corporais na seleção desportiva do basquetebol (Drinkwater et al., 2008). A média estatural dos jovens basquetebolistas do presente estudo situa-se no percentil 90% dos dados de referência produzidos pelo *Centers for Disease Control and Prevention* (Kuczmarski, et al., 2000). O elevado tamanho corporal reflete, em parte, as solicitações seletivas do basquetebol, bem como a tendência dos basquetebolistas serem maturacionalmente adiantados nas idades estudadas.

A avaliação pericial dos caracteres sexuais secundários (Coelho e Silva et al., 2010) e a idade esquelética de jovens basquetebolistas portugueses (Carvalho et al., 2011), já se encontra disponível na literatura.

A estatura atual expressa como uma percentagem de estatura matura predita é baseada na estatura atingida. Trata-se, assim, de um resultado que expressa a variação no *tempo* (ritmo) de crescimento. Não é um indicador de *tempo* (ritmo) por si só, como o é o pico de velocidade de crescimento (Beunen & Malina, 2008). O protocolo é útil para distinguir jovens que são altos numa dada idade porque são geneticamente altos ou pelo contrário, são altos porque estão adiantados no processo de maturação, quando comparados com os seus pares (Beunen & Malina, 2008). O método para estimar a estatura matura predita baseia-se na IC, estatura, massa corporal do atleta e a estatura média parental (Khamis & Roche, 1994).

A maioria dos dados disponíveis sobre o $VO_{2máx}$ de basquetebolistas são frequentemente expressos como uma rácio para controlar os efeitos da massa corporal. As potenciais falhas nas interpretações associadas a este tipo de aproximação estatística, já foram identificadas na literatura (Nevill et al., 1992; Tanner, 1949). Apesar de o basquetebol não ser um desporto de endurance por si só, os valores elevados das funções cardiopulmonares são frequentemente encarados como importantes na manutenção de um elevado nível de atividade física durante a totalidade do jogo (Ziv & Lidor, 2009). Adicionalmente, assume-se como fundamental na recuperação de episódios repetidos de esforço em regimes intermitentes de elevada intensidade (Castagna et al., 2007).

É espectável que os valores absolutos de $VO_{2máx}$ aumentem como função do tamanho corporal durante a infância e adolescência, estando ou não as crianças e jovens envolvidos na prática de desporto organizado ou outras atividades físicas.

Os dados longitudinais de jovens canadianos e belgas indicam que, em média, o pico de velocidade de crescimento do $VO_{2máx}$ é coincidente com o pico de velocidade em crescimento para a estatura (Geithner et al., 2004; Mirwald & Bailey, 1986).

Estudos que recorreram à modelação multinível também demonstraram um efeito significativo da maturação no $VO_{2máx}$, independente do tamanho corporal (Armstrong & Welsman, 2001; Beunen et al., 2002).

Em geral, os incrementos no $VO_{2máx}$ associados à idade parecem mediados em grande parte pelas alterações de tamanho corporal. As alterações de massa corporal e $VO_{2máx}$ podem ser ocultados pelas diferenças individuais no *timing* (momento) e *tempo* (ritmo) do processo de maturação biológica (Eisenmann, Pivarnik, & Malina, 2001).

Dado que uma parte substancial da variabilidade inter-individual nas dimensões corporais ocorre durante o desenvolvimento pubertário e o pico da velocidade de crescimento (Malina et al., 2004), é recomendada a utilização dos modelos alométricos proporcionais (Nevill & Holder, 1994).

Os procedimentos de modelação alométrica não linear mostraram-se estatisticamente apropriados para controlar as diferenças de tamanho corporal. Os modelos alométricos proporcionais obtidos através das regressões múltiplas (método *stepwise*) mostraram-se igualmente ajustados para fornecer interpretações mais plausíveis dos dados de $VO_{2máx}$.

Os expoentes alométricos obtidos através dos modelos alométricos (equação 1) confirmaram as observações prévias da literatura em que as associações entre o tamanho corporal e o $VO_{2máx}$ não são lineares (Nevill et al., 1992; Tanner, 1949; Welsman, Armstrong, Nevill, Winter, & Kirby, 1996).

Os expoentes alométricos obtidos para a massa corporal e para MIG são razoavelmente consistentes com a teoria da similaridade geométrica. Os seres humanos não são geometricamente similares (Nevill, Stewart, Olds, & Holder, 2004), e os atletas em particular possuem um desenvolvimento muscular mais robusto. Com efeito, seria de esperar a obtenção de expoentes mais elevados para o tamanho corporal, indicando um crescimento do $VO_{2máx}$ mais acentuado por unidade de massa corporal.

Em resumo, elevadas porções de variância inter-individual no $VO_{2máx}$ de jovens basquetebolistas são devidas a variações de maturação biológica, de anos de experiência desportiva e tamanho corporal. A maturação biológica e os anos de treino evidenciam uma contribuição significativa e independente, após se controlar estatisticamente para o efeito da massa corporal e MIG.

A acumulação de cargas específicas de treino parece exercer um efeito positivo e independente no desenvolvimento das vias energéticas aeróbias em fases mais tardias da adolescência. A generalização dos resultados obtidos com a presente amostra para outras populações de jovens, em geral, ou jovens atletas de outras modalidades deve ser feita com algumas reservas.

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PARTE II

MAXIMAL OXYGEN UPTAKE IN MALE ADOLESCENT BASKETBALL PLAYERS: contribution of size, maturation and training using allometric models

1. INTRODUCTION

Aerobic fitness is positively associated with recovery during repeated bouts of hig hintensity intermittent exercise and by inference, aerobic fitness is associated with an important component of basketball, specifically, the ability to recovery from and perform repeated sprints (Castagna, et al., 2007). Mean values for VO_{2max} in young basketball players are well reported in the literature (Apostolidis, Nassis, Bolatoglou, & Geladas, 2004; Castagna, Chaouachi, Rampinini, Chamari, & Impellizzeri, 2009; Castagna, Impellizzeri, Rampinini, D'Ottavio, & Manzi, 2008; Castagna, et al., 2007).

In addition, morphological characteristics play an important role in determining roles of individual players (Drinkwater, Pyne, & McKenna, 2008) and are often central to the selection process for young players (Coelho e Silva, Figueiredo, Carvalho, & Malina, 2008; Malina, 1994).

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 (Armstrong & Welsman, 2001; Beunen, et al., 2002; Geithner, et al., 2004). Training induces changes in maximal oxygen uptake (VO_{2max}) and are associated with improvements in the oxidative profile of skeletal muscle (Holloszy, Rennie, Hickson, Conlee, & Hagberg, 1977).

Maximal oxygen uptake is routinely expressed as a ratio standard (e.g., $ml.min^{-1}.kg^{-1}$), despite theoretical and statistical limitations (Nevill, Ramsbottom & Williams, 1992; Tanner, 1949). Allometric models are effective for partitioning body-size effects in physiological variables or performances (Nevill, et al., 1992). Alternate statistical models using linear regression and allometric scaling (log-linear regression) have been recommended to provide a "size-free" expression of VO_{2max} (Armstrong & Welsman, 1994; Nevill, et al., 1992).

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 (Malina, 1994).

The purpose of this study was to evaluate the contribution of chronological age (CA), biological maturity status, training experience and body dimensions characteristics to explain inter-individual variation in VO_{2max} in adolescent male basketball players.

2. METHODS

2.1. Sample

The sample included 37 male adolescent basketball players (15.3±0.6 years, 14.0 – 16.3 years). All players were of Portuguese ancestry with the exception of two who were of African ancestry. All participants were volunteers and were classified as under 16 years (U16) by the *Federação Portuguesa de Basquetebol* (Portuguese Basketball

Federation).

At the time of study, all players trained regularly (4-6 sessions . week^{-1}; ~360-510 min.week^{-1}) and typically played one or two games per week over a 10 month season (mid-September to June).

All participants had been in formal training and competition for at least two years with a mean of 6.4±2.6 years. Years of training was obtained by interview and confirmed in the online database of the *Federação Portuguesa de Basquetebol* (FPB, 2009).

The study was approved by the *Portuguese Foundation for Science and Technology* and also by the *Scientific Committee* of the *University of Coimbra* and was conducted in accordance with recognized ethical standards (Harriss & Atkinson, 2009). Participants were informed about the nature of the study and that participation was voluntary and they could withdraw from the study at any time.

2.2. Anthropometry and body composition

All measurements were taken by a single experienced observer following standard procedures (Lohman, Roche, & Martorell, 1988). Stature was measured with a portable stadiometer (Harpenden model 98.603, Holtain Ltd, Crosswell, UK) to the nearest 0.1 cm. Body mass was assessed to the nearest 0.01 kg 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 was used to estimate body volume (Bod Pod Composition System, model Bod Pod 2006, Life Measurement, Inc., Concord, CA, USA). Principles and operating procedures (versão 3.2.5; DLL, 2.40; versão de controlo 5.90) have been previously described (Dempster & Aitkens, 1995; McCrory, Gomez, Bernauer & Mole, 1995). 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 two values within 150 mL were obtained. If more than three raw body volumes were necessary, then two to three additional measurements were obtained after recalibrating the Bod Pod. Body density (body mass/body volume) was calculated and used to estimate percentage fat using the age- and sex-specific constants in Lohman (Lohman, 1986). Percentage of fat mass was in turn converted to fat mass (FM); fat-free mass (FFM) was estimated by subtraction.

2.3. Age and maturity status

CA was calculated to the nearest 0.1 year as birth date minus testing date. CA, stature and body mass of the player and midparent stature were used to predict mature (adult) stature with the Khamis–Roche protocol (Khamis & Roche, 1994). Current stature of each player was then expressed as a percentage of predicted mature stature to provide an estimate of biological maturity status. The individual who is closer (e.g., 94%) to mature stature is advanced in maturity status compared with the individual who is further (e.g., 89%) from mature stature (Malina, Bouchard, & Bar-Or, 2004).

2.4. Maximum oxygen uptake

Maximal oxygen uptake was determined using an incremental running test on a motorized treadmill (Quasar, HP Cosmos, Germany). Participants started with a 3 min at 8 km.h^{-1} with subsequent increments of 2 km.h^{-1} every 3 min until 14 km. h^{-1}. Exercise intensity was subsequently increased through increasing the treadmill elevation by 2.5% after 12 min and every 3 min until exhaustion, which was reached in 8 – 12 min.

Attainment of VO_{2max} was confirmed if the athlete met any two of the following criteria: volitional exhaustion; respiratory exchange rate equal to or greater than 1.10; heart rate reached a value within 10% of the age predicted maximal heart rate; a plateau in oxygen consumption, despite increased exercise intensity (Gore, 2000).

Expiratory O2 and CO2 concentrations and flow were measured every 10 s using a Gas analyser (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, USA). CO2 and O2 sensors were calibrated using a calibration Kit (Cosmed, UN1956, 560L, 2200 psig, 70º F) with known concentrations of CO2 and O2 (5% CO2, 16% O2, BAL. N2). HR was measured throughout exercise with a commercially available HR-monitor (Polar, Finland).

2.5. Analysis

Descriptive statistics were calculated for the total sample. Correlation coefficients were initially calculated to examine the linearity between body dimensions (body mass, FFM) and VO_{2max} expressed in absolute terms ($L.min^{-1}$). Allometric model was used to examine the relationship between body dimensions and VO_{2max}:

$$Y = a \cdot X^{k} \cdot \varepsilon$$

[Equation 1]

where *a* is the intercept of the regression line on the Y axis and *k* is the slope of the line.

Values of *a* and *k* were derived from linear regressions of the logarithmic regression transformations in the form of:

$$\text{Log } Y = \text{Log } a + k \cdot \text{Log } X + \text{Log } \varepsilon,$$

[Equation 2[

where Y was the dependent variable of VO_{2max} (Log VO_{2max}) and X are body dimensions descriptors (i.e., Log body mass and Log FFM).

Subsequently, multiple regression was conducted using the linearized equation with log-transformation of variables based on proportional allometric models (Nevill & Holder, 1994). The models incorporated training experience (in years) and training pexperience plus % of attained mature stature as exponential terms in addition to one of the morphological dimensions (body mass or FFM) as follows:

$$VO_{2max} = \text{size descriptor}^{k} \,.\, \exp\,[a + b \,.\, (\text{age or \% mature stature}) + c \,.\, (\text{training years})] \,.\, \varepsilon$$

[Equation 3[

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

$$\text{Log } (VO_{2max}) = k \,.\, \text{Log (size descriptor)} + a + b \text{ (age or \% mature stature)} + c \text{ (training years)} + \text{Log } \varepsilon$$

[Equation 4]

The coefficient of determination (R^2) provides an indication of the variance explained by the independent variables in each proportional allometric model. Correlations were considered trivial ($r < 0.1$), low ($0.1 < r < 0.3$) moderate ($0.3 < r < 0.5$), moderately high ($0.5 < r < 0.7$), high ($0.7 < r < 0.9$) or nearly perfect ($r > 0.9$) (Hopkins, 2002).

3. RESULTS

Characteristics of the total sample are summarized in Table 1. Relationships between VO_{2max} and body dimensions (log transformed data) are illustrated in Table 2. Estimates for body dimension exponents from the separate allometric models for VO_{2max} 0.649 and 0.731 respectively for body mass and fat-free mass.

Table 1. Descriptive statistics for the total sample (*n* = 37).

	Mean	Standard deviation	Range
Chronological age, yrs	15.3	0.6	14.0 – 16.3
Percentage of predicted mature stature, %	97.5	2.3	90.5 – 100.9
Years of training, yrs	6.38	2.60	2.00 – 11.00
Stature, 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 O2 consumption, L/min	4.65	0.66	3.20 – 6.49

Table 2. Allometric exponent (*k* value) to complete equation 1 for two size descriptors (body mass and fat-free mass).

Predictors	Allometric exponents (*k*)	*95% CI*
Log - body mass	0.649	(0.372 - 0.926)
Log - fat free mass	0.731	(0.446 - 1.016)

Results of the multiple regressions for allometric models are summarized in Tables 3a-d. The independent variables explained 47.0% to 60.3% of the variance (Table 4).

Chronological was not a significant predictor once training experience and body size variables were considered in the regressions. Percent of mature stature was a significant predictor with training experience and separately with body mass and FFM (Models 2 and 4, respectively in Table 3b and Table 3d).

As expected, all independent variables entering the final models had a positive association with VO2max. In all models the body size variables were the first predictors identified.

The estimated body size exponents derived from multiple regression increased the contribution each body dimensions descriptor in the models incorporating training experience and somatic maturation.

Table 3a. Allometric modeling of maximum oxygen output for body mass and years of training in 14-16 years-old basketball players (Model 1).

Predictors	Allometric exponents	*P*	*Partial correlation*
Log - body mass	0.732	0.000	0.707
Years of training	0.019	0.011	0.337

Table 3b. Allometric modeling of maximum oxygen output for fat-free mass and years of training in 14-16 years-old basketball players (Model 2).

Predictors	Allometric exponents	*P*	*Partial correlation*
Log - fat-free mass	0.840	0.000	0.759
Years of training	0.021	0.003	0.370

Table 3c. Allometric modeling of maximum oxygen output for body mass, years of training and somatic maturation in 14-16 years-old basketball players (Model 3).

Predictors	Allometric exponents	*P*	*Partial correlation*
Log – body mass	0.578	0.000	0.558
Years of training	0.022	0.002	0.399
% of predicted mature stature	0.022	0.012	0.345

Table 3d. Allometric modeling of maximum oxygen output for fat-free mass, years of training and somatic maturation in 14-16 years-old basketball players (Model 4).

Predictors	Allometric exponents	*P*	*Partial correlation*
Log – fat-free mass	0.686	0.000	0.620
Years of training	0.024	0.001	0.421
% of predicted mature stature	0.020	0.015	0.314

Table 4. Summary of allometric models presented in Tables 3a-d.

	R *(multiple regressions coefficient)*	*R^2* *(explained variance)*	*R^2 adjusted* *(adjusted explained variance)*
Modelo 1	0.707	50.0%	47.0%
Modelo 2	0.751	56.4%	53.8%
Modelo 3	0.767	58.9%	55.1%
Modelo 4	0.798	63.6%	60.3%

4. DISCUSSION

The contributions of years of sport-specific training, chronological age, somatic maturity status (percent of attained mature stature), body mass and FFM to VO2max among adolescent basketball players were evaluated. The allometric models identified body dimensions and training experience as significant predictors of VO2max.

Biological maturation, training experience and either body mass or FFM were among significant predictors of VO2max. The independent variables incorporated in the allometric models explained between 47.0% and 60.3% of variance in VO2max, emphasizing the importance of the inter-relationships among muscle mass, accumulated training experience and biological maturation to maximal aerobic performance in this sample of late adolescent basketball players.

Variation in stature, body mass and fat free mass was considerable (Table 1) and probably reflected position-specific characteristics, consistent with the importance of body dimensions in basketball selection (Drinkwater, et al., 2008). Mean statures and body masses of the basketball players approximated agespecific 90th percentiles for U.S. reference males (Kuczmarski, et al., 2000). The larger size reflected in part the selective demands of basketball and also advanced maturity status.

Pubertal status assessed by stages of pubic hair (Coelho e Silva, et al., 2010) and skeletal age in Portuguese youth basketball players (Carvalho, et al., 2011) were already available in the literature.

Current stature expressed as a percentage of predicted mature stature is based on size attained and is the result of variation in tempo of growth; it is not an indicator of tempo per se as is age at peak height velocity (Beunen & Malina, 2008). 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 to peers (Beunen & Malina, 2008). The method for predicting mature stature was based on current CA, stature and body mass of the player and midparent stature (Khamis & Roche, 1994).

Most available data for VO2max in basketball are reported as ratio standards to control for the effects of body mass. Potential misinterpretations associated with this approach have been noted (Nevill, et al., 1992; Tanner, 1949). Although basketball is not an endurance sport per se, the high values for cardiopulmonary functions are often viewed as important for the maintenance of a high level of activity during an entire game (Ziv & Lidor, 2009) and for effective recovery from high-intensity, short bursts of movement (Castagna, et al., 2007).

It is expected that absolute VO2max increases as a function of body size during childhood and adolescence, whether or not youth are engaged in organized sports and other physical activities.

Longitudinal data based on Canadian and Belgian boys indicated, on average, coincident occurrence of peak velocity of growth in stature and VO2max (Geithner, et al., 2004; Mirwald & Bailey, 1986).

Studies using multilevel modeling also demonstrated a size-independent effect of biological maturation on VO2max (Armstrong & Welsman, 2001; Beunen, et al., 2002).

In general, age-related increases in VO2max appeared to be mediated largely by changes in size dimensions. Changes in body mass and VO2max may be masked by individual differences in the timing and tempo of biological maturation (Eisenmann, Pivarnik, & Malina, 2001).

Although interest in the development of VO2max in youth is considerable, few studies have addressed the topic in children and adolescents engaged in highly structured training regimens. A substantial part of the current sample was recruited for the Portuguese national training centre. Since important inter-individual variability in body dimensions occurs during pubertal development and growth spurt (Malina, et al., 2004), proportional allometric models (Nevill & Holder, 1994) were recommended.

The non-linear allometric modeling procedures were statistically appropriate to account for differences in body size. The proportional allometric models derived from stepwise regressions were adjusted to fit the VO2max data.

The size exponents derived from the allometric model (equation 1) confirmed observation in the literature that the relationship between body dimensions and VO2max is not proportional (Nevill, et al., 1992; Tanner, 1949; Welsman, Armstrong, Nevill, Winter, & Kirby, 1996).

Exponents derived from the models for body mass and FFM were reasonably consistent with the theory of geometrical similarity. Humans are not geometrically similar (Nevill, Stewart, Olds, & Holder, 2004), and athletes in particular have greater muscular development. It might be expected, therefore, to have inflated size exponents indicating greater growth in VO2 per body mass.

In summary, large portions of the variance in VO2max of adolescent basketball players is accounted for by biological maturation, years of training experience and body size. Biological maturation and training experience had a relative contribution via body mass and FFM, but interestingly, an independent positive relationship with aerobic performance.

The accumulation of basketball-specific training loads through the years appears to have a positive independent effect on the development of aerobic energy pathways in late adolescence. Generalizations from the present sample to other youth populations in general and to youth participants in other sports should be made with caution.

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ANEXO 1: BASE DE DADOS (variáveis pessoais e desportivas)

Nord	Study	birth_d	birth_m	birth_y	observ_d	observ_m	observ_y	CA
2010101	2	14	7	1995	11	5	2010	14.8
2010102	2	24	2	1995	11	5	2010	15.2
2010103	2	18	4	1995	11	5	2010	15.1
2010104	2	13	6	1995	11	5	2010	14.9
2010105	2	1	4	1996	11	5	2010	14.1
2010106	2	7	5	1996	11	5	2010	14.0
2010107	2	14	8	1995	11	5	2010	14.7
2010108	2	13	8	1995	11	5	2010	14.7
2010109	2	19	4	1995	11	5	2010	15.1
2010110	2	26	2	1995	11	5	2010	15.2
2010111	2	8	2	1995	11	5	2010	15.3
2010112	2	17	10	1995	11	5	2010	14.6
2010201	2	21	2	1994	5	5	2010	16.2
2010202	2	5	7	1994	5	5	2010	15.8
2010203	2	24	10	1994	5	5	2010	15.5
2010204	2	13	1	1994	5	5	2010	16.3
2010205	2	24	6	1994	5	5	2010	15.9
2010206	2	12	4	1994	5	5	2010	16.1
2010207	2	2	8	1994	5	5	2010	15.8
2010208	2	3	3	1994	5	5	2010	16.2
2010209	2	28	4	1994	5	5	2010	16.0
2010210	2	2	3	1995	5	5	2010	15.2
2010211	2	11	1	1994	5	5	2010	16.3
2010212	2	18	3	1994	5	5	2010	16.1
20110402	2	21	5	1995	22	12	2010	15.6
20110501	2	24	4	1996	3	5	2011	15.0
20110502	2	3	8	1995	3	5	2011	15.7
20110503	2	13	8	1996	3	5	2011	14.7
20110504	2	18	5	1996	3	5	2011	15.0
20110507	2	28	12	1996	3	5	2011	14.3
20110508	2	7	8	1996	3	5	2011	14.7
20110509	2	8	10	1996	3	5	2011	14.6
20110510	2	4	4	1995	3	5	2011	16.1
20110512	2	18	11	1995	3	5	2011	15.5
20110515	2	6	7	1995	21	5	2011	15.9
20110517	2	9	1	1996	21	5	2011	15.4
20110518	2	12	1	1996	21	5	2011	15.4
mínimo								14.01
máximo								16.32
media								15.32
desvio padrão								0.64

Nord	club_a	club_n	level_12_a	yers_training
2010101	CTPP	1	seleccao nacional	3
2010102	CTPP	1	seleccao nacional	5
2010103	CTPP	1	seleccao nacional	9
2010104	CTPP	1	seleccao nacional	9
2010105	CTPP	1	seleccao nacional	3
2010106	CTPP	1	seleccao nacional	8
2010107	CTPP	1	seleccao nacional	8
2010108	CTPP	1	seleccao nacional	8
2010109	CTPP	1	seleccao nacional	10
2010110	CTPP	1	seleccao nacional	5
2010111	CTPP	1	seleccao nacional	9
2010112	CTPP	1	seleccao nacional	9
2010201	CTP	2	seleccao nacional	4
2010202	CTP	2	seleccao nacional	6
2010203	CTP	2	seleccao nacional	11
2010204	CTP	2	seleccao nacional	8
2010205	CTP	2	seleccao nacional	9
2010206	CTP	2	seleccao nacional	8
2010207	CTP	2	seleccao nacional	5
2010208	CTP	2	seleccao nacional	6
2010209	CTP	2	seleccao nacional	6
2010210	CTP	2	seleccao nacional	3
2010211	CTP	2	seleccao nacional	10
2010212	CTP	2	seleccao nacional	4
20110402	AAC	3	selecção distrital	8
20110501	AAC	3	local	8
20110502	AAC	3	selecção distrital	2
20110503	AAC	3	local	8
20110504	AAC	3	local	2
20110507	AAC	3	local	8
20110508	AAC	3	local	7
20110509	AAC	3	local	7
20110510	AAC	3	local	4
20110512	AAC	3	selecção distrital	5
20110515	AAC	3	local	2
20110517	AAC	3	local	2
20110518	AAC	3	local	7
mínimo				2.00
máximo				11.00
media				6.38
desvio padrão				2.60

Nord	Estimated_mature_h_cm	Percent_attained_estimated_mature_h
2010101	198.7	98.5
2010102	178.9	99.6
2010103	188.2	96.6
2010104	189.7	95.4
2010105	194.1	100.2
2010106	194.3	90.5
2010107	178.6	95.8
2010108	185.0	97.0
2010109	189.5	96.9
2010110	189.6	98.2
2010111	193.4	96.8
2010112	178.1	96.7
2010201	191.9	98.3
2010202	196.7	98.9
2010203	183.4	99.3
2010204	180.4	98.9
2010205	187.7	98.4
2010206	185.5	100.5
2010207	192.1	98.8
2010208	184.7	100.6
2010209	189.8	100.7
2010210	198.8	97.1
2010211	181.1	99.5
2010212	187.2	98.7
20110402	183.5	96.0
20110501	175.0	97.3
20110502	182.28	97.10
20110503	184.0	95.1
20110504	178.41	96.24
20110507	179.77	93.56
20110508	186.43	96.50
20110509	178.10	92.92
20110510	190.0	97.6
20110512	188.39	94.22
20110515	184.12	100.75
20110517	183.64	100.85
20110518	181.7	97.54
mínimo	175.0	90.5
máximo	198.8	100.9
media	186.3	97.5
desvio padrão	6.1	2.3

Nord	w	h	sth	BP_FM_perc	BP_FFM_perc	BP_FM_kg	BP_FFM_kg
2010101	90.7	195.6	98.3	6.3	93.7	5.7	85.0
2010102	66.0	178.2	93.2	8.9	91.1	5.6	60.4
2010103	75.8	181.8	95.6	18.3	81.7	13.8	62.0
2010104	75.7	181.0	94.3	14.6	85.4	10.9	64.8
2010105	98.9	194.4	93.4	22.9	77.1	22.6	76.3
2010106	62.6	175.9	89.6	4.8	95.2	2.4	60.2
2010107	62.8	171.2	89.0	12.3	87.7	7.9	54.9
2010108	80.5	179.5	95.1	11.3	88.7	9.3	71.2
2010109	72.7	183.7	94.1	7.3	92.7	5.3	67.4
2010110	72.8	186.1	94.6	13.3	86.7	10.1	62.7
2010111	80.4	187.2	96.8	20.3	79.7	16.5	63.9
2010112	68.8	172.2	89.0	11.1	88.9	7.9	60.9
2010201	78.5	188.6	96.1	7.5	92.5	6.0	72.5
2010202	67.5	194.6	94.7	9.6	90.4	6.3	61.2
2010203	67.9	182.1	91.3	11.1	88.9	7.8	60.1
2010204	72.6	178.5	91.2	14.7	85.3	10.6	62.0
2010205	73.9	184.7	95.7	8.0	92.0	5.5	68.4
2010206	82.7	186.4	95.4	7.9	92.1	6.1	76.6
2010207	91.6	189.8	95.6	15.6	84.4	14.0	77.6
2010208	74.6	185.9	95.1	10.5	89.5	7.9	66.7
2010209	81.0	191.1	97.9	10.6	89.4	8.8	72.2
2010210	84.2	193.1	99.6	5.8	94.2	4.2	80.0
2010211	71.1	180.3	94.0	13.6	86.4	9.5	61.6
2010212	87.8	184.7	93.6	18.0	82.0	16.0	71.8
20110402	59.4	176.2	91.4	4.2	95.8	1.5	57.911
20110501	55.8	170.3	90.5	10.2	89.8	6.0	49.817
20110502	66.8	177	90.1	1.7	98.3	1.4	65.366
20110503	62.3	175.0	92.6	8.2	91.8	5.9	56.44
20110504	56.5	171.7	94.6	9.8	90.2	5.7	50.845
20110507	83	168.2	89	38.3	61.7	31.9	51.105
20110508	72.8	179.9	93.9	13.2	86.8	9.7	63.09
20110509	58.8	165.5	84.4	11.7	88.3	7.0	51.835
20110510	77.4	185.5	94.1	11.9	88.1	9.3	68.079
20110512	58.8	177.5	89.7	7.8	92.2	4.8	54.021
20110515	77.4	185.5	91.4	25.3	74.7	15.7	61.693
20110517	76.9	185.2	97	19.7	80.3	15.6	61.259
20110518	66.9	177.2	92.1	15.1	84.9	10.4	56.53
mínimo	55.8	165.5	84.4	1.7	61.7	1.4	49.8
máximo	98.9	195.6	99.6	38.3	98.3	31.9	85.0
media	73.3	181.7	93.4	12.5	87.5	9.3	64.0
desvio padrão	10.3	7.6	3.1	6.8	6.8	5.9	8.5

Nord	VO2_L_min	Ln_w	Ln_BP_FFM_kg	Ln_VO2_L_min
2010101	5.16	4.508	4.442	1.641
2010102	4.59	4.190	4.101	1.524
2010103	4.90	4.328	4.127	1.589
2010104	4.61	4.327	4.171	1.528
2010105	4.82	4.594	4.335	1.573
2010106	4.33	4.137	4.097	1.466
2010107	4.24	4.140	4.005	1.445
2010108	5.01	4.388	4.265	1.611
2010109	4.89	4.286	4.210	1.587
2010110	5.06	4.288	4.138	1.621
2010111	5.38	4.387	4.157	1.683
2010112	4.64	4.231	4.109	1.535
2010201	5.03	4.363	4.284	1.615
2010202	4.41	4.212	4.115	1.484
2010203	5.33	4.218	4.096	1.673
2010204	4.42	4.285	4.127	1.486
2010205	5.32	4.303	4.226	1.671
2010206	4.97	4.415	4.339	1.603
2010207	6.49	4.517	4.351	1.870
2010208	5.12	4.312	4.200	1.633
2010209	5.37	4.394	4.279	1.681
2010210	5.25	4.433	4.382	1.658
2010211	5.34	4.264	4.121	1.675
2010212	5.35	4.475	4.274	1.677
20110402	3.72	4.084	4.059	1.314
20110501	4.28	4.022	3.908	1.454
20110502	3.79	4.202	4.180	1.332
20110503	4.03	4.132	4.033	1.394
20110504	3.2	4.034	3.929	1.163
20110507	3.77	4.419	3.934	1.327
20110508	4.27	4.288	4.145	1.452
20110509	3.92	4.074	3.948	1.366
20110510	3.49	4.349	4.221	1.250
20110512	3.95	4.074	3.989	1.374
20110515	4.67	4.349	4.122	1.541
20110517	4.51	4.343	4.115	1.506
20110518	4.32	4.203	4.035	1.463
mínimo	3.20	4.022	3.908	1.163
máximo	6.49	4.594	4.442	1.870
media	4.65	4.286	4.151	1.526
desvio padrão	0.66	0.141	0.132	0.146

Notes

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	Cases Used	All non-missing data are used.
Syntax		DESCRIPTIVES VARIABLES=CA Percent_attained_estimated_mature_h yers_training h w BP_FFM_kg BP_FM_perc VO2_L_min /STATISTICS=MEAN STDDEV MIN MAX.
Resources	Processor Time	00:00:00,032
	Elapsed Time	00:00:00,047

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
CA	37	14,0	16,3	15,323	,6365
Percent_attained_estimated_mature_h	37	90,5	100,9	97,507	2,3318
yers_training	37	2	11	6,38	2,596
h	37	165,5	195,6	181,657	7,6047
w	37	55,8	98,9	73,349	10,3109
BP_FFM_kg	37	49,8	85,0	64,009	8,5167
BP_FM_perc	37	1,7	38,3	12,470	6,7747
VO2_L_min	37	3,20	6,49	4,6473	,66415
Valid N (listwise)	37				

Notes

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	Cases Used	Statistics are based on cases with no missing values for any variable used.
Syntax		

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REGRESSION
  /MISSING LISTWISE
  /STATISTICS COEFF OUTS CI(95) R ANOVA
  /CRITERIA=PIN(.05) POUT(.10)
  /NOORIGIN
  /DEPENDENT Ln_VO2_L_min
  /METHOD=ENTER Ln_w.
```

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Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,627[a]	,393	,376	,115

a. Predictors: (Constant), Ln_w

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	,300	1	,300	22,656	,000[a]
	Residual	,463	35	,013		
	Total	,763	36			

a. Predictors: (Constant), Ln_w

b. Dependent Variable: Ln_VO2_L_min

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-1,256	,585		-2,148	,039
	Ln_w	,649	,136	,627	4,760	,000

a. Dependent Variable: Ln_VO2_L_min

Coefficients[a]

Model		95,0% Confidence Interval for B	
		Lower Bound	Upper Bound
1	(Constant)	-2,444	-,069
	Ln_w	,372	,926

a. Dependent Variable: Ln_VO2_L_min

Notes

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Missing Value Handling	Definition of Missing	User-defined missing values are treated as missing.
	Cases Used	Statistics are based on cases with no missing values for any variable used.
Syntax		

```
REGRESSION
  /MISSING LISTWISE
  /STATISTICS COEFF OUTS CI(95) R ANOVA
  /CRITERIA=PIN(.05) POUT(.10)
  /NOORIGIN
  /DEPENDENT Ln_VO2_L_min
  /METHOD=ENTER Ln_BP_FFM_kg.
```

Resources	Processor Time	00:00:00,031
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	Additional Memory Required for Residual Plots	0 bytes

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,661[a]	,437	,421	,111

a. Predictors: (Constant), Ln_BP_FFM_kg

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	,333	1	,333	27,148	,000[a]
	Residual	,430	35	,012		
	Total	,763	36			

a. Predictors: (Constant), Ln_BP_FFM_kg

b. Dependent Variable: Ln_VO2_L_min

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-1,509	,583		-2,589	,014
	Ln_BP_FFM_kg	,731	,140	,661	5,210	,000

a. Dependent Variable: Ln_VO2_L_min

Coefficients[a]

Model		95,0% Confidence Interval for B	
		Lower Bound	Upper Bound
1	(Constant)	-2,692	-,326
	Ln_BP_FFM_kg	,446	1,016

a. Dependent Variable: Ln_VO2_L_min

Notes

Output Created		16-Mai-2013 10:23:54
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	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	37
Missing Value Handling	Definition of Missing	User-defined missing values are treated as missing.
	Cases Used	Statistics are based on cases with no missing values for any variable used.

Syntax

```
REGRESSION
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   /NOORIGIN
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Model Summary

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1	,707[a]	,500	,470	,106

a. Predictors: (Constant), yers_training, Ln_w

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	,381	2	,191	16,984	,000[a]
	Residual	,382	34	,011		
	Total	,763	36			

a. Predictors: (Constant), yers_training, Ln_w

b. Dependent Variable: Ln_VO2_L_min

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-1,732	,567		-3,056	,004
	Ln_w	,732	,129	,707	5,661	,000
	yers_training	,019	,007	,337	2,694	,011

a. Dependent Variable: Ln_VO2_L_min

Coefficients[a]

Model		95,0% Confidence Interval for B	
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1	(Constant)	-2,885	-,580
	Ln_w	,469	,995
	yers_training	,005	,033

a. Dependent Variable: Ln_VO2_L_min

Notes

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Syntax

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Model Summary

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1	,751[a]	,564	,538	,099

a. Predictors: (Constant), yers_training, Ln_BP_FFM_kg

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	,430	2	,215	21,986	,000[a]
	Residual	,333	34	,010		
	Total	,763	36			

a. Predictors: (Constant), yers_training, Ln_BP_FFM_kg

b. Dependent Variable: Ln_VO2_L_min

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-2,092	,552		-3,788	,001
	Ln_BP_FFM_kg	,840	,130	,759	6,463	,000
	yers_training	,021	,007	,370	3,148	,003

a. Dependent Variable: Ln_VO2_L_min

Coefficients[a]

Model		95,0% Confidence Interval for B	
		Lower Bound	Upper Bound
1	(Constant)	-3,215	-,970
	Ln_BP_FFM_kg	,576	1,104
	yers_training	,007	,034

a. Dependent Variable: Ln_VO2_L_min

Notes

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Model Summary

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1	,767[a]	,589	,551	,098

a. Predictors: (Constant), Percent_attained_estimated_mature_h, yers_training, Ln_w

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	,449	3	,150	15,739	,000[a]
	Residual	,314	33	,010		
	Total	,763	36			

a. Predictors: (Constant), Percent_attained_estimated_mature_h, yers_training, Ln_w

b. Dependent Variable: Ln_VO2_L_min

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-3,196	,757		-4,223	,000
	Ln_w	,578	,132	,558	4,368	,000
	yers_training	,022	,007	,399	3,399	,002
	Percent_attained_estimated_mature_h	,022	,008	,345	2,670	,012

a. Dependent Variable: Ln_VO2_L_min

Coefficients[a]

Model		95,0% Confidence Interval for B	
		Lower Bound	Upper Bound
1	(Constant)	-4,736	-1,656
	Ln_w	,309	,847
	yers_training	,009	,036
	Percent_attained_estimated_mature_h	,005	,038

a. Dependent Variable: Ln_VO2_L_min

Notes

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Missing Value Handling	Definition of Missing	User-defined missing values are treated as missing.
	Cases Used	Statistics are based on cases with no missing values for any variable used.

Syntax

```
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   /CRITERIA=PIN(.05) POUT(.10)
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   /DEPENDENT Ln_VO2_L_min
   /METHOD=ENTER Ln_BP_FFM_kg yers_training
Percent_attained_estimated_mature_h.
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Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,798[a]	,636	,603	,0917

a. Predictors: (Constant), Percent_attained_estimated_mature_h, yers_training, Ln_w

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	,485	3	,162	19,258	,000[a]
	Residual	,277	33	,008		
	Total	,763	36			

a. Predictors: (Constant), Percent_attained_estimated_mature_h, yers_training, Ln_BP_FFM_kg

b. Dependent Variable: Ln_VO2_L_min

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-3,380	,717		-4,715	,000
	Ln_BP_FFM_kg	,686	,135	,620	5,092	,000
	yers_training	,024	,006	,421	3,807	,001
	Percent_attained_estimated_mature_h	,020	,008	,314	2,566	,015

a. Dependent Variable: Ln_VO2_L_min

Coefficients[a]

Model		95,0% Confidence Interval for B	
		Lower Bound	Upper Bound
1	(Constant)	-4,839	-1,922
	Ln_BP_FFM_kg	,412	,960
	yers_training	,011	,036
	Percent_attained_estimated_mature_h	,004	,035

a. Dependent Variable: Ln_VO2_L_min

ANEXO 3:
PARECER DE ACEITAÇÃO DE ORIENTAÇÃO

Produzido e assinado por:

Humberto Jorge Gonçalves Moreira

e

Manuel João Cerdeira Coelho e Silva

Data:

04/10/2011

PARECER

ORIENTAÇÃO DE TESE DE MESTRADO

Os abaixo assinados assumem a responsabilidade de orientação do PROJECTO de dissertação que o Licenciado Hector José Almeida Carvalho apresentou sob o título provisório "Consumo máximo de oxigénio em jogadores de basquetebol masculino adolescente: contribuições de tamanho, maturação e treino usando alometria", no âmbito do curso de Mestrado de Treino Desportivo para Crianças e Jovens.

O projecto apresenta um formato de artigo científico, tendo a introdução e metodologia aprovadas, encontrando-se em estado adiantado de recolha de dados e análise de dados .

Coimbra, 4 de Outubro de 2011

Humberto Jorge Gonçalves Moreira de Carvalho

Manuel João Coelho e Silva

Manuel João Cerdeira Coelho e Silva

ANEXO 4:
VERSÃO SUBMETIDA AO "JOURNAL OF SPORTS SCIENCES"

Criação na plataforma (http://mc.manuscriptcentral.com/rjsp):
20/07/2011

Submissão:
06/08/2011

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Contact author:
Humberto Carvalho

Autores:
Humberto Carvalho, Manuel J Coelho-e-Silva, Hector Carvalho, Fátima Rosado, Joey C Eisenmann, Robert M Malina

Maximal oxygen uptake in male adolescent basketball players: contributions of maturation, size and training using allometry

Journal:	*Journal of Sports Sciences*
Manuscript ID:	RJSP-2011-0475
Manuscript Type:	Original Manuscript
Keywords:	percentage of mature stature, youth sports, allometric scaling, young athletes

Title: Maximal oxygen uptake in male adolescent basketball players: contributions of maturation, size and training using allometry

Running head: Aerobic performance, maturation and allometry

ABSTRACT

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

KEYWORDS: percentage of mature stature, youth sports, allometric scaling, young athletes

INTRODUCTION

Many activities in basketball are performed at near maximal intensities and tax anaerobic capacities (McInnes, Carlson, Jones, & McKenna, 1995). However, most game-related activities are of low (~40%) and medium (50%) intensities, and along with recovery are accomplished via aerobic energy pathways (Stone & Kilding, 2009). Aerobic fitness is positively associated with recovery during repeated bouts of high-intensity intermittent exercise; by inference, aerobic fitness is associated with an important component of basketball, specifically, the ability to recovery from and perform repeated sprints (Castagna, et al., 2007). In addition, morphological characteristics play an important role in determining roles of individual players (Drinkwater, Pyne, & McKenna, 2008) and are often central to the selection process for young players (Coelho e Silva, Figueiredo, Carvalho, & Malina, 2008; Malina, 1994). Nevertheless, inter-individual variability in functional and morphological characteristics is considerable among youth (Carvalho, et al., 2011; Hoare, 2000) and adult (Ziv & Lidor, 2009) basketball players.

Aerobic fitness requires integration of pulmonary, cardiovascular, and hematological components of oxygen delivery and oxidative mechanisms of the exercising muscle (Armstrong & Welsman, 1994; Stone & Kilding, 2009). Training-induced changes in maximal oxygen uptake (VO_{2max}) are associated with improving the oxidative profile of skeletal muscle (Holloszy, Rennie, Hickson, Conlee, & Hagberg, 1977). An important factor in the interpretation of VO_{2max} is the influence of body dimensions, in particular fat-free mass which is often considered a surrogate for skeletal muscle mass.

Maximal oxygen uptake is routinely expressed as a ratio standard (e.g., ml·min^{-1}·kg^{-1}), despite theoretical and statistical limitations (Nevill, Ramsbottom, & Williams, 1992; Tanner, 1949). Accordingly, mean values for VO_{2max} in young basketball players 13-18 years range from 52 ml·min^{-1}·kg^{-1} to 60 ml·min^{-1}·kg^{-1} (Apostolidis, Nassis, Bolatoglou, & Geladas, 2004; Bogdanis, Ziagos, Anastasiadis, & Maridaki, 2007; Castagna, Chaouachi, Rampinini, Chamari, & Impellizzeri, 2009; Castagna, Impellizzeri, Rampinini, D'Ottavio, & Manzi, 2008; Castagna, et al., 2007). Allometric models are effective for partitioning body-size effects in physiological variables or performances, in particular VO_{2max} (Nevill, et al., 1992). Alternate statistical models using linear regression and allometric scaling (log-linear regression) have been recommended to provide a "size-free" expression of VO_{2max} (Armstrong & Welsman, 1994; Nevill, et al., 1992).

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 (Armstrong & Welsman, 2001; Beunen, et al., 2002; Geithner, et al., 2004; Mirwald & Bailey, 1986; Nevill, Holder, Baxter-Jones, Round, & Jones, 1998). On the other hand, intensive training programs and high level competitions are experienced by many young athletes (Pearson, Naughton, & Torode, 2006). 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 (Malina, 1994). In addition to confounding effects of body dimensions VO_{2max}, the potential influence of inter-individual differences in the timing and tempo of biological maturation on physiological performance of adolescents, both athletes and non-athletes, needs consideration. In this context, the purpose of this study was to evaluate the extent chronological age (CA), biological maturity status, training experience and body dimensions characteristics account for the inter-individual variation in VO_{2max} in adolescent male basketball players. Given the trend towards intensive training in youth sports at relatively young ages, examining the relationships between CA, morphology, maturation and training and VO_{2max} 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 years, 14.0 – 16.3). All players were of Portuguese ancestry with the exception of two who were of African ancestry. All participants were volunteers and were classified as under 16 years (U16) by the *Federação Portuguesa de Basquetebol* (Portuguese Basketball Federation). The players were classified by their coaches as: guards (n = 13), forwards (n = 14) and centers (n = 10). At the time of study, all players trained regularly (4-6 sessions·week^{-1}; ~360-510 min·week^{-1}) and typically played one or two games per week over a 10 month season (mid-September to June). All participants had been in formal training and competition for at least two years with a mean of 6.4±2.6 years. Years of training was obtained by interview and confirmed in the online database of the *Federação Portuguesa de Basquetebol* (FPB, 2009).

The study was approved by the *Portuguese Foundation for Science and Technology* and also by the *Scientific Committee* of the *University of Coimbra* and was conducted in accordance with recognized ethical standards (Harriss & Atkinson, 2009). 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 following standard procedures (Lohman, Roche, & Martorell, 1988). Stature was measured with a portable stadiometer (Harpenden model 98.603, Holtain Ltd, Crosswell, UK) to the nearest 0.1 cm. Eighteen players were measured twice within one week; the intra-observer technical error of measurement was 0.54 cm and within the range reported for intra- and inter-observer errors for a variety of studies (Malina, 1995). Body mass was assessed to the nearest 0.01 kg 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 (Dempster & Aitkens, 1995; McCrory, Gomez, Bernauer, & Mole, 1995). Principles underlying the Bod Pod and operating procedures have been previously described (Dempster & Aitkens, 1995). The unit was calibrated using a two-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 two values within 150 mL were obtained. If more than three raw body volumes were necessary, then two to three 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 in Lohman (Lohman, 1986). % 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, stature and body mass of the player and midparent stature were used to predict mature (adult) stature with the Khamis–Roche protocol (Khamis & Roche, 1994). Current stature of each player was then expressed as a percentage of predicted mature stature to provide an estimate of biological maturity status. The individual who is closer (e.g., 94%) to mature stature is advanced in maturity status compared with the individual who is further (e.g., 89%) from mature stature (Malina, Bouchard, & Bar-Or, 2004).

Maximum oxygen uptake

Maximal oxygen uptake was determined using an incremental running test on a motorized treadmill (Quasar, HP Cosmos, Germany). Participants started with a 3 min at 8 $km \cdot h^{-1}$ with subsequent increments of 2 $km \cdot h^{-1}$ every 3 min until 14 $km \cdot h^{-1}$. Exercise intensity was subsequently increased through increasing the treadmill elevation by 2.5% after 12 min and every 3 min until exhaustion, which was reached in 8 – 12 min. Attainment of VO_{2max} was confirmed if the athlete met any two of the following criteria: volitional exhaustion; respiratory exchange rate equal to or greater than 1.10;

heart rate reached a value within 10% of the age predicted maximal heart rate; and a plateau in oxygen consumption, despite increased exercise intensity (Gore, 2000). Expiratory O_2 and CO_2 concentrations and flow were measured every 10 s using a Gas analyser (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, USA). CO_2 and O_2 sensors were calibrated using a calibration Kit (Cosmed, UN1956, 560L, 2200 psig, 70º F) with known concentrations of CO_2 and O_2 (5% CO_2, 16% O_2, BAL. N_2). HR was measured throughout exercise with a commercially available HR-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 (stature, body mass, FFM) and VO_{2max} expressed in absolute terms ($L \cdot min^{-1}$). An initial allometric model was used to examine the relationship between body dimensions and VO_{2max}:

$$Y = a \cdot X^k \cdot \varepsilon$$

(Equation 1)

where *a* is the intercept of the regression line on the Y axis and *k* is the slope of the line. Values of *a* and *k* were derived from linear regressions of the logarithmic regression transformations in the form of:

$$\text{Log } Y = \text{Log } a + k \cdot \text{Log } X + \text{Log } \varepsilon,$$

(Equation 2)

where Y was the dependent variable of VO_{2max} (natural logarithms, i.e., Log VO_{2max}) and body dimensions descriptors (i.e., Log stature, Log body mass and Log FFM).

Subsequently, multiple stepwise regression was conducted using the linearized equation with log-transformation of variables based on proportional allometric models (Nevill & Holder, 1994). The models incorporated CA or percentage of predicted mature stature and years of training experience as exponential terms in addition to one of the morphological dimensions (stature, body mass or FFM) as follows:

$$VO_{2max} = \text{size descriptor}^{k1} \cdot \exp\,[a + b \cdot (\text{age or \% mature stature}) + c \cdot (\text{years of training})] \cdot \varepsilon$$

(Equation 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:

$$\text{Log } (VO_{2max}) = k_1 \cdot \text{Log (size descriptor)} + a + b \cdot (\text{age or \% mature stature}) + c \cdot (\text{years of training}) + \text{Log } \varepsilon$$

(Equation 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's product-moment correlations to check the assumptions of scaled VO_{2max} 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 as not been completely successful in rendering VO_{2max} independent of CA or biological maturation, training experience and body dimensions (Nevill, et al., 1992). The coefficient of determination (R^2) provides an indication of the variance explained by the independent variables in each proportional allometric model. Correlations were considered trivial ($r < 0.1$), low ($0.1 < r < 0.3$) moderate ($0.3 < r < 0.5$), moderately high ($0.5 < r < 0.7$), high ($0.7 < r < 0.9$) or nearly perfect ($r > 0.9$) (Hopkins, 2002). 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 stature attained at the time of study (15.3±0.6 yrs) was 97.5±2.3%. The estimate was in advance of that for the sample upon which the stature prediction protocol was developed, 96.0±1.3% at 15.0 years (participants were measured within one month of their birthdays) (Roche et al., 1983). By inference, the sample of basketball players was somewhat advanced in biological maturity status for CA. Mean stature and body mass approximated age-specific 90th percentiles of the U.S. reference for males (Kuczmarski, et al., 2000).

[Table 1 near here]

Relationships between VO_{2max} and body dimensions (log transformed data) are illustrated in Figure 1. Estimates for body dimension exponents (95% CI) from the separate allometric models for VO_{2max} were, respectively: stature 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 between 39% and 44% of variance in the VO_{2max}. 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_{2max} "size free scores" for each of the size variables. However, substantial residual size correlations were apparent when residuals were correlated with other size variables (e.g., residuals of VO_{2max} modelled for stature against body mass). The correlations ($0.10 < r < 0.23$) indicated that the stature, body mass or FFM individually did not completely partition out the influence of body dimensions in VO_{2max}.

[Figure 1 near here]

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_{2max}. 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, percent of mature stature was a significant predictor with training experience and separately with body mass and FFM (Models 5 and 6, $p \leq 0.01$), but not with stature (Model 4).

As expected, all independent variables entering the final models had a positive association with VO_{2max}. In all models the body size variables were the first predictors identified. Introduction of training experience as significant predictor ($p \leq 0.01$) in the models contributed 11% to 16% to the explained variance. For the final models, the explained variance added by percentage of adult stature as significant predictor ($p \leq 0.01$) 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 each body dimensions descriptor in the models incorporating chronological age 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 stature.

[Table 2 near here]

DISCUSSION

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

The growth characteristics of this sample of Portuguese adolescent basketball players were consistent with other reports for young male basketball players (Carvalho, et al., 2011; Hoare, 2000). Variation in body dimensions was considerable (Table 1) and probably reflected position-specific characteristics, consistent with the importance of body dimensions in basketball selection (Drinkwater, et al., 2008),

Mean statures and body masses of the basketball players approximated age-specific 90th percentiles for U.S. reference males (Kuczmarski, et al., 2000). The larger size reflected in part the selective demands of basketball and also advanced maturity status. Mean percentage of predicted mature stature attained at the time of the study (15.3±0.6 yrs) was 97.5±2.3% (Table 1) which was in advance of longitudinal samples in the Fels Growth Study upon which the stature prediction protocol was developed, 96.0±1.3% at 15.0 years (participants were measured within one month of their birthdays) (Roche, Tyleshevski, & Rogers, 1983) and in the Berkeley Guidance Study, 96.0±3.3% at 15.5 years (Bayer & Bayle, 1959). Observations for estimated maturity status were consistent with assessments of pubic hair (Coelho e Silva, et al., 2010) and skeletal age (Fels method) in Portuguese youth basketball players (Carvalho, et al., 2011). Skeletal maturity assessments in other samples of youth basketball players are apparently not available, although a sample of active boys, which included primarily basketball players followed longitudinally through adolescence, was advanced in skeletal age at CAs of 14-16 years (Parizkova, 1974; Ulbrich, 1970).

Current stature expressed as a percentage of predicted mature stature is based on size attained and is the result of variation in tempo of growth; it is not an indicator of tempo per se as is age at peak height velocity (Beunen & Malina, 2008). 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 to peers (Beunen & Malina, 2008). The method for predicting mature stature was based on current CA, stature and body mass of the player and midparent stature (Khamis & Roche, 1994). The method was modified from an earlier protocol which also included skeletal age among predictors (Roche, Wainer, & Thissen, 1975). Differences between the two protocols with and without skeletal age among predictors were relatively small (Wainer, Roche, & Bell, 1978).

VO_{2max} of the adolescent basketball players (Table 1) was higher than previously reported for a similar age range in the general population (Beunen, et al., 2002; Geithner, et al., 2004). Most available data for VO_{2max} in basketball are reported as ratio standards to control for the effects of body mass. Potential misinterpretations associated with this approach have been noted (Nevill, et al., 1992; Tanner, 1949). Nevertheless, allowing for statistical limitations and sampling, there was considerable variability in VO_{2max} among male basketball players 13 to 18 years (Apostolidis, et al., 2004; Bogdanis, et al., 2007; Castagna, et al., 2009; Castagna, et al., 2008; Castagna, et al., 2007). Although basketball is not an endurance sport per se, the high values for cardiopulmonary functions are often viewed as important for the maintenance of a high level of activity during an entire game (Ziv & Lidor, 2009) and for effective recovery from high-intensity, short bursts of movement (Castagna, et al., 2007). Higher levels of aerobic fitness among basketball players may also have a potentially important role in the prevention of performance decrements throughout a season (Hakkinen, 1993; Ziv & Lidor, 2009).

It is expected that absolute VO_{2max} increases as a function of body dimensions during childhood and adolescence, whether or not youth are engaged in organized sports and other physical activities. Longitudinal data based on Canadian and Belgian boys indicated, on average, coincident occurrence of peak velocity of growth in stature and VO_{2max} (Geithner, et al., 2004; Mirwald & Bailey, 1986). Studies using multilevel modeling also demonstrated a size-independent effect of biological maturation on VO_{2max} (Armstrong & Welsman, 2001; Beunen, et al., 2002). Peak VO_2 adjusted for age and body dimensions increased with pubertal status in male athletes in the Training of Young Athletes study (Baxter-Jones, Goldstein, & Helms, 1993; Nevill, et al., 1998). In general, age-related increases in VO_{2max} appeared to be mediated largely by changes in size dimensions; however, year-to-year changes in body mass and VO_{2max} may be also masked by individual differences in the timing and tempo of biological maturation (Eisenmann, Pivarnik, & Malina, 2001).

Although interest in the development of VO_{2max} in youth is considerable, few studies have addressed the topic in children and adolescents engaged in highly structured training regimens. Interpretation of the relationship between body dimensions and VO_{2max} may be influenced by growth and maturation per se and by a potential influence 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 an adolescent peak velocity that occurs, on average, after age at PHV (Malina, et al., 2004).

As noted, expression of VO_{2max} as a ratio standard presents theoretical and statistical limitations (Nevill, et al., 1992; Tanner, 1949). Allometric scaling (log-linear regression) techniques were adopted in the present study. Initially, it was used as a power function (Schmidt-Nielsen, 1984) to relate VO_{2max} to body dimensions. Since important inter-individual variability in body dimensions occurs during pubertal development and growth spurt (Malina, et al., 2004), proportional allometric models (Nevill & Holder, 1994) were used. Two exponential terms were added to the size term: the first incorporated either chronological age or maturity status and the second term incorporated years of formal training. The non-linear 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 VO_{2max} "size free scores" for each of the adopted size variables (Nevill, et al., 1992; Schmidt-Nielsen, 1984). The proportional allometric models derived from stepwise regressions were also adjusted to fit the VO_{2max} data, as absolute residuals from each of the models were uncorrelated with the log transformed independent variables in each of the models. These results were consistent with application of similar allometric models (Nevill, et al., 1992) for partitioning body-size effects from physiological variables or performances, in particular VO_{2max} in youth (Chamari, et al., 2005; Cunha, et al., 2011) and adult (Markovic, Vucetic, & Nevill, 2007; Nevill, Markovic, Vucetic, & Holder, 2004) team-sport athletes.

The size exponents derived from the allometric model (equation 1) confirmed observation in the literature that the relationship between body dimensions and VO_{2max} is not proportional (Nevill, et al., 1992; Tanner, 1949; Welsman, Armstrong, Nevill, Winter, & Kirby, 1996). Exponents derived from the models for stature, body mass and

FFM were reasonably consistent with the theory of geometrical similarity (Schmidt-Nielsen, 1984). Humans are not geometrically similar (Nevill, Stewart, Olds, & Holder, 2004), and athletes in particular have greater muscular 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 (Beunen, et al., 2002) and also in studies of young athletes (Cunha, et al., 2011; Eisenmann, et al., 2001). These results may be explained by higher mean statures in the sample of basketball sample than young athletes from other sports (e.g., long distance runners and soccer). Hence, generalizations from the present 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 indicate potential dangers of using body-mass power functions to model VO_{2max} (Nevill, Markovic, et al., 2004).

In summary, large portions of the variance in VO_{2max} of adolescent basketball players is accounted for by biological maturation, years of training experience and body dimensions. Biological maturation and training experience had a relative contribution via body mass and FFM, but interestingly, an independent positive relationship with aerobic performance. These results highlight the importance of considering variability associated with biological maturation on aerobic performance, even in individuals beyond peak height velocity, where rate of changes in dimensions, physique and body composition, and various systems tends to be lower (Malina, et al., 2004). 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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Tables and Figures

Table 1. Descriptive statistics for the total sample (*n* = 37).

Table 2. Allometric modeling of maximum oxygen output for body size variables in 14-16 years-old basketball players

Figure 1. Relationships between the log transformed VO_{2max} and body dimensions

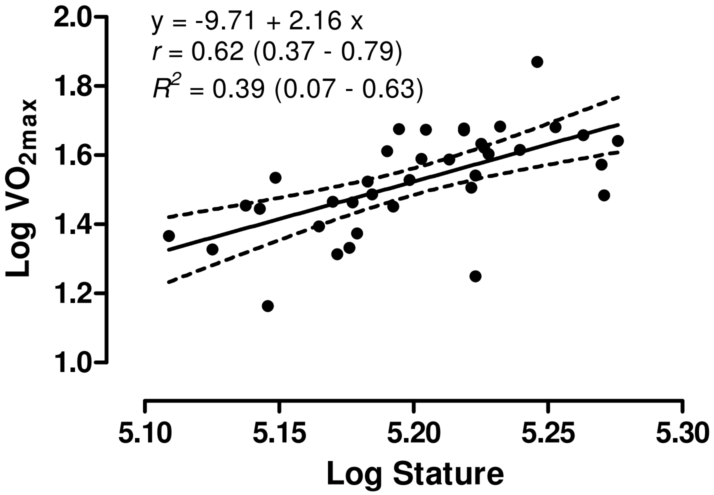
Table 1. Descriptive statistics for the total sample (*n* = 37).

	Mean	Standard deviation	Range
Chronological age, yrs	15.32	0.64	14.01 – 16.32
Percentage of predicted mature stature, %	97.5	2.3	90.5 – 100.9
Years of training, yrs	6.38	2.60	2.00 – 11.00
Stature, 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

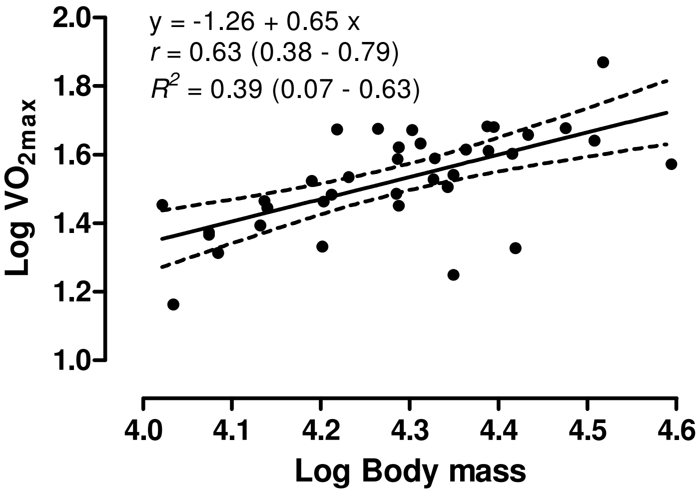
Table 2. Allometric modeling of maximum oxygen output for body size variables in 14-16 years-old basketball players

Initial Model	Final model	Exponents	*P*	*r*	R^2	*Adjusted* R^2
	Model 1			0.74 (0.55 – 0.86)	0.55 (0.28 – 0.74)	0.53 (0.25 – 0.73)
Stature	Stature	2.67 (1.81 – 3.53)	0.00	0.77 (0.60 – 0.88)		
Years of training	Years of training	0.02 (0.01 – 0.04)	0.00	0.43 (0.13 – 0.66)		
Chronological age						
	Model 2			0.71 (0.50 – 0.84)	0.50 (0.21 – 0.71)	0.47 (0.17 – 0.69)
Body mass	Body mass	0.73 (0.47 – 0.99)	0.00	0.73 (0.53 – 0.85)		
Years of training	Years of training	0.02 (0.00 – 0.34)	0.01	0.34 (0.01 – 0.60)		
Chronological age						
	Model 3			0.75 (0.56 – 0.86)	0.56 (0.29 – 0.75)	0.54 (0.26 – 0.73)
Fat-free mass	Fat-free mass	0.84 (0.58 – 1.10)	0.00	0.76 (0.58 – 0.87)		
Years of training	Years of training	0.02 (0.01 – 0.03)	0.00	0.37 (0.05 – 0.62)		
Chronological age						
	Model 4			0.74 (0.55 – 0.86)	0.55 (0.28 – 0.74)	0.53 (0.25 – 0.73)
Stature	Stature	2.67 (1.81 – 3.53)	0.00	0.77 (0.60 – 0.88)		
Years of training	Years of training	0.02 (0.01 – 0.04)	0.00	0.43 (0.13 – 0.66)		
% of predicted mature stature						
	Model 5			0.767 (0.59 – 0.87)	0.59 (0.33 – 0.767)	0.55 (0.28 – 0.74)
Body mass	Body mass	0.58 (0.31 – 0.85)	0.00	0.56 (0.29 – 0.75)		
Years of training	Years of training	0.02 (0.01 – 0.04)	0.00	0.40 (0.09 – 0.64)		
% of predicted mature stature	% of predicted mature stature	0.02 (0.01 – 0.04)	0.01	0.34 (0.02 – 0.60)		
	Model 6			0.80 (0.64 – 0.89)	0.64 (0.39 – 0.80)	0.60 (0.35 – 0.77)
Fat-free mass	Fat-free mass	0.69 (0.41 – 0.01)	0.00	0.62 (0.37 – 0.79)		
Years of training	Years of training	0.02 (0.01 – 0.04)	0.00	0.42 (0.11 – 0.66)		
% of predicted mature stature	% of predicted mature stature	0.02 (0.00 – 0.03)	0.01	0.31 (-0.01 – 0.58)		

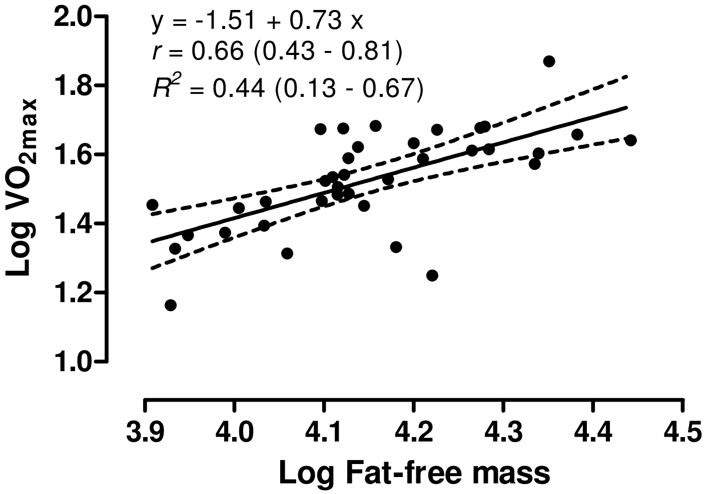
a.


y = -9.71 + 2.16 x
r = 0.62 (0.37 - 0.79)
R2 = 0.39 (0.07 - 0.63)
Log VO2max
2.0
1.8
1.6
1.4
1.2
1.0
5.10
5.15
5.20
5.25
5.30
Log Stature

b.


y = -1.26 + 0.65 x
r = 0.63 (0.38 - 0.79)
R2 = 0.39 (0.07 - 0.63)
Log VO2max
Log Body mass
2.0
1.8
1.6
1.4
1.2
1.0
4.0
4.1
4.2
4.3
4.4
4.5
4.6

c.


y = -1.51 + 0.73 x
r = 0.66 (0.43 - 0.81)
R2 = 0.44 (0.13 - 0.67)
Log VO2max
2.0
1.8
1.6
1.4
1.2
1.0
3.9
4.0
4.1
4.2
4.3
4.4
4.5
Log Fat-free mass

ANEXO 5:

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Submission Type: Original investigation

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ABSTRACT

Relationships among chronological age (CA), maturation, training experience and body dimensions with peak oxygen uptake (VO_{2max}) were considered in male basketball players 14-16 years. Data for all players included maturity status estimated as percentage of predicted adult stature attained at the time of the study (Khamis-Roche protocol), years of training, body dimensions and VO_{2max} (incremental maximal test on a treadmill). Proportional allometric models derived from stepwise regressions were used (1) to incorporate either CA or maturity status and (2) to incorporate years of formal training in basketball. Estimates for size exponents (95% CI) from the separate allometric models for VO_{2max} were, respectively: stature 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 between 39% and 44% of variance. The independent variables in the proportional allometric models explained between 47% and 60% of variance in the VO_{2max}. Estimated maturity status (11% to 16% of explained variance) and training experience (7% to 11% of explained variance) were significant predictors with either body mass or estimated fat-free mass ($P \leq 0.01$), but not with stature. Biological maturity status and training experience in basketball had a significant contribution to VO_{2max} via body mass and fat-free fat mass, and interestingly, also had an independent positive relation with aerobic performance. The results highlight importance of considering variation associated with biological maturation on aerobic performance of late adolescent boys.

KEYWORDS: percentage of mature stature, adolescent, allometric scaling, young athletes

INTRODUCTION

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, inter-individual 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_{2max}), as an indicator of aerobic fitness, is routinely expressed as a ratio standard (e.g., $ml \cdot min^{-1} \cdot kg^{-1}$), despite theoretical and statistical limitations.[9] Allometric models are also effective for partitioning body-size effects in physiological variables or performances, in particular VO_{2max}.[9] Alternate statistical models using linear regression and allometric scaling (log-linear regression) have been recommended to provide a "size-free" expression of VO_{2max}.[9] Allometric models may also be used to accommodate potentially confounding variables to explain inter-individual 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_{2max} in young athletes engaged in organized training programs has not been clearly addressed. In addition to confounding effects of body dimensions on VO_{2max}, the potential influence of inter-individual differences in the timing and tempo of biological maturation on physiological performance of adolescents, both athletes and non-athletes, needs consideration. In this context, the purpose of this study was to evaluate the extent chronological age (CA), biological maturity status, training experience and body dimensions characteristics account for the inter-individual variation in VO_{2max} in adolescent male basketball players. Given the trend towards intensive training in youth sports at relatively young ages, examining the relationships between CA, morphology, maturation and training and VO_{2max} 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 years, 14.0 – 16.3). All players were of Portuguese ancestry with the exception of two who were of African ancestry. All participants were volunteers and were classified as under 16 years (U16) by the *Federação Portuguesa de Basquetebol* (Portuguese Basketball Federation). At the time of study, all players trained regularly (4-6 $sessions \cdot week^{-1}$; ~360-510 $min \cdot week^{-1}$) and typically played one or two games per week 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 two years with a mean of 6.4±2.6 years. 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. Stature was measured with a portable stadiometer (Harpenden model 98.603, Holtain Ltd, Crosswell, UK) to the nearest 0.1 cm. Realiability estimates are reported elsewhere.[7] Body mass was assessed to the nearest 0.01 kg 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 two-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 two values within 150 mL were obtained. If more than three raw body volumes were necessary, then two to three 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.[13] Percent 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, stature and body mass of the player and midparent stature were used to predict mature (adult) stature with the Khamis–Roche protocol.[14] Current stature of each player was then expressed as a percentage of predicted mature stature to provide an estimate of biological maturity status. The individual who is closer (e.g., 94%) to mature stature is advanced in maturity status compared with the individual who is further (e.g., 89%) from mature stature.

Peak oxygen uptake

Peak oxygen uptake was determined using an incremental running test on a motorized treadmill (Quasar, HP Cosmos, Germany). Participants started with a 3 min at 8 $km{\cdot}h^{-1}$ with subsequent increments of 2 $km{\cdot}h^{-1}$ every 3 min until 14 $km{\cdot}h^{-1}$. Exercise intensity was subsequently increased through increasing the treadmill elevation by 2.5% after 12 min and every 3 min until exhaustion, which was reached in 8 – 12 min. Attainment of VO_{2max} was confirmed if the athlete met any two of the following criteria: volitional exhaustion; respiratory exchange rate equal to or greater than 1.10; heart rate reached a value within 10% of the age predicted maximal heart rate; and a plateau in oxygen consumption, despite increased exercise intensity. Expiratory O_2 and CO_2 concentrations and flow were measured every 10 s using a Gas analyser (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, USA). CO_2 and O_2 sensors were calibrated using a calibration Kit (Cosmed, UN1956, 560L, 2200 psig, 70º F) with known concentrations of CO_2 and O_2 (5% CO_2, 16% O_2, BAL. N_2). HR was measured throughout exercise with a commercially available HR-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 (stature, body mass, FFM) and VO_{2max} expressed in absolute terms ($L \cdot min^{-1}$). An initial allometric model was used to examine the relationship between body dimensions and VO_{2max}:

$$Y = a \cdot X^k \cdot \varepsilon$$

(Equation 1)

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:

$$\text{Log } Y = \text{Log } a + k \cdot \text{Log } X + \text{Log } \varepsilon,$$

(Equation 2)

where Y was the dependent variable of VO_{2max} (natural logarithms, i.e., Log VO_{2max}) and body dimensions descriptors (i.e., Log stature, 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.[15] The models incorporated CA or percentage of predicted mature stature and years of training experience as exponential terms in addition to one of the morphological dimensions (stature, body mass or FFM) as follows:

$$VO_{2max} = \text{size descriptor}^{k1} \cdot \exp\,[a + b \cdot (\text{age or \% mature stature}) + c \cdot (\text{years of training})] \cdot \varepsilon$$

(Equation 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:

$$\text{Log}\ (VO_{2max}) = k_1 \cdot \text{Log}\ (\text{size descriptor}) + a + b \cdot (\text{age or \% mature stature}) + c \cdot (\text{years of training}) + \text{Log}\ \varepsilon$$

(Equation 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’s product-moment correlations to check the assumptions of scaled VO_{2max} 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 as not been completely successful in rendering VO_{2max} 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 stature attained at the time of study (15.3±0.6 yrs) was 97.5±2.3%. The estimate was in advance of that for the sample upon which the stature prediction protocol was developed, 96.0±1.3% at 15.0 years (participants were measured within one month of their birthdays).[16] By inference, the sample of basketball players was somewhat advanced in biological maturity status for CA. Mean stature and body mass approximated age-specific 90th percentiles of the U.S. reference for males.[17]

Estimates for body dimension exponents (95% CI) from the separate allometric models for VO_{2max} were, respectively: stature 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 between 39% and 44% of variance in the VO_{2max}. 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_{2max} "size free scores" for each of the size variables. However, substantial residual size correlations were apparent when residuals were correlated with other size variables (e.g., residuals of VO_{2max} modelled for stature against body mass). The correlations ($0.10 < r < 0.23$) indicated that the stature, body mass or FFM individually did not completely partition out the influence of body dimensions in VO_{2max}.

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_{2max}. 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, percent of mature stature was a significant predictor with training experience and separately with body mass and FFM (Models 5 and 6, $P \leq 0.01$), but not with stature (Model 4).

As expected, all independent variables entering the final models had a positive association with VO_{2max}. In all models the body size variables were the first predictors identified. Introduction of training experience as significant predictor ($P \leq 0.01$) in the models contributed 11% to 16% to the explained variance. For the final models, the explained variance added by percentage of adult stature as significant predictor ($P \leq 0.01$) 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 each body dimensions descriptor in the models incorporating chronological age 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 stature.

DISCUSSION

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

The growth characteristics of this sample of Portuguese 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 statures and body masses of the basketball players approximated age-specific 90th percentiles for U.S. reference males. [17] The larger size reflected in part the selective demands of basketball and also advanced maturity status. Mean percentage of predicted mature stature attained at the time of the study (15.3±0.6 yrs) was 97.5±2.3% (Table 1) which was in advance of longitudinal samples in the Fels Growth Study upon which the stature prediction protocol was developed, 96.0±1.3% at 15.0 years (participants were measured within one month of their birthdays) [16] 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, which included primarily basketball players followed longitudinally through adolescence, was advanced in skeletal age at CAs of 14-16 years.[19, 20]

Current stature expressed as a percentage of predicted mature stature 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 to peers.[21] The method for predicting mature stature was based on current CA, stature and body mass of the player and midparent stature.[14] The method was modified from an earlier protocol which also included skeletal age among predictors.[22] Differences between the two 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 moderate concordance with maturity classifications based on skeletal age in samples of American football players 9-14 years [24] and soccer players 11-13 years of age.[25] Nevertheless, there is a need for further refinement and validation of non-invasive methods for the estimation of biological maturity status.

VO_{2max} 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 VO_{2max} in basketball players are reported as ratio standards to control for the effects of body mass. Potential misinterpretations associated with this approach have been noted. Nevertheless, allowing for statistical limitations and sampling, there was considerable variability in VO_{2max} among male basketball players 13 to 18 years.[27-29] Although basketball is not an endurance sport per se, the high values for cardiopulmonary functions are often viewed as important for the maintenance of a high level of activity during an entire game[8] 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 decrements throughout a season.[8]

It is expected that absolute VO_{2max} increases as a function of body dimensions during childhood and adolescence, whether or not youth are engaged in organized sports and other physical activities. Longitudinal data based on Canadian and Belgian boys indicated, on average, coincident occurrence of peak velocity of growth in stature and VO_{2max}.[11, 30] Studies using multilevel modelling also demonstrated a size-independent effect of biological maturation on VO_{2max}.[10, 26] Peak VO_2 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 VO_{2max} appeared to be mediated largely by changes in size dimensions; however, year-to-year changes in body mass and VO_{2max} may be also masked by individual differences in the timing and tempo of biological maturation.[31]

Although interest in the development of VO_{2max} in youth is considerable, few studies have addressed the topic in children and adolescents engaged in highly structured training regimens. Interpretation of the relationship between body dimensions and VO_{2max} may be influenced by growth and maturation per se and by a potential influence 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 PHV. [21]

As noted, expression of VO_{2max} as a ratio standard presents theoretical and statistical limitations. [9] Allometric scaling (log-linear regression) techniques were adopted in the present study. Initially, it was used as a power function to relate VO_{2max} to body dimensions. Since important inter-individual 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 chronological age or maturity status and the second term incorporated years of formal training. The non-linear allometric modelling 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 VO_{2max} “size free scores” for each of the adopted size variables. The proportional allometric models derived from stepwise regressions were also adjusted to fit the VO_{2max} data, as absolute residuals from each of the models were uncorrelated 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_{2max} in youth [32] and adult [33] team-sport athletes.

The size exponents derived from the allometric model (equation 1) is consistent with observation in the literature that the relationship between body dimensions and VO_{2max} is not proportional. [33] Exponents derived from the models for stature, body mass and FFM were reasonably consistent with the theory of geometrical similarity. Humans are not geometrically similar,[34] and athletes in particular have greater muscular 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 [26] and also in studies of young athletes.[31, 32] The results may be explained by higher mean statures in the sample of basketball players than young athletes from other sports (e.g., long distance runners and soccer). Hence, generalizations from the present 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 indicate potential dangers of using body-mass power functions to model VO_{2max}.[33]

PRACTICAL APPLICATIONS AND CONCLUSIONS

Large portions of the variance in VO_{2max} 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 contribution via body mass and FFM, but interestingly, 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 and body composition, and various bodily systems tend to be lower as physical and physiological maturity is approached.[21] 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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Table 1. Descriptive statistics for the total sample (*n* = 37).

	Mean	Standard deviation	Range
Chronological age, yrs	15.32	0.64	14.01 – 16.32
Percentage of predicted mature stature, %	97.5	2.3	90.5 – 100.9
Years of training, yrs	6.38	2.60	2.00 – 11.00
Stature, 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

Table 2. Allometric modeling of peak oxygen output for body size variables in 14-16 years-old basketball players

Initial Model	Final model	Exponents	*P*	*r*	R^2	*Adjusted* R^2
	Model 1			0.74 (0.55 – 0.86)	0.55 (0.28 – 0.74)	0.53 (0.25 – 0.73)
Stature	Stature	2.67 (1.81 – 3.53)	0.00	0.77 (0.60 – 0.88)		
Years of training	Years of training	0.02 (0.01 – 0.04)	0.00	0.43 (0.13 – 0.66)		
Chronological age						
	Model 2			0.71 (0.50 – 0.84)	0.50 (0.21 – 0.71)	0.47 (0.17 – 0.69)
Body mass	Body mass	0.73 (0.47 – 0.99)	0.00	0.73 (0.53 – 0.85)		
Years of training	Years of training	0.02 (0.00 – 0.34)	0.01	0.34 (0.01 – 0.60)		
Chronological age						
	Model 3			0.75 (0.56 – 0.86)	0.56 (0.29 – 0.75)	0.54 (0.26 – 0.73)
Fat-free mass	Fat-free mass	0.84 (0.58 – 1.10)	0.00	0.76 (0.58 – 0.87)		
Years of training	Years of training	0.02 (0.01 – 0.03)	0.00	0.37 (0.05 – 0.62)		
Chronological age						
	Model 4			0.74 (0.55 – 0.86)	0.55 (0.28 – 0.74)	0.53 (0.25 – 0.73)
Stature	Stature	2.67 (1.81 – 3.53)	0.00	0.77 (0.60 – 0.88)		
Years of training	Years of training	0.02 (0.01 – 0.04)	0.00	0.43 (0.13 – 0.66)		
% of predicted mature stature						
	Model 5			0.767 (0.59 – 0.87)	0.59 (0.33 – 0.767)	0.55 (0.28 – 0.74)
Body mass	Body mass	0.58 (0.31 – 0.85)	0.00	0.56 (0.29 – 0.75)		
Years of training	Years of training	0.02 (0.01 – 0.04)	0.00	0.40 (0.09 – 0.64)		
% of predicted mature stature	% of predicted mature stature	0.02 (0.01 – 0.04)	0.01	0.34 (0.02 – 0.60)		
	Model 6			0.80 (0.64 – 0.89)	0.64 (0.39 – 0.80)	0.60 (0.35 – 0.77)
Fat-free mass	Fat-free mass	0.69 (0.41 – 0.01)	0.00	0.62 (0.37 – 0.79)		
Years of training	Years of training	0.02 (0.01 – 0.04)	0.00	0.42 (0.11 – 0.66)		
% of predicted mature stature	% of predicted mature stature	0.02 (0.00 – 0.03)	0.01	0.31 (-0.01 – 0.58)		