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HUMBERTO JORGE GONÇALVES MOREIRA DE CARVALHO

SHORT-TERM MAXIMAL EFFORT AND ISOKINETIC STRENGTH IN YOUTH BASKETBALL: SCALING THE EFFECTS OF AGE, MATURATION AND BODY SIZE

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ABBREVIATIONS

APHV - Age at peak height velocity

ATP - Adenosine triphosphate

BM - Body mass

BST - Bangsbo sprints test

CA - Chronological age

CI - Confidence interval

CON - Concentric

CV - Coefficient of variation

CT - Computed tomography

DXA - Dual-energy X-ray absorptiometry

ECC - Eccentric

ES-*r* - Effect size correlation

FFM - Fat-free mass

FI – Fatigue index

FIBA - *Fédération International de Basketball*

ICC - Intra-class coefficient

KE - Knee extension

KF - Knee flexion

LD - Line-Drill Test

LLFFM - Lower-limbs fat-free mass

LLV - Lower-limb volume

LLFFV - Lower-limb fat-free volume

MP - Mean power

MRI - Magnetic resonance imaging

NMR - Nuclear magnetic resonance

PHV - Peak height velocity

PCr - Phosphocreatine

PP - Peak power

PFK - Phosphofructokinase

PRESS - Predicted residual sum of squares

PE - Pure error

R^2 - Coefficient of determination

RSA - Repeated-sprint ability

SA - Skeletal age

SA/CA - Chronological age by chronological age

SEE - Standard error of estimation

TEM - Technical errors of measurement

TV - Thigh volume

WAnT - Wingate Anaerobic Test

ABSTRACT

Sport participation is a major component of daily activity in children and adolescents and its importance is often perceived as positive. In particular, Basketball is one the most popular team-sports in the world. In this team sport, the body dimensions largely determine the individual roles of players, and may have a major influence on sport selection of young players. Movement patterns in team sports, in particular basketball, are characterised by short burst, predominantly short-tem activities. Despite major children and adolescent participation in team sports, data estimating maximal short-term performance related to specific sport movement patterns during growth and maturation is limited. Determinants of short-term performance, i.e., muscle quantity, quality, endurance and neuromuscular activation and musculoskeletal architecture, in young athletes should be considered in the context of changes associated with growth, maturation and perhaps training. However, the issue of maturity-associated variation in maximal short-term power and strength outputs and performance has not received much attention. Thus, the main purpose of the present study was to investigate the relations of short-term performance characteristics with inter-individual variability in chronological age (CA), maturation, body size, using allometric scaling approach, in adolescent basketball players.

The present study was organized in two parts. The first part addressed methodological issues: (i) validity of lower-body muscle mass estimation by anthropometry; (ii) reliability and validity of field test assessment of short-term performance; (iii) reproducibility of day-to-day testing of isokinetic concentric and eccentric muscular actions, and in particular the examination of the relationships of average within-subject variation in two isokinetic testing sessions with age, biological maturation, training experience, body size, lower-body morphology and initial strength performance; (iv) statistical approaches to account for the effects of body dimensions on maximal short-term performance, investigating the influence of body dimension on short-term performance using body mass (BM), fat-free mass (FFM) and estimated lower-limb volume (LLV) as separate scaling factors in young athletes.

The second part of the study addressed applied context: (i) maturation, training experience, body size and LLV were investigated as predictors of maximal short-term power outputs; (ii) the variation of maximal short-term muscular and strength outputs of adolescent basketball players in relation to years before and after age at estimated peak height velocity (PHV) and variation in body size was considered.

The methodological studies highlighted that: (i) anthropometry is a valid method to quantify lower-limb volumes in late adolescent/young adult athletes, and the inclusion of age, body size and lower-limb skinfolds can increase the precision of LLV estimates using anthropometry; (ii) the 140-Line Drill test provided reliable data and seems sensitive to differentiate adolescent players by competitive level; (iii) familiarization sessions may improve reliability of concentric and eccentric knee isokinetic strength testing at 60º s^{-1} in adolescent basketball players, and age, maturity status and training experience of young athletes should be considered as significant sources of error; (iv) allometric scaling was the most appropriate statistic technique to remove the influence of body dimensions on 30-s Wingate test (WAnT) power outputs (peak power, PP; mean power, MP), with expression of power outputs by BM^{-1} and $BM^{-0.67}$ providing biased short-term power estimates, tending to favour young athletes with lower body dimensions.

As for the applied studies, the incorporation of multi-linear regression models with years of sport-specific training, CA, skeletal maturity status (SA/CA ratio), body size and estimated leg length and thigh volume as independent variables, large portions of variance of concurrent assessments of maximal short-term performance were explained by different models.

An allometric approach was used to evaluate the relationship between time before and after estimated age at peak height velocity and short-term maximum intensity performance and isokinetic strength indicators among adolescent basketball players. As for short-term muscle power outputs, indicators of body size (BM, FFM and LLV) were largely correlated with the WAnT PP and MP, and curvilinear power functions models (log-linear regressions) provided an adjusted fit to both PP and MP, i.e., maximal short-term performance independent of body size. The results showed an increment of short-term power outputs across adolescence which was also apparent when body size is partitioned out by allometric scaling. When analyzed independently of body size, increases across adolescence appeared to be unrelated to training experience. As for strength outputs, the influence of estimated time from age at PHV on isokinetic strength performance was partially reduced when BM, FFM and LLV were allometrically scaled, suggesting that dimensional changes do not account for all of the variation in isokinetic strength performance at 60 $^{o}\cdot s^{-1}$ in 14 to 16 year-old basketball players. It should be noted that the distinction between the linear trend of isokinetic quadriceps strength values and the quadratic pattern observed with increase of distance to PHV indicate potential concern for knee joint stability.

The results in the present study emphasize the importance considering the effects of biological maturation and body size on maximal short-term and isokinetic strength performance and the need to be accounted appropriately, whether in research or in the context of youth basketball.

KEYWORDS: maturation, athletes, basketball, isokinetic strength, allometric scaling, body size

RESUMO

Na população infanto-juvenil, a actividade desportiva é provavelmente uma das componentes mais importantes da actividade diária. Em particular, o Basquetebol é um dos jogos desportivos mais populares no mundo, em que a dimensão corporal é determinante na selecção dos atletas por posição específica de jogo. Os padrões de movimento apresentam um carácter acíclico, caracterizado pela intermitência de esforços específicos de alta intensidade com momentos de recuperação activos ou passivos. Apesar do período de maior participação desportiva em jogos desportivos ser a adolescência, a informação disponível sobre as relações que se estabelecem entre desempenhos em padrões de movimento específicos das modalidades e o estado de crescimento e maturação são limitados. As determinantes dos desempenhos máximos de curta duração incluem a quantidade e qualidade muscular, activação neuromuscular, arquitectura musculo-esquelética. Apesar da grande participação de crianças e jovens nos jogos desportivos, a informação sobre a performance máxima de curta duração, potência e força muscular, relacionada com estado de crescimento, maturação biológica e o treino é limitada. Deste modo, o objectivo geral do presente estudo foi investigar as relações entre indicadores de performance máxima de curta duração com a variabilidade inter-individual na idade cronológica, maturação e tamanho corporal considerando uma abordagem alométrica, em jovens basquetebolistas de 14-16 anos de idade.

O presente estudo foi organizado em duas partes. Na primeira parte focou-se em aspectos metodológicos: (i) validade de estimativas antropométricas de volume apendicular do membro inferior; (ii) fiabilidade e validade de uma prova de terreno para a avaliação de desempenho máximo de curta duração; (iii) reprodutibilidade de avaliação isocinética em modos de acção muscular concêntrica e excêntrica, examinando as relações entre idade, maturação, experiência de treino, tamanho corporal, morfologia apendicular do membro inferior e nível inicial de desempenho de força com a variabilidade intra-individual em medidas replicadas; (iv) abordagens estatísticas para remover o efeito do tamanho corporal, examinando os diferentes expoentes alométricos das variáveis de tamanho corporal nos esforços máximos de curta duração.

A segunda parte do estudo focou-se em contextos aplicados: (i) avaliação da contribuição relativa da maturação, experiência desportiva, tamanho corporal, volume da coxa na explicação da variância no desempenho máximo de curta duração; (ii) estudo da variação na potência e força muscular em basquetebolistas adolescentes quando a idade foi alinhada ao pico de velocidade de crescimento estimado, adoptando uma perspectiva alométrica.

Dos estudos metodológicos destaca-se: (i) a validade do método antropométrico para estimar volumes apendiculares do membro inferior em atletas jovens/adultos, sendo que a inclusão da idade, tamanho corporal, pregas de gordura, subcutânea, poderão aumentar a concordância do método antropométrico com método concorrente; (ii) o 140-m Line Drill test produziu dados fiáveis e mostrou-se sensível para distinguir basquetebolistas adolescentes por nível competitivo; (iii) sessões de familiarização na avaliação de indicadores de força isocinética poderão reduzir a variabilidade intra-individual em jovens basquetebolistas, sendo que a idade, maturação e nível de treino dos jovens basquetebolistas devem ser considerados como factores de erro na fiabilidade da avaliação isocinética; (iv) a utilização de modelos não lineares mostrou-se a técnica estatística mais apropriada para controlar os efeitos do tamanho corporal em indicadores de potência em esforços máximos de 30 s em ciclo-ergómetro, sendo que a assumpção de proporcionalidade ou de similaridade geométrica no controlo dos indicadores de potência produz estimativas enviesadas, tendendo a favorecer os jovens atletas de menor dimensão corporal.

Quanto aos estudos aplicados, a incorporação da idade, experiência desportiva, maturação esquelética, tamanho corporal, volume da coxa como variáveis independentes regressões lineares múltiplas explicou porções de variância moderadas a elevadas nos vários traços de desempenho máximo de curta duração.

Foi utilizada uma abordagem alométrica na avaliação das relações entre desempenhos de potência e força muscular com distância que os sujeitos estavam do pico de velocidade de crescimento e o tamanho corporal. Quantos aos indicadores de potência em ciclo-ergómetro, observou-se uma associação elevada com os indicadores de tamanho corporal (massa corporal, massa não gorda, volume apendicular do membro inferior), e modelos não-lineares revelaram-se apropriados para remover o efeito do tamanho corporal. Os resultados mostraram que os incrementos na potência muscular na adolescência foram

também aparentes quando o efeito do tamanho corporal foi removido. No entanto, a experiência desportiva não se mostrou associada à variabilidade inter-individual nos indicadores de potência absolutos ou após removidos os efeitos do tamanho corporal. Quanto aos indicadores de força isocinética, a influência do indicador de maturação na variabilidade inter-individual foi parcialmente reduzida quando os efeitos do tamanho corporal foram controlados pelos modelos alométricos, sugerindo que as alterações nas dimensões corporais durante a adolescência não explicam a totalidade da variação nos indicadores de força isocinética avaliada a 60 º·s^{-1} em jovens basquetebolistas de 14-16 anos de idade. Os resultados mostraram ainda uma distinção entre a tendência linear na variabilidade inter-individual nas acções musculares isocinéticas dos músculos extensores da coxa com o aumento da idade ao pico de velocidade de crescimento, em contraste com uma tendência hiperbólica observada nas acções musculares isocinéticas dos músculos flexores. Estes dados indicam potencial instabilidade na articulação do joelho com o aumento da idade ao pico de velocidade de crescimento, consequentemente maior importância do acumular de anos de treino passados os efeitos associados ao crescimento e maturação.

Os resultados do presente estudo evidenciam a importância de considerar os efeitos da maturação e crescimento, e do tamanho corporal nos desempenhos máximos de curta duração (potência e força muscular), assim como a necessidade de se considerarem abordagens estatísticas apropriadas na análise, quer em contextos de investigação científica quer nos contextos de treino de jovens.

PALAVRAS-CHAVE: maturação, atletas, basquetebol, força isocinética, alometria, tamanho corporal

PUBLICATIONS

The results presented in this dissertation are published or were submitted in peer-reviewed scientific publications, as follows:

Carvalho HM, Coelho-e-Silva MJ, Figueiredo AJ, Gonçalves CE, Castagna C, Philippaerts RM, Malina RM.Cross-validation and reliability of the line-drill test of anaerobic performance in basketball players 14-16 years. Journal of Strength and Conditioning Research. 2011;25(4):1113-9.

Carvalho HM, Coelho-e-Silva MJ, Figueiredo AJ, Gonçalves CE, Philippaerts RM, Castagna C, Malina RM. Predictors of maximal short-term power outputs in basketball players 14-16 years. European Journal of Applied Physiology. 2011;111(5):789-96.

Carvalho HM, Coelho-e-Silva MJ, Vaz V, Gonçalves CE, Figueiredo AJ, Malina, RM. Normalising maximal short-term performance to body dimensions in adolescent athletes. Proceedings of the International Society for the Advancement of Kinanthropometry Conference 2010. Oral presentation and accepted for publication.

Carvalho HM, Coelho-e-Silva MJ, Figueiredo AJ, Ronque ERV, Gonçalves RS, Philippaerts RM, Malina RM Assessment of reliability in isokinetic testing among adolescent basketball players. Medicina. Submitted

Carvalho HM, Coelho-e-Silva MJ, Gonçalves CE, Philippaerts RM, Castagna C, Malina RM. Age-related variation of maximal short-term effort after controlling for size and maturation in adolescent athletes. Annals of Human Biology. Submitted

Carvalho HM, Coelho-e-Silva MJ, Figueiredo AJ, Ferry B, Hidalgo-Hermanni, Courteix D, Malina RM. Lower-limb volumes and composition in athletes using dual-energy X-ray absorptiometry and anthropometric equations. Applied Physiology, Nutrition and Metabolism, Submitted

Carvalho HM, Coelho-e-Silva MJ, Valente-dos-Santos J, Gonçalves RS, Philippaerts RM, Malina RM Age-related variation in lower-limb isokinetic strength controlling maturation in late adolescent basketball players. European Journal of Applied Physiology. Submitted

Note: The results presented in this dissertation, included in Chapters 3-9, are formatted according to the style of the journal where the papers were published or submitted for publication, with minor modifications.

TABLE OF CONTENDS

CHAPTER 1

Introduction

This chapter focuses on the following objectives:

- identify the key patterns of participation of youngsters in competitive sport;
- discuss the profile of the physical demands in basketball;
- defining the key terms necessary to understand maximal short-term performance in the context of growth and maturation among adolescent athletes;
- assessing growth and maturity status in adolescent athletes;
- discuss the interdependence between physical growth, biological maturation, body size and short-term performance in young athletes;
- discuss determinants of short-term exercise during adolescence;
- discuss the analysis and interpretation methods to normalize the variation attributed to body size on maximal short-term performance;
- draw the objectives and outlines of the study.

PATTERNS OF PARTICIPATION IN YOUTH SPORTS

Sport participation is a major component of daily activity in children and adolescents and its importance is often perceived as positive. Among the potential benefits emerges the impact of its experiences for enhancing interactions with peers, coaches and other significant adults, believed to be essentials in character development (1).

The beginning of participation in organized, competitive sport occurs frequently at early ages as 6-7 years. Regular participation in physical activities is considered to be fundamental for the development and maintenance of desirable levels of motor and metabolic fitness. Generally, time devoted to participation in organized sports in youth increases until adolescence, and after tends to decrease with the shift of interest of youngster to other activities (2-5). Estimates of the number of participants in four organized team sports (basketball, soccer, baseball, softball, football) in the United States in 2000 indicated around 30 million youngsters from 6 to 17 years of age engaged in team-sports programs (6). In Portugal, approximately 226.000 participants, in a population of near 10 million (7), were participating in sport, with about half of them bellow 20 years of age (8).

Sport is characterized by a hierarquical organization in which the level of performance of an athlete matches the appropriate level of competition. The path to elite status in sport is highly exclusive (6). Expert performance in sport may be defined as the consistent superior athletic performance over an extended period (9). Excellence in sport´s performance has a strong positive relationship with the accumulated number of hours of practice, where the specialization years are seen as a decisive moment to lift an athlete’s skill level, readiness and commitment (10, 11). The assumption behind the argument is that experts are always made, not born (12). The translation of this theory to the youth sport domain means that if an athlete wants to be a real high level performer, he/she needs a deliberate engagement in practice during the specialization years, spending time wisely and always focusing on tasks that challenge the current performance. This belief led the sport organizations responsible for the development of young sport talents to increase the amount of hours spent in organized practice, under the supervision of specialized coaches, at increasingly lower ages. Trying to adjust to the model, many sport organizations in several countries around the world (e.g., *Centre Fédéral du Basketball* installed in the *Institut du Sport et Education Physique* in Paris, France; *Australian Institute of Sport* in Australia; *Aspire* in Qatar) created specialized training centres, where selected young talents practice aiming to become professional athletes and integrate youth national teams. In team sports this process has been adopted by professional clubs or national sports associations, and starts usually at around 14 years of age. In most cases, a part or all the youngsters live, go to school and practice at the training campus, often isolated from the families and native environments. Hence, during adolescence years intensive training programs and high level competition is experienced by numerous young athletes (13).

This choice towards an elite restricted group at early ages raises the problem of talent identification and selection. The concept of readiness, associated with growth and maturation (14) underlines the risks associated with high training loads and the complexity of decision making about future performances of immature individuals. To recruit adolescents or pre-adolescents to join a demanding training program in a full commitment basis is a complex task that should be well scientifically grounded, in order to prevent errors in prognosis. It has been acknowledged by sport scientists that performance is resultant of complex factors and multidimensional approaches are advised to study sport-specific performance characteristics in young athletes (15-22).

PROFILE OF DEMANDS IN BASKETBALL

Basketball is one of the most popular team-sports in the world, involving approximately 450 million registered participants from 213 national federations throughout the world that belong to the *Fédération International de Basketball* (FIBA) (23). The game of basketball, similarly to other team-sports, involves short, intense and repeated episodes of activity that require rapid changes in direction (24-26). Players may cover several kilometers (approximately 3 to 8 km) during a basketball game with intermittent nature, comprising many high speed movements in forward and lateral directions combined with decelerations from frequent sprint efforts (24, 25, 27-30). Explosive vertical jumps may be executed up to 50 times per game and (24, 25); it has been observed that a basketball game is characterized by approximately 1000 changes of movement patterns (24). Altogether, basketball specific-movement patterns require high level of lower-limb muscle strength.

A range of mean match heart rates between 85–95% maximal heart rate has been reported previously in basketball (24, 25, 29, 30), with near 15% of the game efforts exceeding 95% of maximal heart rate (24). Assessment of blood lactate concentrations indicate that anaerobic metabolism makes a substantial contribution to the supply of energy for muscular contraction, albeit blood lactate is only a surrogate indicator of anaerobic metabolism. Blood lactate concentration mean values reported in literature range from approximately 4 to 13 $\text{mmol} \cdot \text{L}^{-1}$ (24, 25, 29, 30).

In general, available data indicates that the physical demands of this sport vary according to many factors, such as the level of competition, tactical strategies and the physical capacity of players (31). Although the majority of play time is devoted to aerobic activities in nature (25, 32), anaerobic metabolism makes an important contribution to the energy demands of basketball (25). Maximal short-term performance was identified as a predictor of playing time in youth (33) and of playing level (34) in adults.

The importance of fitness and body size in basketball is highlighted in literature (31, 35) and appears self-evident. The body dimensions largely determine the individual roles of players in the team and game (31), and may have a major influence on sport selection of young players (36, 37). It is advised that testing methods should be carefully selected for their specificity to the game of basketball and different methods of statistical processing must be taken in to account to draw more meaningful conclusions from data collected for athletes (31).

The previous observations are based mostly on young athletes well beyond pubertal development (25, 33, 38) and adult basketball players, both male (24, 27, 28, 31, 34, 38) and female (29, 30). It should be kept in mind that younger players may have lower technical and tactical proficiency, thus the profile of demands during the game of basketball may be somewhat different of those based on adult athletes, and in particular at elite levels.

DEFINING KEY TERMINOLOGY

The processes of growth and maturation represent distinct tasks during the two first decades of life. They occur and interact at the same time. Often these processes are regarded in literature as having the same meaning and not systematically considered in the context of youth sports (17, 22, 39-46). Growth refers to the increase of body size on the whole and on its parts. Height and weight increase gradually during childhood. Maturation refers to a biological process that leads to an adult stage that varies according to the organic system, and it comprises variations in time and tempo. There is considerable inter-individual variation in timing and tempo during the pubertal development period. (47)

In literature, very confusing terminology is used to define muscle anaerobic function; even in high-standard scientific journals the terms are sometimes indiscriminately used. The present research incorporates maximal short-term exercises with chronological age, biological maturation and training experience in youth basketball players, considering the nature of efforts in this applied context. Therefore, regarding performance, we considered maximal short-term outputs, repeated sprint ability, strength, isokinetic strength in concentric and eccentric muscular actions.

The power developed by a muscle contraction is equal to the product of force and velocity, i.e., the ability of the neuromuscular system to produce the greatest possible impulse in a given time period (48). Maximal short-term power-output is defined as the highest mechanical power that can be produced during exercise of up to 30-s duration, with the time period depending on the force or load against which the individual has to work and organization of the acceleration (49).

The ability to repeatedly produce maximal or near-maximal sprints of short duration (1 to 7-s) interspersed with brief recovery periods is termed repeated-sprint ability (RSA) (50), having potentially important physiological implications and relevance to team-sports (35, 51-53).

Strength corresponds to maximal force generated (in N) or moments of force (N·m) developed by a muscle or muscle group during maximal voluntary contraction under a given set of conditions (54). Isokinetic muscular action is defined as the dynamic muscular contraction when the velocity of movement is controlled and maintained through a range of motion by a special device (55).

Concentric muscle action results when the muscle tension developed is greater than the resistance, while the origin and insertion of the muscle approach each other. Eccentric muscle action results when the tension developed is less than the resistance, the origin and insertion of the muscle move away from each other (i.e., the muscle attempts to shorten, but is actually lengthened). (56)

PHYSICAL GROWTH AND BIOLOGICAL MATURATION

Chronologic age is the common reference in studies of growth and performance. However, chronological age is of limited utility in the assessment of growth and maturation (57). The range of variability among individual of the same chronological age in somatic and biological growth, and performance is large, especially during the pubertal years (14, 58-60).

The most commonly used indicators of biological maturation include sexual, skeletal and morphological (somatic) maturity. Stature and body mass are two of the body dimensions used primarily to monitor growth of children and adolescents (14, 61). It is expected that children become taller, heavier with age, and the size attained at a given age (status) and rate of growth (progress) are monitored relative to growth charts (47). The growth rate of stature is highest during the first year of life then gradually declines until the onset (take-off) of the adolescent growth spurt (about 12 years in boys) (14). With the spurt, growth rate increases, reaching a peak (peak height velocity, PHV) at about 14 years in boys, and then gradually declines and eventually ceases with the attainment of adult stature (14, 62). Longitudinal data allows estimates of when adolescent growth spurt begins, and when maximal growth occurs during the spurt. It can provide an indication of the intensity (PHV) and timing (age at PHV) of the adolescent growth spurt. The estimation of individual growth curves is usually done fitting non-linear models on estimated velocities from the longitudinal data (63, 64). The fitting of these models is also applicable to estimate growth curves in other somatic indicators (e.g., body mass, fat-free mass) (65) as well as physical performance characteristics (e.g., sprinting, strength, peak aerobic power) (66-68). Discussion about the development of short-term performance during pubertal period based on longitudinal is provided ahead (Chapters 8 and 9).

Based on longitudinal data, the maturity offset method was developed to estimate the years from age at PHV (69). This predicted maturity offset age is quick, noninvasive to administer, and can be used in cross-sectional studies. The method was derived from gender specific multiple-regression equations, based on segmental growth patterns that predict the maturity offset age parameter using measures of stature, trunk length, and leg length, as well as body mass and chronological age, estimating age from PHV within ± 1 year in 95% of cases. Estimations of age at PHV were previously limited to longitudinal studies based on serial data. Limitations of the offset protocol with young female gymnasts have been pointed (70) and this may also apply to other samples of athletes. Range of variation in maturity offset, and consequently in estimated age at PHV, of cross-sectional data needs to be compared to standard deviations from longitudinal studies determining age at PHV (14, 71, 72) in order to provide information about the sensitivity of the indicator for a given sample.

Other somatic indicator is the estimation of percentage of adult stature attained. This method is calculated from present stature and adult stature and available prediction formulas are based on European and American samples (73-79), but have not been validated on other populations. The percentage of adult stature is an indirect technique that requires the estimation of skeletal maturation, at least for the most accurate systems. Also, formulas to predict adult stature without the use of skeletal age have been proposed (80, 81).

The maturation of the skeleton is widely recognized as the best single indicator of maturity status (82). This maturity indicator focuses on the examination of the development of bones of the hand and wrist, which generally reflect the remainder of the skeleton. Three methods for the assessment of skeletal maturity - the Greulich-Pyle (83), Tanner-Whitehouse (74-76) (see Malina et al. 2007), and Fels methods (84) - are commonly used. Skeletal maturity is expressed as a skeletal age. Details about skeletal maturation are provided in Chapter 7.

Sexual maturation is based on the development of the testes and pubic hair in boys. Its assessment ordinarily requires clinical examination. The development has been categorized in five stages where: there is no pubic hair growth in stage 1; stage 2 marks the onset of the pubertal process, in this instance with the first signs of pubic hair seen around the labia or base of penis; darker, coarser hair is visible in stage 3; stage 4 represents pubic hair which is adult in type although the area covered is still less than most adults; stage 5 represents full pubic hair development which is both adult in type and coverage (62). Sexual maturation in boys is accompanied with marked increases in muscle mass and strength, and broadening of the shoulders relative to the hips (14, 47).

Longitudinal comparisons of studies in children and adolescents classified as active or athletes are limited (66, 85-87), thus inferences about influence of growth and maturation on performance are largely based on cross-sectional data (21, 37, 88-97). Physical performance is related to changes in body size, composition and functional capacities that occur with biological maturation during adolescence (63, 65, 66, 85, 86, 98). The relationship is more pronounced when boys of contrasting maturity status are compared. Boys who are advanced in biological maturity are generally better performers than their later maturing peers (71), and late-maturing boys appear to be excluded from many team sports (97, 99).

The methodologies to assess maturation are generally beyond the resources of sport-governing bodies or youth sport organizations, hence, the need to revert to chronological age as the classification criteria. Despite the important maturity-related differences in stature, body mass, speed and endurance of children and adolescents at identical chronological age classifications (91, 97, 100), chronological age remains the only accepted classification criterion. To date, maturity status has rarely been a factor used in participant classification into youth sports. Moreover, the attempt to include skeletal age as reference to include or exclude late adolescent in international level competition has been debated (101-103). In particular caution should be taken given the inter-individual variability during adolescence growth spurt, and methodological limitations of using skeletal age estimation. Limitations include evidence of ethnic variation in comparisons of elite athletes within and among sports (104, 105), thus a confounding factor (14), considerable inter-individual variation in skeletal maturation or age at epiphyseal union in the hand-wrist and the range of variation in skeletal age within a given chronological age group can exceed four or five years which has implications for chronological verification (101), when normal variation is generally accepted as plus and minus three standard deviations except as maturity is approached (84).

MAXIMAL SHORT-TERM PERFORMANCE

The long-term performance (predominantly based on aerobic metabolism) of children and adolescents has been well documented (68, 106-114) but movement patterns in team sports, in particular basketball, are characterised by short burst, predominantly short-tem activities. Despite major children and adolescent participation in game sports, data estimating maximal short-term performance related to specific sport movement patterns during growth and maturation is limited. Moreover, when considering repeated sprint efforts in young athletes, the lack of data in literature is surprising (115).

Testing children and adolescents

Invasive methods to assess the metabolic pathways during exercises lasting few seconds, (i.e., needle biopsies technique) have ethical concerns (49). The first studies using these methods on muscle tissue in pediatric populations have shown the content of the peripheral-energy-delivering substrate is the same for both children and adults (116-118). These observations raised the assumption that lower phosphofructokinase (PFK) activity in children limits the rate of anaerobic glycosis. However, within the limited evidence available, more metabolic factors than the muscle enzyme activities at rest or post-exercise must be considered (49). More recently non-invasive methods have been used to study muscle bioenergetics using nuclear magnetic resonance (NMR) spectroscopy. This method provides a safe way to measure intracellular inorganic phosphate, phosphocreatine (PCr), adenosine triphosphate (ATP) and pH at rest, during exercise and recovery (119), and may give further insight on muscle metabolic pathways in the future.

The measurement of mechanical output in short-term high-intensity exercise during growth is a reasonable and usefull alternative, since in ecological contexts, such as performance in a game or training of basketball, only the subject´s maximal performance will be considered as the criterion, not the quantity of anaerobic energy yielded by by ATP or glycolysis. There is a lack of standardized methods to assess maximal short-term power outputs in children and adolescents (49), with the major part of data derived from cycle-ergometry. In particular, the Wingate Anaerobic Test (WAnT), based on standard resistance (7.5 % of body mass), has been used extensively and in a variety of settings in children and adolescents (120-126) and has been showed to be highly reliable and sensitive (127). For now, the specificity of the WAnT for athletes in non-cycling sports has not been yet established. Additionally, the single load used (75g/kg of body mass) may or may not elicit individual´s maximal power output because it may identify a sub-maximal point on the power-velocity relationship, and power varies parabolically with velocity or pedaling rate (128-130). The effort made in the protocol is highly anaerobic, mostly by glycolysis (~50%) and PCr breakdown (~30%) with a minor aerobic component (~20%) (131). Maximum cycling short-term power outputs is lower in children than adolescents and adults, being suggested that limitations of glycolysis, PCr breakdown and oxidative re-phosphorylation confine maximal sort-term muscular power performance throughout pubertal development (125). Considering limitations, reliability, anaerobic metabolic profile and extensive available data, the WAnT continues to be a useful test for maximal short-term performance.

Other cycle-ergometer based protocols have been proposed to examine external maximal short-term power outputs based on the estimation optimal load to establish the optimal peak power (49, 132). These assessments are limited when one has interest on the ability to produce maximal power during periods greater than approximately 8-s, available data is more limited, particularly in young athletes and the specificity and validity is not yet established for non cycling-sports.

Maximal sprints during games in team-sports are often clustered with short recovery between repetitions (i.e., < 60-s) (25, 28, 29, 133). Hence, the assessment of the ability to perform maximal short-sprints repeatedly has logical validity and may be amenable to specific physiological interpretation. Numerous sport-specific protocols have been proposed for the evaluation of repeated-sprint ability (46, 134-139). Maximal sprint exercise of short duration requires high rates of ATP generation. Anaerobic ATP production during a single short-duration sprinting (< 10-s) is provided by PCr degradation and anaerobic glycolysis (140, 141), but the relative contribution of anaerobic glycogenolysis to performance in subsequent sprints throughout the test is reduced, possibly limited by on the resynthesis of PCr and the buffering of hydrogen ions (H+) (142, 143). The reduction of the contribution of anaerobic glycogenolysis to performance throughout sprints may conduct to an increase in aerobic metabolism (51). Metabolic profiles of repeated-sprint ability tests are strongly dependent of sprint and recovery duration (53, 144, 145).

Isokinetic dynamometry has been favoured in the assessment of dynamic muscle functions in both research and sports environment (146). This strength assessment procedure provides information about the maximal dynamic muscular contraction when the velocity of the movement is controlled and maintained constant through a range of motion. Isokinetic dynamometers measure torque, which is a function of muscle force (proportional to cross-sectional area and the biomechanical advantage of the lever system, i.e., moment arm). The assessment of human muscle function in isokinetic conditions has several competing demands on the design of protocols that need to be considered to establish validity, including: velocities, number and mode of muscle actions, gravity correction, learning effects and familiarization, possible modifications to equipment for pediatric populations or exceptionally tall subjects (such as basketball players < 205 cm), visual and verbal feedback (146-149).

Determinants of short-term performance during adolescence

The power generated during high intensity exercise is lower in adolescents than in adults (48, 150, 151). Several physiological mechanisms have been suggested to explain the lower ability to produce maximal short-term power in younger populations, including: lower levels of PFK which is a rate-limiting enzyme of the glycolytic pathway (118), lower sympathoadrendal activity (152), maturational differences in muscle fiber distribution (153), and immature anabolic hormonal responses such as lower levels of testosterone (154). A progressively increased anaerobic metabolism potential in boys during adolescence compared with preadolescence is supported by observations of increased enzymatic activity (153), with maximal short-term efforts (anaerobic metabolism determined by post-exercise oxygen consumption) and serum lactate levels (155).

Differences in muscle structure and size (156-160) and neuromuscular coordination (49, 161) have also been noted to explain differences in maximal short-term performance between youngsters and adults. Considerable human variation exists in the ability to perform maximally over a short time period and the contribution of genetic factors to the differences observed in short-term performance phenotype are highlighted in literature (162-165).

Considering the preceding observations, determinants of short-term performance, i.e., muscle quantity, quality, endurance and neuromuscular activation and musculoskeletal architecture, in young athletes should be considered in the context of changes associated with growth, maturation and perhaps training (166). However, the issue of maturity-associated variation in maximal short-term power and strength outputs and performance has not received much attention (14, 149).

Both maximal short-term power and strength outputs during adolescence are related to body size (49, 149). A combination of variables related to body size (stature, leg length, body mass, lean body mass, leg volume and total muscle mass) explained up to 92% of variance in peak power assessed by the 30-s WAnT in young males (120). Results of longitudinal study spanning 12-13 years of age suggested that body mass was the major contributor to peak and mean power in the WAnT, although skinfold thickness had a slight negative effect (123). Further, estimated lean leg volume was strongly associated with short-term power output in youth (Doré et al. 2000). Available data also suggest that factors of qualitative nature should be considered in determining short-term power output (167). The preceding observations illustrate the complexities involved in trying to partition the specific contributions of age, growth, and maturity to maximal short-term power outputs in adolescence (14).

In general, data indicates that absolute values of short-term power and isokinetic strength outputs increase progressively during childhood and adolescence (120, 168-171). Also when these variables were adjusted to body mass it was observed increases with age. Meanwhile, it has been noted that assuming that short-term power and strength performance improvements during childhood and adolescence at a greater rate can be explained by changes in body size alone raises several concerns (172). These cautions are based on possible limitation of the means used to normalise the effects of body size in short-term power outputs and muscle strength (discussed later), and also to the possible limitation of body mass´s validity as the best size descriptor in non-weight bearing protocols (48), such as the WAnT and isokinetic strength assessment of the knee joint. Additionally, the previous observations were based on non-athletes youngsters, and did not consider systematically the inter-individual variability in maturity status. Thus, meaningful insights about the factors that contribute to changes in maximal short-term performance may be provided by the examination of the relative contribution of different measures of body size in young athletes, considering the variation attributed to age and maturation.

Analysis and interpretation of influence of size on short-term performance

From the precedent observations, the processes of growth and maturation are associated with important changes in body size; in the specific context of basketball, size is one of the most valued components to performance; exercise performance, in particular maximal short-term power outputs and strength, are influenced by body size. Thus, physiological variables need to be expressed in respect to body size.

The normalization for body size has often been inconsistently applied when presenting data from physical performance and mostly using ratio standards (e.g., Watt.kg^{-1} body mass, Watt.L^{-1} lean leg volume). However, the limitations of this method to remove potentially spurious effects associated with body size have been widely addressed yet largely ignored (173-175). It has been demonstrated that the use of ratio standards are applicable only when the ratio between the coefficients of variation of the dependent and independent variable are equal to the correlation between the dependent and independent variables, but the criteria is rarely met when relating exercise performance and body size (174).

Regression standards, using an additive adjustment, have been proposed as an alternative approach to produce individual size-adjusted measurements (174, 176). The “size-free” are produced by adding the subject´s residual error, obtained from the linear regression, to the group mean. The assumptions to use the regression standards are: the relation between dependent (Y) and independent (X) variables is linear, i.e., given by $Y = a + b \cdot X + \varepsilon$; the error term ε has constant variance throughout the range of observations (175). The regression models tend to produce biased results due to correlated random variation in the dependent and independent variables and this is, in essence, the classic phenomenon of regression to the mean. Positive intercepts are common when fitting data (e.g., peak power and body mass), indicating a physiological response for individuals with zero body mass (177). Another reason of concern with regressions standards is that the variance of the error term may not be constant throughout the range of observations (178).

The most appropriate statistical model of size-structure and size-function relationships is provided by allometry (173, 175, 179). Allometry is a method of mathematically express the extend of which a variable is related to a unit of body size, as size increases (172). Allometric equation, $Y = a \cdot X^b \cdot \varepsilon$ has been employed most frequently in scaling studies [where Y is the structural or functional variable of interest, a is the proportionality coefficient, X is the body size variable (usually body mass), and b is the size exponent] (175, 180, 181). The power function can become linear by the application of natural logarithmic transformations, in the form of $\log Y = \log a + b \cdot \log X + \log \varepsilon$ (175). The resultant power function ratio Y/X^b should provide a “size-free” variable, i.e., a value of a performance measure which appropriately accounts for body size but retains no correlation with the original size variable (182). The use of allometric modeling requires the verification of several assumptions for its use in scaling the data sets may be valid and defensible (179). The assumptions are: there is a curvilinear relationship between performance variable and the body size descriptor (i.e., in most cases body mass or fat-free mass); in log-transformed allometric model, there is a strong and linear relationship between the dependent variable (i.e., performance variable, WAnT peak power) and the independent variable (i.e., body size descriptor); that performance variable and body size are heteroscedastic; and the adjustment of performance variable using power function modeling, i.e., WAnT peak power (watt/kg^b) is indeed body size independent (183). These recommendations for the appropriate use of allometric scaling are rarely regarded in most cases of allometric scaling in physiological variables (184, 185). Allometric models should be adequately addressed since the use of the technique is encouraged to many physiological, human performance and anthropometric variables (186).

Allometric models have been shown to be more appropriate for partitioning body size effects from physiological variable or performance (175, 184). The technique has been used to partition size variables on short-term power outputs in children and adolescents (121, 122, 150, 170, 187), but, with few exceptions (45), do not appear to have been used in studies involving young athletes.

Under the presumption of “geometric similarity” of human subjects (188, 189), individual body components (e.g. muscles, heart, lungs) should have masses proportional to body mass (BM), cross-sectional or surface areas proportional to $BM^{0.67}$ and linear dimensions (L), such as heights or limb girths, proportional to $L = m^{0.33}$. Under such circumstances, if energy expenditure obeys the surface-area law, then MR should be proportional to $BM^{0.67}$ (or L^2). Similarly, physiological functions, with particular emphasis in literature on maximum oxygen consumption, in humans should also theoretically be proportional to L^2 or $BM^{0.66}$ (188). The use of the allometric parameter *b* values based geometric similarity has been recently recommended, considering the different performance characteristics (190-192), noting the authors the limitations of the standardization. However, it has been demonstrated that human adults presented systematic deviations from geometric similarity, having serious implications for the allometric scaling of variables such as energy expenditure, oxygen uptake, anaerobic power, and thermodynamic or anthropometric studies involving individuals of differing size (193). The applicability of allometric parameter *b* assuming geometric similarity in young athletes as not been established yet.

In summary, the sparse amount of data on short-term performance in young athletes, the influence of maturation on size and performance, in particular sport-related expressions of performance such as maximal short-term power and strength, raise many research questions that may provide the coaches with more accurate and precise methods and informations in order to optimize sport performance of young basketball players. Thus, the aim of this thesis is to gain a deeper insight of the relations of short-term performance characteristics with inter-individual variability in chronological age, maturation, body size, using allometric scaling approach, in adolescent basketball players.

CHAPTER 2

Methodological considerations

The present study is a cross-sectional study of the growth, maturation and performance of adolescent male basketball players. It has been conducted in accordance with recognized ethical standards (194). The study was approved by the *Scientific Committee* of the *University of Coimbra* and also by the *Portuguese Foundation for Science and Technology*. Participants were informed about the nature of the study and also that participation was voluntary and that they could withdraw from the study at any time. Players and their parents or legal guardians provided informed written consent.

The sample was composed of 119 male basketball players (14.0-16.0 years) who volunteered for the study. All players were classified as under 16 (U16) by the Portuguese Basketball Federation, and were engaged in formal training and competition (2-11 years). Players from clubs from the *Associação de Basquetebol de Coimbra* (Coimbra´s basketball association - *Associação Cultural e Desportiva Telecom Coimbra*, *Ginásio Clube Figueirense*), *Associação de Basquetebol de Aveiro* (Aveiro´s basketball association - *Anadia Futebol Clube*, *Illiabum Clube*, *Sangalhos Desporto Clube*), and the national training programs from the *Federação Portuguesa de Basquetebol* (Portuguese basketball federation - *Centro de Nacional de Treino Paulo Pinto*, *Centro de Nacional de Treino Rota dos Móveis-Paredes*).

The variables considered in this study included chronological age, skeletal age, estimated age at peak height velocity, years of formal training experience; stature, body mass, sitting height, estimated thigh and lower-limb volumes by anthropometry (details presented in Chapter 2). The maximal short-term performance measures in the present research included the running field tests [Line Drill Test (LD), Bangsbo Sprints Test (BST)], laboratory tests [30-s Wingate Anaerobic Test (WAnT), isokinetic knee extension and flexion assessment].

DATA QUALITY AND CONTROL

Reliability is a focus of interest in sport science, being anthropometry assessment and performance testing some of most common and important measures used. Reliability of a measure refers to the reproducibility of the protocol to provide a similar result from day to day administration when no intervention is used (195). Knowledge of the reliability (reproducibility) of the measure is important for the correct interpretation of performance data.

Three components of reliability, important when undertaking repeated testing of athletes, were considered: changes in the mean, within-individual variation and retest correlation. Changes in the mean indicate the extent to which individuals improve or deteriorate overall on repeated testing (196). Within-individual variation obtained from replicate measures is often called the technical error of measurement (195, 197, 198) [also named typical error (196)]. The technical error of measurement is the square root of the squared differences of replicates (d^2) divided by twice the number of pairs:

$$\sigma_e = \surd(\Sigma d^2/2N).$$

It has been suggested that logarithmic transformations should be performed on heteroscedastic data or one is interested in the within variation expressed as the percentage of the mean when calculating the coefficient of variation (CV) (196). In particular, functional capacities measures in the present study were logarithmically transformed and the CV was calculated from the standard deviation of 100 times the logged differences using the following formula:

$$\mathrm{CV} = 100\ (e^{sd/100}-1).$$

Retest correlation represents how well athletes retain their rank order on retest. The coefficient of reliability (R) is based on the ratio of within-subject (r) and inter-subject (s) variances (195, 196, 198):

$$R = 1 - (r^2 / s^2).$$

A reliable measure is one that has small changes in the mean, a small within-individual variation and a high test retest correlation.

Details of the estimates of reliability for anthropometrical measurements, skeletal maturity status assessment, as well as anaerobic, aerobic and strength performances are provided in the following sections. The change in the mean, technical errors of measurement, coefficients of variation and retest coefficients were calculated based on the replicate tests on independent subsamples (196-199). Additionally, uncertainty in the difference between the replicate measures was expressed as the 95% confidence interval. Data were checked for heteroscedasticity using plots of the log transformed data and reliability measurements (absolute and percent typical errors) were calculated (196, 199).

In chapters 3, 4 and 5 are provided deeper insights about the reliability estimates of the Line Drill Test, isokinetic strength assessment in young athletes and estimation of leg volumes by the anthropometrical method.

Anthropometry

Based on replicate measurements within one week in a sample of 20 basketball players aged 14-15 years, intra-observer reliability estimates for anthropometric dimensions were calculated and are summarized in Table 2.1.

The technical errors of measurement compare favorably with corresponding intra- and inter-observer errors in several surveys in the United States and a variety of field surveys including studies of young athletes (200), while reliability coefficients indicate moderate to high reliabilities which are adequate for group comparisons and correlation analysis.

Skeletal maturity status

Sixteen radiographs were independently assessed by HMM and RMM to estimate inter-observer variability. Intra-observer reliability was determined by blind assessment of 22 radiographs (20%) a second time after several months. Estimates of reliability in skeletal age assessment are presented in Table 2.2.

Table 2.1. Intra-observer measurement variation (95% confidence limits) of anthropometry assessment among 14-15 years basketball players (n = 20).

	Changes in the mean	Technical error of measurement	Coefficient of variation	Retest correlation
Stature, cm	1.6 (1.2 – 2.1)	0.54 (0.38 – 0.91)	0.3 (0.2 – 0.4)	0.99 (0.98 – 1.00)
Body mass, kg	0.64 (-0.18 – 1.45)	0.88 (0.62 – 1.55)	1.2 (0.8 – 2.1)	0.99 (0.98 – 1.00)
Sitting height, cm	0.68 (0.03 – 1.33)	0.74 (0.52 – 1.25)	0.7 (0.5 – 1.3)	0.96 (0.87 – 0.99)
Skinfolds, mm				
mid thigh anterior	1.5 (0.5 – 2.5)	0.9 (0.6 – 1.8)	6.5 (4.3 – 13.7)	0.89 (0.49 – 0.98)
mid thigh posterior	0.0 (-0.1 – 0.1)	0.8 (0.6 – 1.7)	6.9 (4.5 – 14.5)	0.96 (0.78 – 0.99)
maximum calf lateral	0.3 (-0.5 – 1.0)	0.7 (0.4 – 1.3)	7.6 (5.0 – 16.2)	0.98 (0.90 – 1.00)
maximum calf medial	0.2 (-0.5 – 0.9)	0.8 (0.5 – 1.4)	9.0 (6.1 – 17.1)	0.95 (0.80 – 0.99)
Circumferences, cm				
Subgluteal	0.15 (-0.25 – 0.55)	0.46 (0.32 – 0.77)	0.8 (0.6 – 1.4)	0.98 (0.92 – 0.99)
mid thigh	-0.08 (-0.64 – 0.47)	0.63 (0.45 – 1.08)	1.3 (0.9 – 2.2)	0.85 (0.53 – 0.96)
minimum thigh	-0.21 (-0.85 – 0.44)	0.74 (0.51 – 1.25)	1.8 (1.3 – 3.1)	0.96 (0.85 – 0.99)
Patella	0.21 (-0.11 – 0.52)	0.34 (0.24 – 0.60)	0.9 (0.6 – 1.6)	0.97 (0.88 – 0.99)
anterior calf	-0.01 (-0.48 – 0.47)	0.54 (0.38 – 0.92)	1.5 (1.0 – 2.5)	0.95 (0.83 – 0.99)
maximum calf	-0.06 (-0.31 – 0.20)	0.29 (0.20 – 0.49)	0.8 (0.6 – 1.6)	0.98 (0.94 – 0.99)
minimal ankle	0.02 (-0.41 – 0.45)	0.44 (0.30 – 0.80)	1,9 (1.3 – 3.4)	0.75 (0.23 – 0.94)
Lengths, cm				
proximal thigh	0.11 (-0.02 – 0.23)	0.16 (0.12 – 0.26)	1.7 (1.3 – 2.7)	0.99 (0.97 – 1.00)
distal thigh	0.09 (-0.09 – 0.28)	0.25 (0.18 – 0.38)	1.8 (1.4 – 2.9)	0.98 (0.95 – 0.99)
upper knee	0.09 (-0.07 – 0.25)	0.21 (0.16 –0.33)	4.1 (3.3 – 7.1)	0.90 (0.74 –0.97)
lower knee	0.13 (-0.03 – 0.30)	0.21 (0.16 – 0.34)	4.5 (3.3 – 7.2)	0.95 (0.82 – 0.98)
proximal calf	0.20 (0.07 – 0.33)	0.18 (0.13 – 0.28)	1.7 (1.2 – 2.6)	0.98 (0.94 – 0.98)
distal calf	0.44 (0.10 – 0.78)	0.46 (0.34 – 0.71)	2.2 (1.6 – 3.4)	0.97 (0.90 – 0.99)

Table 2.2. Inter- and intra-observer technical error of measurement in skeletal maturity status assessment.

	N	Mean	Technical error of measurement	Correlation
Inter-observer				
Autor	16	16.64	0.26	0.92 (Pearson correlation)
Expert		16.93		
Intra-observer				
First assessment	22	16.56	0.10	0.99 (retest correlation)
Second assessment		16.80		

The mean difference between skeletal age assessments of the two assessors (0.29 years) and the inter-observer technical error of measurement were small. Also, the intra observer error of measurement skeletal age mean differences were 0.22 years with a technical error of measurement of 0.10 years (i.e. small) (200). This estimates where similar with other studies with youth athletes (102, 201).

Maximal short-term performance

The assessment of maximal short-term performance has problems that are common to most of the available tests, including (132): lack of optimal resistance when calculating power output; measuring power when muscular power is no longer maximal; measuring mean power instead of peak power; motivational factors in the participants; not always considering limitations in the exercise device. Considering these limitations, the maximal short-term performance measures in the present study included the sport-specific running field tests, LD and BST, as well as the 30-s

WAnT in cycle-ergometer. Reliability in the maximal short-term measures was based on replicate tests in independent subgroups (*n* = 12, *n* = 15, *n* = 20 for LD, BST and WAnT, respectively) within a period of 3 to 5 days, and it is presented in Table 2.3.

Table 2.3. Reliability estimates and their 95% confidence limits of anaerobic performance assessment among 14-15 years old young athletes.

	n	Changes in the mean	Technical error of measurement	Coefficient of variation	Retest correlation
Line Drill, s	12	0.05 (0.35 – 0.45)	0.44 (0.31 – 0.75)	1.4 (1.0 – 2.3)	0.91 (0.68 – 0.97)
BST best sprint, s	15	-0.01 (-0.09 – 0.07)	0.10 (0.07 – 0.16)	1.5 (1.1 – 2.3)	0.95 (0.85 – 0.98)
BST total sprints, s	15	-0.14 (-0.60 – 0.32)	0.60 (0.44 – 0.94	1.2 (0.8 – 1.8)	0.98 (0.93 – 0.99)
BST mean sprints, s	15	-0.02 (-0.09 – 0.05)	0.09 (0.06 – 0.13)	1.2 (0.8 – 1.8)	0.98 (0.93 – 0.99)
BST percent of decrement, %	15	-0.19 (-0.88 – 1.36)	0.82 (0.59 – 1.36)	22.2 (15.4 – 39.1)	0.92 (0.75 – 0.97)
WAnT peak power, watt	20	20.2 (8.6 – 31.8)	17.5 (13.3 – 25.5)	2.8 (2.1 – 4.1)	0.98 (0.96 – 0.99)
WAnT mean power, watt	20	3.1 (-9.0 – 15.2)	18.3 (13.9 – 26.8)	3.2 (2.4 – 4.6)	0.98 (0.94 – 0.99)
WAnT fatigue index, %	20	5.3 (3.7 – 6.9)	2.4 (1.8 – 3.5)	8.7 (6.5 – 12.9)	0.71 (0.39 – 0.88)

Reliability estimates for the running tests are within the range of intra-observer estimates reported (50, 134-137, 202-204). However, the reliability estimates for the BST percent of decrement are high. These results are consistent with concerns raised about the use of scores to represent the decline of the performance during the duration effort (205-207). Moreover, through the analysis of different approaches to quantify fatigue in multiples print work, Glaister and collaborators showed that most reliable measure was based on the following:

$$[(\text{Total sprint time} / \text{Ideal sprint time}) \times 100] - 100,$$

where ideal sprint time is the best sprint time, usually the first or second sprint, multiplied by sum of the sprints of the protocol (50, 206).

As for the WAnT, the intra-observer variability was similar with other studies reporting with this protocol (202), in particular considering young populations (208). The WAnT has limitations acknowledged in the literature (209), that can hinder interpretation of the outputs, as well as impose limitations in the validity and reliability of the protocol. In the present study, peak power was defined as the highest 5-s power output (not necessarily the first 5-s), instead of the instant peak power, since the first measure enjoys a considerably better stability and reliability (209). The preliminary flywheel-acceleration phase was set at 60 rev·min^{-1} with minimal resistance (basket supported). The participants that did not attained 60 ± 10 rev·min^{-1} at the onset (load application) of the actual test were not included in the analysis (n = 25). The calculation of the WAnT fatigue index adopted was the following (208):

$$[(\text{peak power} - \text{lowest power}) / \text{peak power} \times 100] - 100.$$

As in the repeated sprint ability, the main shortcoming of the fatigue index is its low level of reliability (209).

Overall, the reliability estimates for the power outputs and sprint times obtained in the used cycling and running protocols showed small values of coefficients of variation; it is therefore suitable for this study.

Lower-limb isokinetic strength

Studies detailing reproducibility of isokinetic assessment in literature, in particular among youth populations and young athletes, are limited. Details about the influence of familiarization to testing procedures with adolescent athletes are provided in Chapter 4. In this section is summarized the intra-observer reliability estimates of concentric and eccentric muscular actions at 60 °·s^{-1}, based in a sample of university students (n=13, chronological age = 21.1 ± 3.1), in order to control variability associated to dynamometer and observer in similar conditions as assessed with the young athletes in the present research project.

Table 2.4. Reliability values and their 95 % confidence limits of concentric and eccentric isokinetic assessment at 60 deg.s^{-1} in 13 university students.

		Changes in the mean	Technical error of measurement	Coefficient of variation	Retest coefficient
Extension, N·m	CON	5.7 (-1.0 – 12.5)	7.9 (5.7 – 13.0)	4.1 (2.9 - 6.8)	0.98 (0.94 – 0.99)
Flexion, N·m	ECC	13.0 (1.7 – 24.2)	12.5 (8.9 – 21.3)	4.8 (3.4 – 8.3)	0.97 (0.90 – 0.99)
Flexion, N·m	CON	4.8 (1.3 – 8.2)	4.0 (2.9 – 6.7)	4.1 (2.9 – 6.9)	0.98 (0.95 – 0.99)
Extension, N·m	ECC	-1.1 (-8.6 – 6.5)	8.4 (6.0 – 14.3)	5.2 (3.6 – 9.0)	0.97 (0.90 – 0.99)

CHAPTER 3

Assessment of anthropometric equations in the estimation of lower-limb volumes and composition in athletes based on dual-energy X-ray absorptiometry

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Background: Interactions between changes in performance (e.g., short-term power, prolonged maximal power) resulting of training and/or diet, and variation in body composition, in particular skeletal muscle mass, are of interest to researchers. The purpose of this study was to assess the validity of lower-limb volume estimates based on anthropometry and dual-energy X-ray absorptiometry (DXA), the criterion reference method, in athletes. Predictive models using the anthropometric dimensions were tested to improve the relative accuracy of the anthropometric approach.
Methods: Female swimmers (*n* = 14; 15.1 ± 1.7 years) and male rugby players (*n* = 23; 20.5 ± 1.2 years) volunteered for the study. Lower-limb volumes (LLV^A) and fat-free volumes ($LLFFV^A$) in both extremities were estimated by anthropometry and also derived using DXA. Cross-validation between the anthropometry technique and DXA was then performed.
Results: Estimates for male athletes slightly overestimated criterion values, but those for female athletes resulted in larger overestimation. Smaller coefficients of variation were observed in rugby players for both LLV^A and $LLFFV^A$. For the total sample, standard errors of measurement for volume estimates by anthropometry ranged from 1.03 L to 1.65 L and correlation with criterion values ranged from 0.89 to 0.95. The explained variance was higher in the prediction model (97% for LLV and ~95% for LLFFV) compared to anthropometric assessments. Smaller pure errors were evident for estimated LLV equations (≈ 6 % for LLV and ≈ 8% for LLFFV) in contrast to higher errors in anthropometric LLV estimates (≈17% for LLV^A and ≈ 20% for $LLFFV^A$).
Conclusions: Overall, anthropometry is a valid method to quantify lower-limb volumes in late adolescent/young adult athletes of both sexes, and is practical when more expensive and complex techniques are not available. The lower accuracy observed in females might be due to the sex differences in lower-body composition (larger variability of fat mass in female compared with male).

Keywords: cross-validation**;** body composition**;** muscle volume estimation

BACKGROUND

Tissue level components of body composition include adipose, skeletal muscle, skeletal, visceral, and brain tissues. The skeletal muscle component is of interest in studies dealing with athletic performance, or body weight management in human. In particular, interactions between changes in performance (e.g., short-term power, prolonged maximal power) induced by training and/or diet intervention, and variation in skeletal muscle mass are of interest to researchers and coaches.

Anthropometry is commonly used for field testing offering a simple, inexpensive and non-invasive technique for the estimation of limb adipose and muscle tissue volumes. For example, the follow up of a training intervention or diet program will be affordable in large sample by using anthropometric techniques. A geometric model of the lower-limb using a truncated cone based on skinfold thicknesses, circumferences and lengths (210) is often used in children and adolescents (150, 167, 170, 187) and healthy adults (211), and also in clinical samples (212). The method relies on several assumptions. First, skinfolds provide an accurate estimate of the thickness of subcutaneous adipose tissue. Second, the limb is circular with subcutaneous adipose tissue forming an annulus. Third, for the determination of muscle volumes, inter-muscular fat and bone volumes are negligible or a constant proportion of the non-subcutaneous adipose tissue. Studies on the validation of the technique in athletes are limited in the literature.

The availability of more advanced techniques, such as computed tomography (CT) and magnetic resonance imaging (MRI), allows the assessment of localized muscle morphology, in particular lower-limb morphology (213). MRI is widely recognized as the `gold standard' for *in vivo* tissue morphometry (214, 215) and is preferred over CT, since it does not involve radiation exposure. However, both methods are expensive and time consuming, and require equipment that is often limited to specialized research units. Dual-energy X-ray absorptiometry (DXA) provides an additional method for estimating regional skeletal muscle *in vivo* at a lower cost and substantially less radiation exposure compared with CT. The technique is based on the differential attenuation of two photon beams as the various tissues of the body absorb them (216), and is described as an accurate method for assessing body composition and skeletal mass (217, 218).

Athletes generally strive to achieve an optimum sport-specific body size and composition in an attempt to maximize performance. They tend to have less relative fatness than nonathletes of the same age and sex (14) and females have greater relative fatness than males in a given sport (219). Similar trend is observed in general population and in overweight people to control body weight (220). Variation in relative fatness also varies with sport, discipline in sport and playing position within a sport (219). Although anthropometric equations are often used to predict relative fatness, predictive accuracy is specific and not generalized to athlete (220).

In the context of the preceding, the purpose of this study was to evaluate the validity of lower-body volume estimated anthropometry relative to estimates by DXA as the criterion in athletes. The analysis also considered an extension of the anthropometric approach by adding age, body size and lower-limb skinfolds in new predictive models, in both male and female athletes.

METHODS

Participants

The sample included 37 French athletes 13.0 to 23.0 years of age at the time of testing. Athletes were female swimmers (n=14, 15.1 ± 1.7 years, elite) and male rugby players (*n* = 23, 20.5 ±1.2 years, professional). All females reached menarche prior to the study. All but one participant (African) were Caucasian. All procedures were approved by the *Scientific Committee* of the *Faculty of Sports Science and Physical Education* of the *University of Coimbra* and the *Auvergne Ethics Committee*, and informed written consent was obtained from each participant.

Anthropometry

All measurements were made by a single individual using the protocols described by Lohman and coallegues (221). Stature was measured with a portable stadiometer (Harpenden model 98.603, Holtain Ltd, Crosswell, UK) to the nearest 0.1 cm. Body mass was measured with a portable balance (Seca model 770, Hanover, MD, USA) to the nearest 0.1 kg. Lower-limb volume (LLV^A), fat-free lower-limb volume ($FFLLV^A$) in both extremities were estimated from four skinfolds, circumferences and partial lengths of both legs (210). The technique partitioned the lower limb into six segments, which are similar to truncated cones. Horizontal circumferences were measured at the gluteal furrow (highest possible horizontal circumference), mid-thigh (at level of the largest mid-thigh circumference), minimum circumference above the knee, maximum circumference around the knee (patella level), minimum circumference below the knee, maximum calf circumference and minimum ankle circumference. Skinfolds were measured on the anterior and posterior aspects of the thigh at the level of mid-thigh circumference and on the medial and lateral aspects of the calf at the level of maximum circumference. The lengths between each circumference from the gluteal furrow to minimum ankle circumference were measured and summed (overall, six partial lengths). The assumption of a circular annular geometry of subcutaneous adipose tissue is built into equations for estimating cross-sectional areas (222, 223):

- $A = C^2/4\pi$, where C is one leg circumference;
- $C_{fat\text{-}free} = C - (\pi / 2) * (\sum skf)$, where $\sum skf$ at mid-thigh circumference level is the sum of anterior and posterior skinfolds, and at maximum calf circumference level is the sum of medial and lateral skinfolds,
- $A_{fat\text{-}free} = [(C - (\pi / 2) * (\sum skf)]^2 / 4 \pi$

Calculation of each assumed truncated cone volume of a limb segment was given by the formula (210):

- $V = [A_1 + A_2 + (A_1 * A_2)^{0.5}] * h / 3$, where A_1 and $A_2$are the areas at the top and bottom of the section and h is its length;
- $V_{corr} = [A_1 + A_{2\mathrm{corr}} + (A_1 * A_{2\mathrm{corr}})^{0.5}] * h / 3$, where, in this example, $A_{2\mathrm{corr}}$ is the areas at bottom of the section.

LLV^A was calculated as the sum of volumes of the six segments. FFLLV^A was estimated using the corrected volumes in the sum of volumes. All equations were entered into widely available data sheet software (Microsoft™ Office Excel, 2007).

Based on 18 participants measured twice within a week, intra-observer technical errors of measurement were calculated for the anthropometric dimensions. Technical errors were 0.29 to 0.74 cm for circumferences, 0.65 to 0.88 mm for skinfolds and 0.16 to 0.46 cm for lengths. The estimates were within the range previously reported for intra- and inter-observer errors in anthropometric surveys (200).

Dual-energy X-ray Absorptiometry (DXA)

Lower-limb volume was also assessed by whole-body DXA (Hologic QDR-4500) and version 9.10 total body scan software (Hologic Inc., Bedford, MA, USA). Subjects lay supine on the bed and were scanned from head to toe in 3.5 min. DXA provides three compartment determinations: lean tissue mass, fat mass, and bone mineral content. Fat-free mass (FFM, kg) represents the sum of lean tissue mass and bone mineral content. Lower-limbs FFM ($LLFFM^{DXA}$, kg) (whole-limb, thigh and calf separated) were derived from whole-body scans, partitioning the legs following the same seven anatomic landmarks used in the anthropometry (Figure 1). Lower-limb volume LLV^{DXA} (L) was calculated as [$LLFFM^{DXA}/1.1 + LLFM^{DXA}/0.9$] with 1.1 $kg.L^{-1}$ being the mean density of FFM and 0.9 $kg.L^{-1}$ being the mean density of FM (224).

__Statistical analysis__

The assumption of normality was checked by the Shapiro-Wilks test and by visual inspection of normality plots. When assumptions were violated, log-transformations were performed to reduce non-uniformity of error. Values were back-transformed to generate estimated means. Differences between lower-body volumes were explored by using paired-sample Student's t-tests.

Concurrent validity between anthropometric volume estimates (practical approach) and estimated volumes based on DXA (criterion measure) was assessed using linear regressions and standard errors of estimation (SEE), coefficients of variation (CVs), and Pearson's correlation coefficients. The limits of agreement between LLV estimates by anthropometry and DXA was also assessed by plotting the mean differences between methods (Bland–Altman analysis) (199).

Stepwise regression of log transformed variables was performed to identify which combination of variables best predicted LLV with estimates based on DXA as the dependent variable., stature, body mass, sum of lower-limb skinfolds (anterior and posterior thigh, medial and lateral calf) and LLV^{A} or $LLFFV^{A}$ were initially included as independent variables in the regression models of LLV estimation for each limb. Individual values of predicted LLV were calculated by back-transformation of the values generated in the corrected estimation equations. The regression models were then internally validated with the predicted residual sum of squares (PRESS) method (225). Pure error (PE) was estimated as independent measure of the validity of each estimation equation (226). Correlation coefficients were considered trivial ($r < 0.1$), small ($0.1 < r < 0.3$) moderate ($0.3 < r < 0.5$), large ($0.5 < r < 0.7$), very large ($0.7 < r < 0.9$) and nearly perfect ($r > 0.9$) and perfect ($r = 1$) (227). Significance was set at $P < 0.05$. Statistical analyses were performed using SPSS for Windows version 14.0 (SPSS, Inc., Chicago, IL, USA).

RESULTS

Characteristics of the athletes and lower-limb composition estimates based on DXA and anthropometry are summarized in Table 3.1. Anthropometric lower-limb estimates were all significantly larger than DXA estimates ($P < 0.01$). No significant differences ($P > 0.05$) were observed between right and left limbs in mass and volume estimates based on DXA and anthropometry.

Relationships between body mass and LLV values (total and fat-free) by DXA and anthropometry based on linear regression are presented in Figure 3.1. The results indicated that a higher proportion of variation was explained body mass in total volume estimates than fat-free volume estimates with both the anthropometric and DXA methods. Total volume estimates by DXA and anthropometry tended to be more similar in males than in females, while the best regression fitted line in fat-free volumes tended to diverge farther apart with an increase of body size in both sexes.

In LLV^A estimations, fitted lines from estimation of equations derived from the linear regressions indicated that the sample of female athletes tended to be further from the criterion values than those of male athletes; higher estimated volumes were closer to the criterion values (see Figure 3.2). As for $LLFFV^A$ values, fitted lines from both groups of athletes indicated that the anthropometric estimates overestimated volumes, and that the slopes tended to increase with an increase in the magnitude of the scale.

Contrasting values of CVs between female swimmers and male rugby players were observed, with the male athletes presenting systematically lower CVs (Figure 3.2). As for the total sample, correlations between anthropometric volume estimations and criterion values ranged from 0.89 to 0.95. The SEEs for right and left LLV^A were 1.25 L (95% CI 1.02 – 1.65 L) and 1.64 L (95% CI 1.33 – 2.14 L), respectively. The SEEs for right and left $LLFFV^A$ were 1.03 L (95% CI 0.84 – 1.35) and 1.27 (95% CI 1.03 – 1.65), respectively. The CV for right and left LLV^A was 12.5% (95% CI 10.0 – 16.6%) and 16.3% (95% CI 13.0 – 21.8%), respectively, and 15.3 (95% CI 12.3 – 20.5%) and 18.6% (95% CI 14.9 – 24.9%) for right and left $LLFFV^A$, respectively. Limits of agreement were 32.4% and 35.4% for LLV^A of the right and left limbs, respectively, and 36.7% and 41.1% for $LLFFV^A$ of the right and left limbs, respectively (see Figure 3.3).

Table 3.1. Lower-limbs volume estimates measures by anthropometry and dual-energyX-ray absorptiometry (DXA).

	Female swimmers (*n* = 14)		Male rugby players (*n* = 23)	
	DXA	Anthropometry	DXA	Anthropometry
Chronological age (age)	15.1 (1.7)		20.5 (1.2)	
Stature (cm)	165.7 (8.0)		181.9 (6.5)	
Body weight (kg)	56.0 (5.7)		95.2 (11.9)	
$LLFFM_R$ (kg)	5.47 (0.64)	10.43 (1.66) **	11.31 (1.18)	15.78 (1.95) **
$LLFFM_L$ (kg)	5.04 (0.66)	10.49 (1.66) **	11.25 (1.28)	15.80 (2.12) **
$[LLFFM_R–LLFFM_L]$ (kg)	0.05 (0.09)	-0.05 (0.57)	0.06 (0.33)	-0.02 (0.56)
LLV_R (L)	7.70 (0.94)	10.59 (1.49) **	14.84 (1.96)	15.35 (2.00)**
LLV_L (L)	7.73 (0.97)	10.55 (1.62) **	14.78 (2.06)	15.24 (2.30)
$[LLV_R –LLV_L]$ (L)	-0.03 (0.12)	0.04 (0.26)	0.06 (0.34)	0.11 (1.05)
$LLFFV_R$ (L)	4.98 (0.58)	9.49 (1.51) **	10.28 (1.07)	14.34 (1.77) **
$LLFFV_L$ (L)	4.93 (0.60)	9.53 (1.51) **	10.23 (1.14)	14.20 (2.07) **
$[LLFFV_R –LLFFV_L]$ (L)	0.00 (0.08)	-0.05 (0.52)	0.05 (0.30)	0.14 (0.99)

** $P < 0.01$

Prediction models for LLV and LLFFV obtained from stepwise regressions of log transformed variables are presented in Table 3.2. Body mass was the strongest predictor of the criterion measure (DXA) in all models. Sum of lower-limbs skinfolds was also included as predictor in the LLFFV models. The prediction models explained from 95% to 97% of the variance in the DXA volume values.

Cross-validation of the new prediction models with the PRESS statistics are summarized in Table 3.2, while agreement of the new LLV prediction equations and the criterion method are shown in Figure 3.4 for total LLV, and Figure 3.5 for LLFFV. Regression analyses between estimated prediction equations and criterion values showed higher percentages of variance explained (97% for LLV and approximately 95% for LLFFV) compared to anthropometric estimates. Limits of agreement of the equations were 12.0 % and 11.2% for LLV of the right and left limbs, respectively, and 16.9% and 15.5% for LLFFV of the right and left limbs, respectively. Smaller PEs were found for the estimated LLV equations (6.1% and 5.7% for LLV_R and LLV_L, respectively; 8,6% and 7,9% for $LLFFV_R$ and $LLFFV_L$, respectively), in contrast to anthropometric LLV estimates (16.5% and 18.1% for LLV^A_R and LLV^A_L, respectively; 18,7% and 21,0% for $LLFFV^A_R$ and $LLFFV^A_L$, respectively).

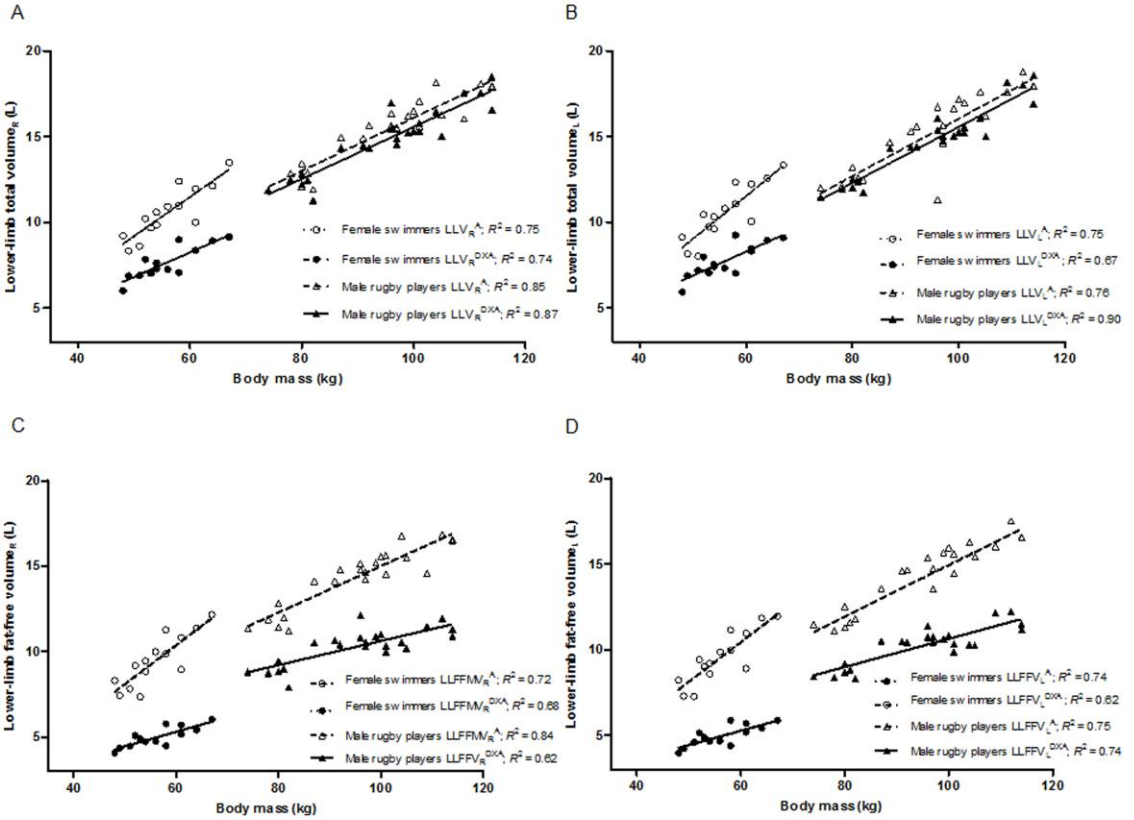

Figure 3.1. Regressions between lower-limb volumes measured by dual-energy X-ray absorptiometry and anthropometry with body mass on male and female athletes. The coefficients of determination (R^2) and the reference line from the equation are presented. (A) right lower-limb volumes (L) and body mass (kg); (B) left lower-limb volumes (L) and body mass (kg).

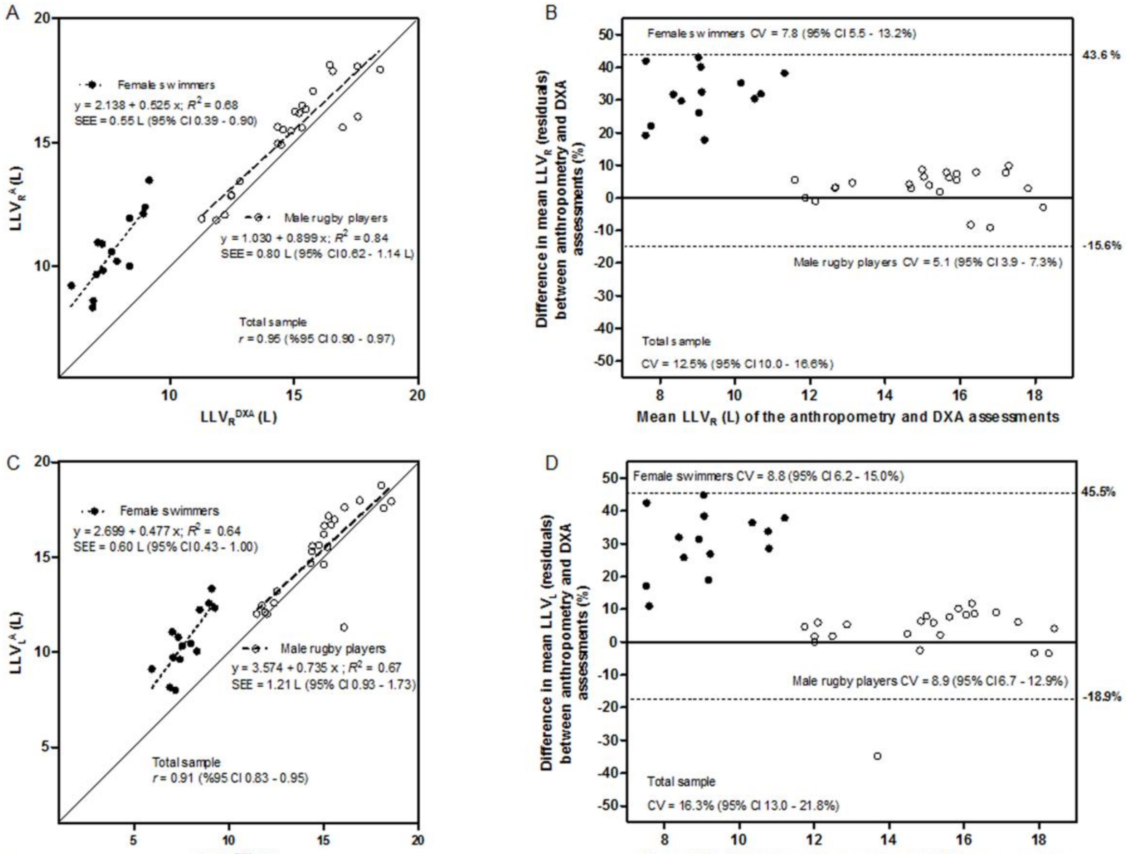

Figure 2

Figure 3.2. Regressions between lower-limb volumes (LLV) measured by dual-energy X-ray absorptiometry (DXA) and anthropometry, and the limits of agreement (Bland–Altman plot) between anthropometry and DXA in estimating the LLV on male and female athletes. (A) Lower-limb volume derived from anthropometry (LLV^A) plotted against lower-limb volume measured by DXA (LLV^{DXA}) in the right lower-limb; (B) Bland–Altman plot comparing volume estimates by anthropometry and DXA in the right lower-limb; (C) LLV^A plotted against LLV^{DXA} in the left lower-limb; (B) Bland–Altman plot comparing volume estimates by anthropometry and DXA in the left lower-limb.

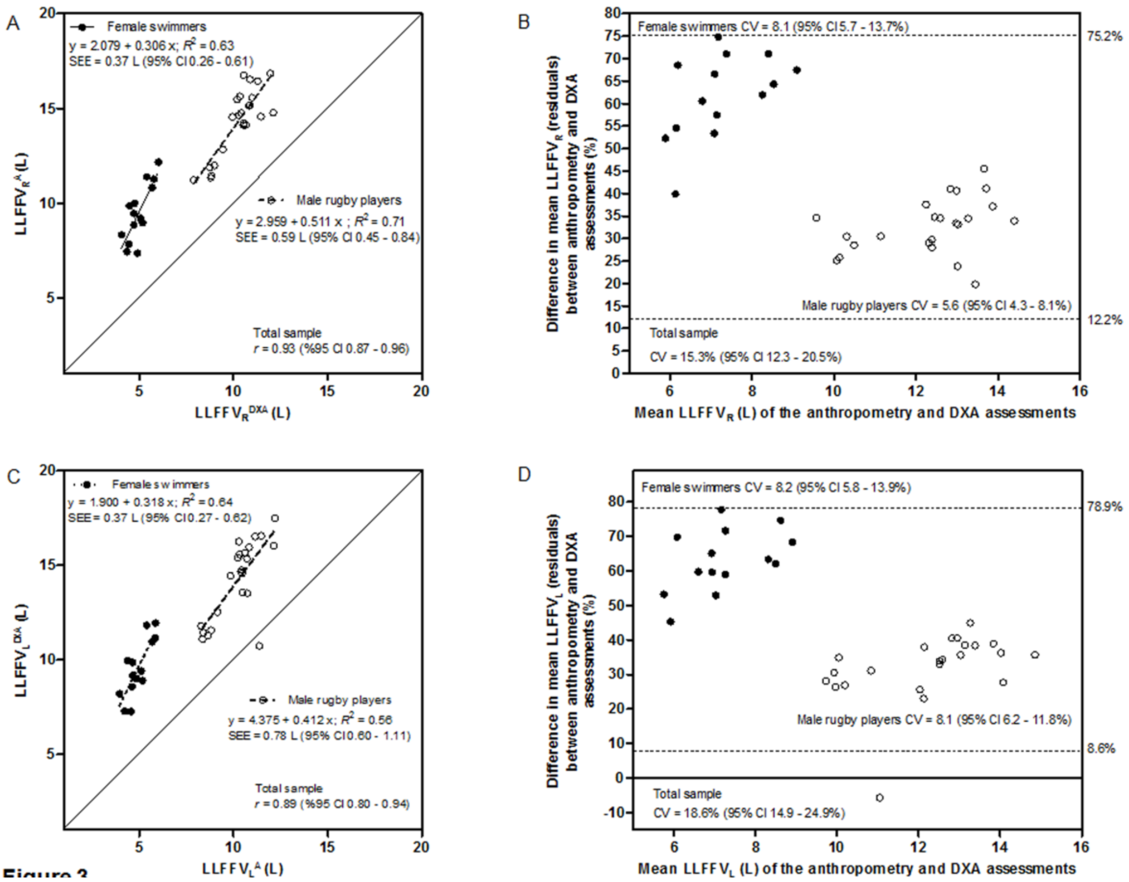

Figure 3.3. Regressions between fat-free lower-limb volumes (FFLLV) measured by dual-energy X-ray absorptiometry (DXA) and anthropometry, and the limits of agreement (Bland–Altman plot) between anthropometry and DXA in estimating the FFLLV on male and female athletes. (A) Fat-free lower-limb volume derived from anthropometry ($FFLLV^{A}$) plotted against lower-limb volume measured by DXA ($FFLLV^{DXA}$) in the right lower-limb; (B) Bland–Altman plot comparing fat-free volume estimates by anthropometry and DXA in the right lower-limb; (C) $FFLLV^{A}$ plotted against $FFLLV^{DXA}$ in the left lower-limb; (B) Bland–Altman plot comparing fat-free volume estimates by anthropometry and DXA in the left lower-limb.

DISCUSSION

LLV estimated by anthropometry using the truncated cone model in late adolescent and young adult athletes is overestimated compared with DXA estimates. Concurrent methods presented high correlation coefficients. Interestingly, differences between LLV^{A} and criterion values tended to be gender specific and related to body mass. Predictive models using anthropometric estimates, adding age, body size and lower-limb skinfolds increased the precision of LLV estimates both for males and females.

The observed overestimation of limb volumes by anthropometry was consistent with reports comparing anthropometric and DXA volume estimates in older male and female adults (211, 212) and MRI estimates in a small sample of athletes (228). In the present study, SEEs ranged from 1.03 L to 1.27 L, corresponding to CV values of 12.5% and 16.3% for right and left LLV^A, respectively. When the truncated cones models included skinfolds, CVs increased in both extremities (Figure 3.3).

The validity estimates in the present study were higher than those reported for healthy active older women, and older male and female adults with clinical indications. The higher lower-limb FFM in the present study of late adolescent and young adult athletes (corresponding to higher thigh and calf muscular hypertrophy compared to non-athletes) may lead to increased estimation errors due to the assumptions that the limb is circular and that subcutaneous adipose tissue forms an annulus, and the limited number of measurement locations used to predict the total volume. Previous observations indicated limitations of anthropometric predictions of thigh volumes relative to MRI estimates with increasing adiposity; results were attributed to a combination of factors, including altered fat distribution and technical difficulty in raising thigh skinfolds (228). Underlying biological variability may also be present in skinfolds measurement due to inter-individual differences in subcutaneous fat distribution (229). Although such limitations increase the uncertainties of LLV^A estimates, they do not prevent its validity in young athletes. The measure of lean and fat mass by DXA includes the bone matrix (BMC is the measure of the bone mineral alone and does not represent the real bone mass). The bone matrix is measured by the way of lean and fat masses and these two compartments appear in the whole lean and fat measures. This can induce another bias in the calculation of body composition and, even of minor value, could partly explain the gap between methods.

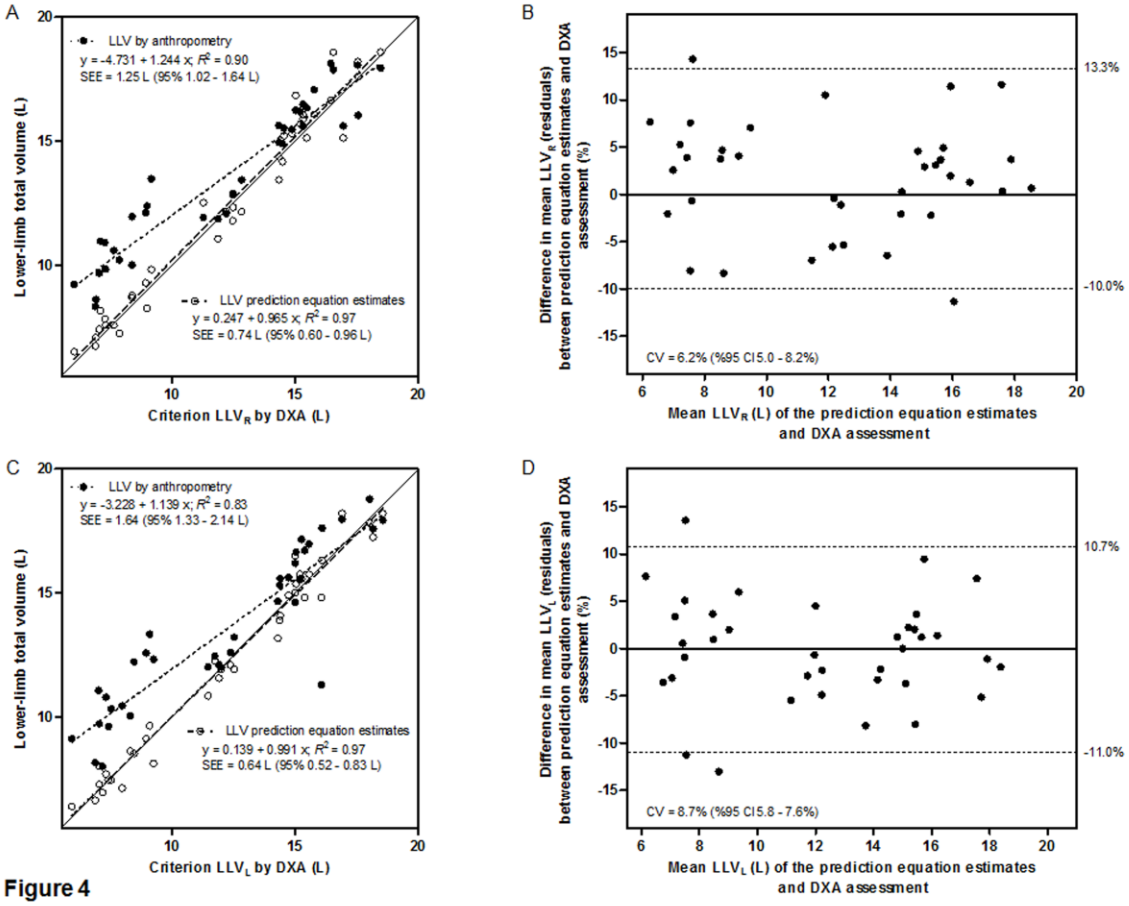

Figure 4

Figure 3.4. Accuracy of the generated anthropometric equations to predict lower-limb volume (LLV^{PRED}) in the young adult athletes with DXA as the reference method. The left panels are linear regressions between LLV measured using the reference method (DXA) and LLV^{PRED} estimated using derived equations (upper panel (A): right lower-limb; lower panel (C): left lower-limb for male and female athlete. The coefficients of determination (R^2), the SEE, and the reference line from the equation are presented. The right panels illustrate the relation between the residuals (mean differences between LLV^{PRED} measured by DXA and predicted by derived equations) and LLV^{PRED} predicted by each of the new equations (upper panel (B): right lower limb; lower panel (D): left lower-limb). The solid lines represent the mean differences between the reference technique and the anthropometric equations. The dashed lines represent 95% limits of agreement (±1.96 SD). All values are expressed in liters.

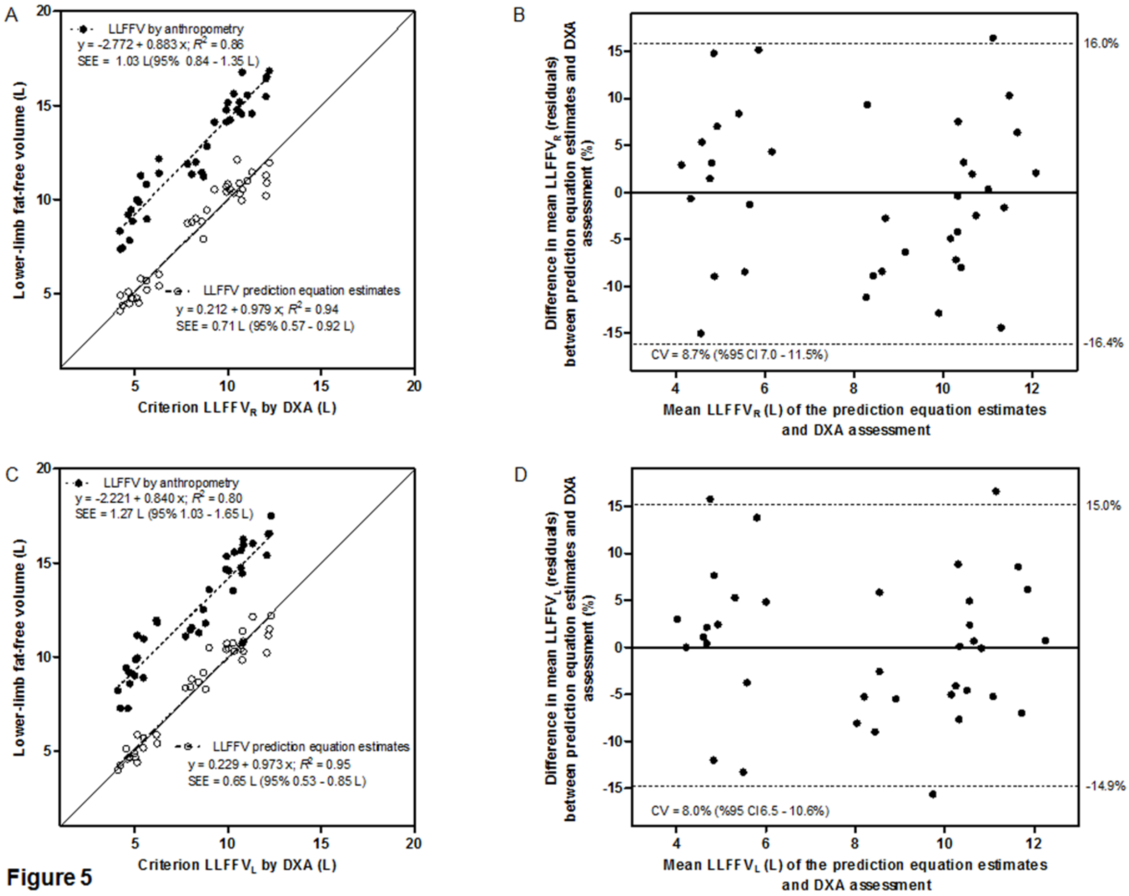

Figure 5

Figure 3.5. Accuracy of the generated anthropometric equations to predict fat-free lower-limb volume (FFLLV^{PRED}) in the young adult athletes with DXA as the reference method. The left panels are linear regressions between LLV measured using the reference method (DXA) and FFLLV^{PRED} estimated using derived equations (upper panel (A): right lower-limb; lower panel (C): left lower-limb for male and female athlete. The coefficients of determination (R^2), the SEE, and the reference line from the equation are presented. The right panels illustrate the relation between the residuals (mean differences between FFLLV^{PRED} measured by DXA and predicted by derived equations) and FFLLV^{PRED} predicted by each of the new equations (upper panel (B): right lower limb; lower panel (D): left lower-limb). The solid lines represent the mean differences between the reference technique and the anthropometric equations. The dashed lines represent 95% limits of agreement (±1.96 SD). All values are expressed in liters.

Table 3.2. Log-regression models and internal cross-validation for the prediction equations.

				Cross-validation	
	R^2 (95% CI)	SEE (95% CI)	Coefficient (95% CI)	R_{PRESS}^2 (95% CI)	$\text{SEE}_{\text{PRESS}}$ (95% CI)
LLV_R					
Intercept			-1.208 (-1.344 – -0.072)		
Body mass			1.201 (1.129 – 1.273)		
Total model	0.97 (0.94 – 0.98)	0.026 (0.021 – 0.034)		0.96 (0.93 – 0.98)	0.72 (0.58 – 0.93)
LLV_L					
Intercept			-1.200 (-1.327 – -1.073)		
Body mass			1.196 (1.129 – 1.263)		
Total model	0.97 (0.95 – 0.99)	0.024 (0.020 – 0.032)		0.97 (0.95 – 0.99)	0.62 (0.50 – 0.80)
LLFFMV_R					
Intercept			-1.308 (-1.543 – -1.073)		
Body mass			1.223 (1.117 – 1.330)		
∑ skinfolds			-0.162 (-0.270 – -0.053)		
Total model	0.95 (0.91 – 0.97)	0.037 (0.030 – 0.048)		0.93 (0.87 – 0.96)	0.69 (0.56 – 0.90)
LLFFMV_L					
Intercept			-1.377 (-1.589 – -1.165)		
Body mass			1.262 (1.166 – 1.357)		
∑ skinfolds			-0.173 (-0.290 – -0.056)		
Total model	0.96 (0.92 – 0.98)	0.034 (0.028 – 0.044)		0.94 (0.89 – 0.97)	0.63 (0.51 – 0.82)

The Bland-Altman plot and regression analyses showed that bias between LLV^A and criterion values were related to gender. Estimates for female athletes tended to be further from DXA values than in male athletes (see Figures 3.2 and 3.3). Differences between genders in anthropometric estimates of total LLV may be explained by differences in body mass since the results showed a tendency of increased accuracy of the anthropometric estimates in subjects with higher values of body mass (male athletes, see Table 3.1). Sex differences in lower-body composition may also be a factor contributing to higher bias in the female athletes. Females tend to have higher body fat (absolute and relative) than males (230-232), and estimated fat mass is higher in females compared to males from late childhood through adolescence into young adulthood (219). Of relevance to the present study, adolescent athletes tend to be leaner than non-athletes, and in young adult athletes, within corresponding sports, percentage fat is, on average, greater in females compared to male athletes (219). The non-significant bias of the difference between right and left lower limb measures suggests that the imprecision of anthropometry contributes to bias between practical and criterion estimates. Estimated variation in fat mass between sexes may indicate that the bias in volume estimates is not due to the measurements per se, but due to the limitation of the anthropometric method in estimating the ‘real’ FFM composition.

Muscular strength is related to body size and/or muscle size (190). Strength testing is performed routinely in studies of its development and determinants in children and adolescents. They are also by physiotherapists to assess the degree of muscular disability and recovery. Moreover, it has been recently argued that LLV as an indicator of active muscle mass may be the most relevant allometric denominator for the scaling of maximal oxygen uptake in samples heterogeneous for body size and composition (181).

To our knowledge, this may be the first study aimed to develop and cross-validate anthropometric equations for LLV based on DXA estimates in late adolescent and young adult athletes. The predictive models using anthropometric estimates were shown to be valid and non-biased, and to accurately predict LLV relative to DXA estimates as the reference. A high percentage of variance was explained by the prediction models (95% to 97%) and body mass identified was the main predictor of criterion estimates. There were no significant mean differences between predicted and measured LLV. Additionally, all derived equations presented high values of R_{PRESS}^2 and low $\mathrm{SEE}_{\mathrm{PRESS}}$ (Table 3.3). Given the sample size in this study, the PRESS method was used to avoid data splitting (225) and permitted the use of a larger number of individuals to develop and cross-validate the new LLV predictive equations. The PEs indicated that the slopes and intercepts of the regressions did not differ from the line of identity. This technique was used as an indication of standard deviation of error relative to the line of identity (226). Small limits of agreement were found and the relationship between residuals and predicted LLV from derived equations showed no significant trend line (see Figures 3.4 and 3.5) suggesting that the new equations fit LLV in late adolescent and young adult athletes of both sexes regardless of body size.

CONCLUSION

In conclusion, anthropometric technique is a valid method to quantify lower-limb volumes in late adolescent/young adult athletes of both sexes, and is practical when more expensive and complex techniques are not available. However, the lower accuracy observed in females might be due to the sex differences in lower-body composition (larger variability of fat mass in female compared with male) (231, 232). It is noteworthy that including age, body size and lower-limb skinfolds might increase the precision of LLV estimates using anthropometry, both for male and female subjects.

ACKNOWLEDGMENTS

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CHAPTER 4

Cross-validation and reliability of the Line-Drill test of anaerobic performance in 14 to 16 years-old basketball players

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This study evaluates the validity and reliability of the Line Drill (LD) test of anaerobic performance in 76 male basketball players 14.0 to 16.0 years of age. The Wingate test (WAnT) was used as the reference for anaerobic performance. WAnT and LD were moderately correlated (0.39 and 0.43, $p < 0.01$). Estimated age at peak height velocity (APHV) was moderately, negatively and significantly ($p < 0.01$) correlated with WAnT peak ($r = -0.69$) and mean ($r = -0.71$) power; earlier maturing players had greater anaerobic power. Training experience was not associated with anaerobic performance, but chronological age and estimated APHV were significant covariates of the LD ($p < 0.05$). National players were better than local players on the LD ($p < 0.01$) after controlling chronological age and body size. Short-term reliability of the LD ($n = 12$, 1 week interval) was good: technical error of measurement = 0.44 s (95% CI 0.31 – 0.75 s), intraclass correlation = 0.91 (95% CI 0.68 – 0.97), coefficient of variation = 1.4% (95% CI 1.0 – 2.3%). Although the relationship between the LD and WAnT was moderate, the LD effectively distinguished local and national level adolescent basketball players. In contrast to WAnT, the LD was not influenced by estimated biological maturity status. Thus, the LD may be suitable for field assessment of anaerobic performance youth basketball programs.

Keywords: Adolescents, athletes, field testing, biological maturation, maturity offset

INTRODUCTION

Basketball, as many other team sports, involves short, intense and repeated episodes of activity that require rapid changes in direction (24-26). The physical demands of basketball vary with age of athletes, level of competition and coaching strategies. Given the intermittent nature of basketball (24), the physiological requirements of the sport place major demands on the cardiovascular and metabolic capacities of players. Although the majority of play time is devoted to activities aerobic in nature (25, 32), anaerobic metabolism makes an important contribution to the energy demands of basketball (25). Anaerobic performance is a predictor of playing time in youth (33) and of playing level (34) in adults.

Field tests of aerobic endurance have been validated in pre-senior basketball players (52). In contrast, anaerobic fitness has been ordinarily measured with the laboratory-based Wingate Anaerobic test (WAnT) which has reasonable reproducibility in adolescent athletes (127). However, its specificity for athletes in non-cycling sports has not been established.

Several repeated-sprint tests have been proposed for the field assessment of anaerobic performance (134-136). The Line Drill test (LD) has been proposed as a viable and practical test of the anaerobic performance of basketball players in field conditions (233). Although there is interest in the LD and emerging evidence of its applicability to anaerobic fitness assessment (22, 52, 126, 234, 235), most of available data were collected using manual chronometers, which may be a source of variability in estimates of reliability and validity.

Physiological tests are often included in talent identification test batteries using a multidimensional approach (18, 20, 236). Mid- to late-adolescence in males, about 14-16 years, is often considered as an initial phase for prediction of success in basketball and other team sports (13) in part because most boys have progressed through the adolescent growth spurt, although inter-individual variability is considerable (14). It is possible that the concurrent validity between laboratory and sport-specific field tests is affected by maturity status of adolescent players in addition to chronological age per se and years of training in the sport.

The purpose of the present study is to determine the reliability of the 140-m LD field test of anaerobic performance and to examine its relationship with the WAnT in youth basketball players 14 to 16 years of age. The study also examines the relationships between the anaerobic tests controlling for chronological age, years of training and estimated biological maturity status, and the effectiveness of the field and laboratory protocols to distinguish adolescent basketball players by competitive level (construct validity).

METHODS

Experimental approach to the problem

The study is cross-sectional in design. Given the importance of anaerobic energy supply (34) and basketball-specific movement demands (24, 25), a running field-test involving shuttle running over 28 m (approximately court length) as in LD may be a practical alternative to laboratory assessments of anaerobic capacity in basketball.

Reliability in the LD was based on replicate tests in a subgroup within a period of 3 to 5 days. To examine criterion validity, LD performance was compared with WAnT power outputs, using the latter as criteria or gold standard. After reliability and criterion validity were established, construct validity was examined by comparing anaerobic performance of adolescent basketball players of different competitive levels. Additionally, chronological age, years of training in basketball and estimated biological maturity status were statistically controlled to determine if criterion and concurrent validity between laboratory and sport-specific field tests was affected by maturation in addition to age and years of training in the sport.

Subjects

The sample included 76 male basketball players 14.0 to 16.0 years of age at the time of testing. All players were of Portuguese ancestry except for four who were of African ancestry. Players were classified as under 16 (U16) by the *Federação Portuguesa de Basquetebol* (Portuguese Basketball Federation). Two competitive levels were represented in the sample: national and local. The former included 24 players who regularly trained at the national centre for elite basketball players, while the latter included 52 players from five local level clubs. Participation in the study was voluntary. Each participant's parents or legal guardians provided written informed consent prior to participation in the study. Players also provided informed consent. The nature of the study and any possible risks associated with participation were explained to the youth and parents in compliance with the Declaration of Helsinki. All procedures were approved by the *Scientific Committee* of the *Faculty of Sport Science and Physical Education* of the *University of Coimbra*.

Procedures

Chronological age (CA) was recorded to the nearest 0.1 year by subtracting birth date from the date of the mid-testing period. The variables considered in this study were part of a larger battery of observations made on the players over a one month interval. Stature and sitting height were measured with a portable stadiometer (Harpenden model 98.603, Holtain Ltd, Crosswell, UK) to the nearest 0.1 cm. Body mass was measured with a portable balance (Seca model 770, Hanover, MD, USA) to the nearest 0.1 kg. Leg (subischial) length was estimated as stature minus sitting height. Anthropometric dimensions were taken by a single individual following the procedures described by Lohman and colleagues (221). Intra-observer technical errors of measurement for height, sitting height and weight were 0.27 cm, 0.31 cm and 0.47 kg, respectively, which were well within the range of intra- and inter-observer errors in several surveys in the United States and a variety of field studies of young athletes (200).

Age at peak height velocity (APHV) was estimated with the maturity offset protocol (69).The technique estimates time before or after PHV from CA, height, sitting height and estimated leg length (height minus sitting height) in cm, and weight in kg as follows:

$$\text{Maturity Offset} = -9.236 + (0.0002708 * (\text{Leg Length} * \text{Sitting Height})) + (-0.001663 * (\text{Age} * \text{Leg Length})) + (0.007216 * (\text{Age} * \text{Sitting Height})) + (0.02292 * ((\text{Weight} / \text{Height}) * 100))$$

Negative values indicated time before PHV and positive values indicated time after PHV. Negative offset values were added to and positive offset values were subtracted from CA to estimate APHV.

Years of training was obtained by interview and confirmed in the online database of the *Federação Portuguesa de Basquetebol* (237).

Anaerobic Testing

Subjects were instructed not to eat for at least 3 hours before each testing session and not to drink coffee or beverages containing caffeine for at least 8-h before testing. Assessments were made at the same time of the day (6:00 to 7:00 PM for field tests, 3:00 to 6:00 PM for laboratory tests). Subjects wore similar clothing and the same footwear on each testing occasion.

The anaerobic tests were completed within a two week period with at least 48-h between test sessions. Data collection for national level players occurred in the last week of September, the early phase of the season. Data collection for local level players was completed during a pre-competitive period in December.

After a standardized warm-up, athletes completed the 30-s WAnT test (208) on a friction-loaded cycle ergometer (Monark 824E, Monark AB, Vargerg, Sweden) that was interfaced with a microcomputer and calibrated for pedal speed and applied resistance. The resistance was set at 0.075 kg (0.74 N) body mass. WAnT began with minimal resistance (basket supported) at 60 rev.min^{-1}. On the command “go”, the resistance was applied abruptly and simultaneously the computer was activated. Athletes remained seated during the test and were verbally encouraged for an all-out effort throughout the test. Measurements included anaerobic peak power (PP, highest mechanical power generated any 5-s period) and mean power (MP, average for the 30-s period). Both were expressed as watts.

In the LD protocol, subjects ran 140 m as fast as possible in the form of four consecutive shuttle sprints of 5.8, 14.0, 22.2 and 28.0 m on a regulation basketball court. Athletes began the test behind a starting gate of photoelectric cells (Globus Ergo Timer Timing System, Codogné, Italy) set at 1 m of the baseline of the basketball court. Time was recorded by the split gate placed on the baseline where athletes changed directions in the shuttle runs (figure 4.1). Verbal encouragement for an all-out effort was given throughout the test.

Statistical analysis

Descriptive statistics for CA, experience/training, anthropometric dimensions, estimated APHV and anaerobic performance were calculated. The assumption of normality was checked by the Kolmogorov-Smirnov test, with Lilliefors’ significance correction, and by visual inspection of normality plots. No assumptions were violated.

The technical errors of measurement (TEM), coefficients of variation (CV) and intraclass correlation coefficients (ICC) were calculated based on the replicate tests of anaerobic performance (196). Uncertainty in the difference between the first and second trials was expressed as the 95% confidence interval (CI). Data were checked for heteroscedasticity using plots of the log transformed data and reliability measurements (absolute and percent typical errors) were calculated (199).

Pearson correlations were calculated between each anaerobic indicator (LD, PP and MP) and CA, estimated APHV and training experience. Correlations between the field (LD) and laboratory (PP, MP) anaerobic indicators were calculated first as zero order and then as partial correlations controlling first for CA and estimated APHV and then for CA, stature and body mass. Using Hopkins (238) as a guide, correlations were considered as trivial ($r < 0.1$), small ($0.1 < r < 0.3$) moderate ($0.3 < r < 0.5$), large ($0.5 < r < 0.7$), very large ($0.7 < r < 0.9$) and nearly perfect ($r > 0.9$).

Anaerobic indicators (LD, PP, MP) were also compared between elite and local level players using one-way ANOVA and ANCOVA (with CA, estimated APHV and body size as covariates). Significance was set at $p < 0.05$. Statistical analyses were performed using SPSS version 17.0 software (SPSS, Chicago, IL).

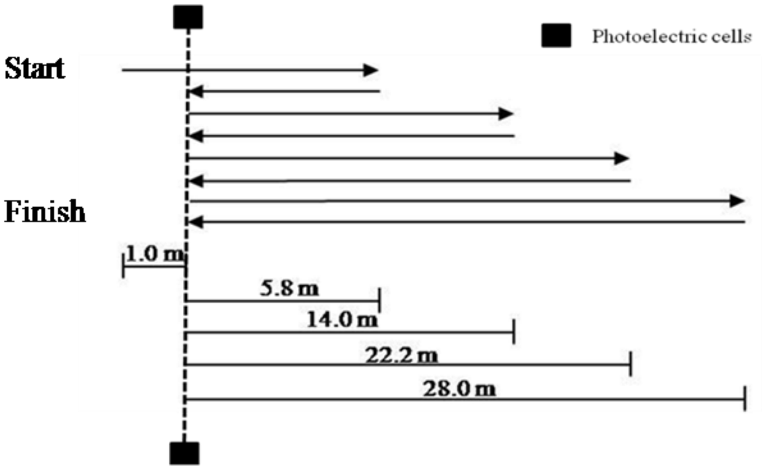

Figure 4.1. Course for the Line Drill Test.

RESULTS

Characteristics of the total sample of youth basketball players are shown in Table 4.1. All maturity offset values were positive except one, indicating that the sample was beyond the age at maximum growth rate in height during the adolescent spurt.

Table 4.1. Descriptive statistics for the total sample (n=76).

	Mean	*SD*	Range
Chronological age (years)	15.2	0.5	14.0 – 16.0
Years of formal training (years)	5.9	2.5	1.0 – 11.0
Stature (cm)	177.7	9.5	155.1 – 197.2
Sitting height (cm)	92.4	4.7	80.9 – 103.2
Estimated leg length (cm)	85.4	5.4	72.5 – 99.0
Body mass (kg)	68.2	9.5	44.6 – 104.5
Maturity offset (years)	1.8	0.8	-0.23 – 3.36
Estimated age at PHV (years)	13.4	0.7	12.0 – 15.0
Line-Drill test (s)	31.02	1.39	28.43 – 35.20
WAnT peak power (watt)	642.3	130.0	357 – 1011
WAnT mean power (watt)	551.3	108.7	312 – 917

Reliability Analysis

The difference (mean of mean differences) between trials of the LD test was 0.2% (95% CI -1.0 – 1.4%) which corresponded to 0.05 s (95% CI -0.35 – 0.45 s). The TEM was 0.44 s (95% CI 0.31 – 0.75 s), the CV was 1.4% (95% CI 1.0 – 2.3%), and the limit of agreement was 4.3% (Figure 4.2). The retest correlation was 0.91 (95% CI 0.68 – 0.97).

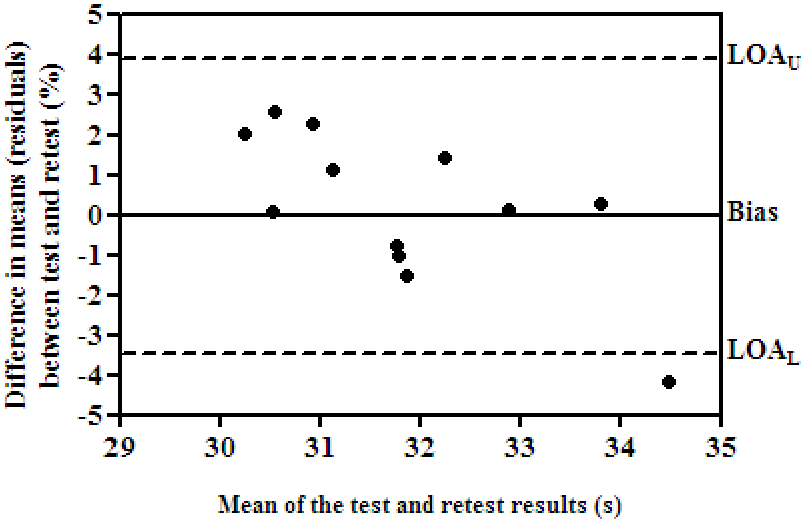

Figure 4.2. Differences between Line Drill test and retest measured against the average performance for the two test sessions. Differences are expressed as a percentage of the average of the Line Drill test and retest. The bias line and the upper and lower 95% limits of agreement (LOA$_U$ and LOA$_L$, respectively) are also presented.

Validity analysis

Correlations between anaerobic indicators and CA, estimated APHV and basketball experience are summarized in Table 4.2. Correlations between CA and PP (*r* = 0.36) and MP (*r* = 0.35) were significant (*p* < 0.01) but moderate in magnitude. Corresponding correlations between estimated APHV and laboratory-based estimates of anaerobic performance were higher and significant (*p* < 0.01), PP (*r* = -0.69) and MP (*r* = -0.71). The negative correlations indicated higher PP and MP in earlier maturing players. In contrast, correlations of CA and estimated APHV with LD were low and not significant, *r* = 0.18 and *r* = -0.19, respectively. Neither LD nor WAnT was significantly correlated with years of training in basketball.

Table 4.2. Correlations between anaerobic performance indicators and age, training experience and estimated age at peak height velocity (APHV).

	Chronological age	Years of formal training	APHV
Line-drill[1]	0.18	0.13	-0.19
WAnT peak power	0.36**	0.00	-0.69**
WAnT mean power	0.35**	-0.07	-0.71**

[1] Signs are reversed since a lower time on the line drill indicates a better performance.
** (I<0.01)

Correlations between the LD field test and PP and MP based on the 30-s cycle ergometer test are presented in Table 4.3. LD time and WAnT power outputs were significantly correlated (p 0.01), PP $r = 0.39$ and MP $r = 0.43$, but the correlations were moderate at best. Controlling for CA and estimated APHV did not alter the correlations, but controlling CA and body size, increased the correlations somewhat, PP $r = 0.47$ and MP $r = 0.55$ ($p < 0.01$).

Table 4.3. Correlations between Line-drill test and WAnT power outputs controlling chronological age (CA), estimated age at peak height velocity (APHV) and body size.

	Bivariate correlation	Partial correlation	
		CA, APHV	CA, stature, body mass
Line-drill vs. WAnT peak power [1]	0.39**	0.33**	0.47**
Line-drill vs. WAnT mean power [1]	0.43**	0.40**	0.55**

[1] Signs are reversed since a lower time on the line drill indicates a better performance.
** ($p<0.01$)

Comparisons of players by level of competition are summarized in Table 4.4. National level players had significantly better anaerobic performances than local level players ($p < 0.01$). Controlling for CA and body size and for CA and estimated APHV with ANCOVA, indicated significant differences between national and local players for the LD test but not for WAnT power outputs.

DISCUSSION

Given the popularity of line drills as a conditioning exercise in basketball training (126), the reliability and validity of the LD protocol under standardized conditions was examined in the context of youth basketball. The running field test of anaerobic performance had high reliability and acceptable validity. The LD is thus an appropriate field test of anaerobic fitness in adolescent basketball players.

The test-retest correlation in the present study, r = 0.91, was consistent with that reported by Hartley et al. (239) for 10 subjects, r = 0.93. However, information on measurement procedures and subject characteristics was not reported. The CV in the present study, 1.4%, was identical with that reported by Hartley et al. (239). Although the LD test had good reliability in the subsample of 12 players, performances tended to decline slightly, on average, from the first to the second trials. Additionally, the plot of residuals in the reliability analysis (Figure 2) showed a tendency for residuals to become more scattered about the zero line among athletes with better times. Familiarity with the testing protocol may have contributed to the high reliability since the test is often described as a conditioning exercise for basketball (126). Intra- and inter-individual differences in motivation and fatigue are potential factors that need to be considered when using this anaerobic testing procedure. The low CV, 1.4% (95% CI = 1.0 – 2.3%), suggests relatively little within-subject variation between trials. Both intra- and inter-individual variation are reflected in the retest correlation, which indicates the maintenance of group position (rank order) on the tests. Thus, simply reporting the correlation may be an insufficient indicator of reliability (199).

Table 4.4. Comparison of anaerobic performance by competitive level groups among 14-15 years-old basketball players (ANOVA), controlling for chronological age (CA) and estimated age at peak height velocity (APHV), and for CA, stature and body mass (ANCOVA).

	National level (n=24)		Local level (n=52)				ANCOVA			
	Mean	*SD*	Mean	*SD*	F	η^2	CA, APHV	η^2	CA, stature, body mass	η^2
Line-drill (s)	30.15	0.94	31.42	1.39	16.59**	0.183	10.83*	0.131	12.89**	0.154
PP (watt)	746.5	113.3	594.2	107.6	31.83**	0.301	0.74	0.010	0.38	0.005
MP (watt)	639.8	97.3	496.0	79.4	33.26**	0.310	0.88	0.012	0.10	0.001

** ($p<0.01$)

The cross-validity of the LD test was verified by comparison with the WAnT which is commonly considered the reference for anaerobic testing. This test has been used extensively and in a variety of settings with pediatric populations spanning childhood through adolescence (127, 240). In these contexts, the test was highly reliable and sensitive. Adolescent basketball players in the present study generated values of PP and MP (Table 1) comparable to those for male subjects of corresponding ages (124, 125, 241, 242), allowing for variation in protocols and instruments. Subjects in the present study, however, presented lower values in both PP and MP compared to older adolescent/young adult basketball players 17 to 19 years of age (126, 234). This suggests that age per se, late adolescent growth in muscle mass and perhaps the accumulated effects of training may contribute to the variation in results.

Several authors have suggested that no single test best measures all aspects of anaerobic performance (132, 243). However, in adults the metabolic profile of the WAnT is highly anaerobic and is dominated by glycolysis and creatine phosphate breakdown with a minor aerobic component (131). The present data showed a moderate correlation between performance in the WAnT and the LD, in particular with MP, suggesting that LD may measure in part the same anaerobic properties as WAnT. Although the time to complete the LD was similar to the protocol of the WAnT, the association between the field and laboratory tests may be influenced by differences in movement patterns, running versus cycling. A similar observation between LD and MP was noted among 17 years-old basketball players (126).

The construct validity of a test may be assessed by comparing two different groups of subjects with different abilities (244). The narrow range of variance in LD values reported in the literature may raise questions about the potential value of the protocol to distinguish athletes by level of ability. The best performances on the LD test among players in the present study were within the range of means (28 s to 30 s) reported in several studies of 16 to 19 years old basketball players (22, 52, 126, 234, 235, 245). Error associated with use of manual chronometers and use of different shuttle distances potentially limit generalizations among reported data for the LD. Photoelectric cells were used in LD testing in the present study and the adolescent basketball players were distinguished by playing ability on the basis of the LD test. The value of this protocol in distinguishing athletes by playing level was highlighted by its independence of estimated maturity status (Table 4). This is relevant since growth- and maturity-related changes during adolescence needs to be considered when evaluating test results and outcomes of talent identification and development programs (13).

Correlations between indicators of anaerobic performance and estimated APHV were negative (Table 2), suggesting that earlier maturing players have better anaerobic performances under laboratory conditions. On the other hand, the correlation between LD performance and estimated APHV was low and not significant (Table 2). The issue of maturity-associated variation in anaerobic performance has not received much attention (49). Some evidence indicated an increase in PP and MP in boys classified as prepubertal, pubertal and mature (120). However, chronological age varied within and among the three maturity groups and was not statistically controlled in the analysis. This is relevant because anaerobic performance improves with age during adolescence independently of pubertal status (14). It is likely that maturity exerts an influence on anaerobic performance via body size and muscle mass. Within a given age group of adolescent boys, those advanced in maturation are, on average, taller and heavier and have a larger muscle mass than boys later in maturation (14). Some limited data for adolescent boys suggest an independent maturity effect on PP and MP that was more apparent in the later stages of sexual maturation, specifically, stages 4 and 5 of pubic hair development (123). Given the age range of the present sample of basketball players, the negative association between estimated APHV and PP and MP was consistent with these observations.

Training experience in basketball was not associated with the three indicators of anaerobic performance (Table 2). It is likely that experience expressed in years was not a sufficiently sensitive indicator of training, i.e., intensity and regularity. Potential effects of training on anaerobic performance are also likely confounded by normal growth and maturation during male adolescence.

PRACTICAL APPLICATIONS

The LD is a sport-specific field test of anaerobic performance in adolescent basketball players. The test provided reliable data and successfully differentiated adolescent players by competitive level. Moreover, LD performance was independent of estimated maturity status in the sample of players 14 to 16 years of age. As such, the results should be of interest to coaches, sport scientists and others involved in the selection and development of youth basketball players.

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CHAPTER 5

Assessment of reliability in isokinetic testing among adolescent basketball players

Submitted to *Medicina*

Background: The reproducibility of day-to-day testing of isokinetic concentric and eccentric muscular actions among youth basketball players 14 to 16 years, and relationships of average within-subject variation in two isokinetic testing sessions with chronological age (CA), biological maturation (estimated age at peak height velocity), training experience, body size, lower-body morphology and initial strength performance was evaluated. **Material & methods:** The sample included 27 basketball players who completed replicate test sessions of 5 repetitions of reciprocal concentric and eccentric knee extensions and flexions at 60 º s^{-1}. A randomly selected subsample of 8 players completed a third testing session to confirm reliability estimates. **Results:** Coefficients of variation (CV) between sessions one and two ranged from 8.1% to 17.4% and intra-class coefficients (ICCs) ranged from 0.72 to 0.89. For sessions two and three, CVs ranged from 3.9% to 6.0% and ICCs ranged from 0.95 to 0.99. Initial level of strength of eccentric knee flexion (r = -0.43) and eccentric knee extension (r = -0.42) were correlated (P < 0.05) with eccentric knee extension within-variation between two sessions. Training experience (r = -0.37, P < 0.05) and initial values of concentric knee flexion (r = -0.62, P < 0.01) were correlated with concentric knee flexion within-subject differences. Within-subject eccentric knee extension variation was correlated (P < 0.05) with CA (r = 0.41), estimated age at peak height velocity (r = -0.38), body size (r = 0.41 to 0.47) and leg volume (r = 0.39). **Conclusions:** Familiarization sessions may improve reliability of concentric and eccentric knee isokinetic strength testing at 60º s^{-1} in adolescent basketball players. Age, maturity status and training experience of young athletes should be considered when testing knee isokinetic strength at 60º s^{-1}.

Keywords: Maturation, strength, young athletes, anthropometry

INTRODUCTION

Isokinetic dynamometry is generally considered the best protocol of dynamic strength measurements (246). However, the literature suggests inconsistency in application of isokinetic measurement protocols which may hinder data interpretation (146). Valid isokinetic data requires reliable assessment techniques for peak moment of force, mean peak moment of force and angle at peak moment of force. It is suggested that coefficients of variation (CV) should not be greater than ± 6.1% and intra-class correlations (ICC) should be greater than 0.88 (247). Most of the available information, however, is derived from studies of adult males and females.

Minimal measurement error (reliability) of performance of a test refers to the consistency or reproducibility of performance when someone performs the test repeatedly (202). A test with poor reliability is unsuitable for tracking changes in performance between trials, and it lacks precision for the assessment of performance in a single trial (196). The magnitude of measurement error in isokinetic testing in general and in particular with young athletes has not been systematically addressed. Young athletes are a highly select group with regard to skill, performance, size and physique; variation in maturity status is an additional factor affecting growth in size and function especially during adolescence (14, 58).

Studies on the reproducibility of the isokinetic peak moment of force assessment in children and adolescents are limited, especially on the eccentric action mode (149). Several reports using a test-retest design with youth suggest that a familiarization session may reduce learning effects (248) and that familiarization may be more important in protocols which include eccentric actions (249). Learning effects may interfere with statistical estimates of reliability (244).

The purpose of this study was to investigate the reproducibility of day-to-day testing of isokinetic concentric and eccentric muscular actions in youth basketball players 14 to 16 years of age. Measurement error in isokinetic testing is hypothesized. Interrelationships of age, biological maturation, training experience, body size, lower-body morphology and initial strength performance with average within-subject variation between two test sessions of different muscular actions were also examined.

MATERIALS AND METHODS

Experimental approach to the problem

Isokinetic dynamometry is a widely recognized component of assessment in athletes (250). As such, reliability of the protocols is important as it provides an indication of the biological and technical variation associated with assessment procedures and conditions (251).

Day-to-day variation in isokinetic assessments was based on repeated tests within a period of three to five days on the 27 basketball players with at least 48-h between test sessions. The randomly selected group of eight of athletes from the total sample completed a third testing session to confirm attainment of optimal performance after the first testing session. Relationships of within-subject variation between two testing sessions to chronological age, years of formal training, body size, estimated lower-limb volume and initial strength values (first test session) were examined with correlations.

Subjects

The sample group included 27 male adolescent basketball athletes aged 14.0-16.0 years at the time of testing, 25 of Portuguese and two of African ancestry. From this group, eight athletes were tested a third time under the same conditions. Participation in the study was voluntary and each participant’s parents (or legal guardians) were provided informed consent following an explanation (in compliance with the *Declaration of Helsinki*) of the nature of the experiment and of any possible risks associated with participation. All procedures were approved by the *Scientific Committee* of the *Faculty of Sport Science and Physical Education* of the *University of Coimbra*. Chronological age (CA) was recorded to the nearest 0.1 year by subtracting birth date from the date of the date of the first laboratory assessment. Years of formal training was obtained by interview.

Anthropometry

Anthropometry was assessed by a single experienced observer following procedures described in Lohman et al. (221). Stature and sitting height were measured with a portable stadiometer (Harpenden model 98.603, Holtain Ltd, Crosswell, UK) to the nearest 0.1 cm. Leg (subischial) length was estimated as stature minus sitting height. Body mass was measured with a portable balance (Seca model 770, Hanover, MD, USA) to the nearest 0.1 kg. To estimate total leg volume of the dominant leg (210) were measured the following measures: circumferences at the gluteal furrow (the highest possible horizontal circumference), mid thigh (the largest possible mid thigh circumference), minimum circumference above the knee, maximum circumference around the knee (patella level), minimum circumference below the knee, maximum calf circumference and minimum ankle circumference; anterior and posterior skinfolds at the level of mid thigh circumference, as well as the medial and lateral skinfolds at the level of maximum calf circumference; and lengths between each circumference from the gluteal furrow, up to the minimum ankle circumference (e.g. distance between mid thigh and minimum thigh circumferences), sum six partial lengths. Although the protocol is valid, it tended to overestimate lower-limb total volume (approximately 6%) compared estimates based on dual-energy X-ray absorptiometry in 37 young athletes 13–22 years. Correlation between estimated volumes ranged between 0.91 and 0.96 (unpublished results).

Based on 18 participants measured twice within one week, intra-observer technical errors of measurement were 0.54 cm for stature, 0.74 cm for sitting height, 0.88 kg for body mass, 0.29 to 0.74 cm for circumferences and 0.16 to 0.46 cm for lengths. The estimated errors were within the range reported for intra- and inter-observer errors for a variety of studies (200).

Maturity status

Age at peak height velocity (APHV) was estimated with the maturity offset protocol (69). The technique estimates time before or after peak height velocity (PHV) from CA, height, weight, sitting height and estimated leg length (height minus sitting height) as follows:

Maturity Offset = -9.236 + (0.0002708 * (Leg Length *Sitting Height)) + (-0.001663 * (Age * Leg Length)) + (0.007216 * (Age*Sitting Height)) + (0.02292 * ((Body mass / Stature) * 100))

Negative values indicated time before PHV and positive values indicated time after PHV. Negative offset values were added to and positive offset values were subtracted from CA to estimate APHV.

Isokinetic assessment

The isokinetic assessment was completed within a week period with at least 48-h interval between sessions. Subjects were instructed not to eat for at least 3-h and not to drink coffee or beverages containing caffeine for at least 8-h before each testing session. Subjects wore similar clothing and the same footwear on each testing occasion. No participant was suffering from lower extremity musculoskeletal injury at the time of testing or during the 6 months before testing that limited activity for more than 48 hours.

Isokinetic concentric and eccentric knee extension and flexion were measured using a calibrated dynamometer (Biodex System 3, Shirley, NY, USA) at angular velocities of 60 ^{o} s^{-1}. After anthropometric assessment, the subject performed a 10 min cycling warm-up on a Monark cycle ergometer (Monark 814E, Varberg, Sweden) with minimal resistance (basket supported) at 60 rev min^{-1}, and a 2 min of static stretching of the hamstring and quadriceps muscles. Athletes were then placed in a seated position, adjusted according to manufacturer guidelines in a standardized 85^{o} hip flexion from the anatomical position. The lever arm of the dynamometer was aligned with the lateral epicondyle of the knee and the force pad was placed approximately 3 to 5 cm superior to the medial malleolus with the ankle in a plantigrade position. Range of motion during testing was set using voluntary maximal full extension (0 ^{o}) to 90 ^{o} of knee flexion. Cushioning was set using a hard deceleration (according to manufacturer guidelines) and therefore, 90 ^{o} constituted the range of motion tested. At the beginning of each session, the participant was asked to relax his leg so that passive determination of the effects of gravity on the limb and lever arm could be accounted for. The participant was instructed to firmly grasp the hand grips at the sides of Biodex System 3 seat during the test procedure. In the concentric action, the participant was instructed to push the arm lever during extension and pull during flexion as hard and fast as possible; in eccentric action, the subject was instructed to resist the lever arm during extension and flexion as hard as possible. Extension was undertaken first in both muscular action modes.

Each subject performed five continuous maximal repetitions. Each set assessed reciprocal muscular action in the dominant leg. The order of testing started with concentric actions, followed by a 120 s period of rest before the performance of the eccentric actions. Visual feedback of moment versus time was provided during the test, but no verbal feedback was given (148). Maximal knee flexion and extension peak moment of force of the best repetition in both concentric and eccentric muscular actions were retained and expressed as Nm.

Analysis

Descriptive statistics for CA, years of formal training, estimated APHV, body size and replicate isokinetic measures were computed for the total sample. Differences between test sessions were examined using paired-*t* test analysis. Coefficients of variation and ICC were calculated (196). Variability in isokinetic dynamic muscle performance between sessions was expressed as the 95% confidence interval (CI). Heteroscedasticity was checked using plots of the log transformed data. Reliabilities (absolute and percent typical errors) were calculated (196, 199). The effect size correlations (ES-*r*) were estimated using the square root of the ratio of *t*-value squared and the difference between *t*-value squared and degrees of freedom (total amount of variance in the sample) (252).

Relationships between variation in means of the differences between the maximal moment of force in concentric and eccentric muscle actions in the first and second test sessions with CA, estimated APHV, years of formal training, stature, body mass, leg length, leg volume and initial isokinetic strength (first test session) was examined with Pearson correlations. Correlations were interpreted as follows: trivial ($r < 0.1$), small ($0.1 < r < 0.3$) moderate ($0.3 < r < 0.5$), large ($0.5 < r < 0.7$), very large ($0.7 < r < 0.9$) and nearly perfect ($r > 0.9$) and perfect ($r = 1$) (227). Significance was set at $P<0.05$. Statistical analyses were performed using SPSS version 17.0 software (SPSS, Chicago, IL).

RESULTS

Characteristics of the sample are presented in Table 5.1. With the exception of two participants, maturity offset were positive indicating that the sample was beyond the age at maximum growth rate in height during the adolescent spurt. Table 2 shows the differences between means of the two test sessions and CVs and ICCs of the isokinetic strength indicators.

Table 5.1. Descriptive statistics for the total sample (*n* = 27).

	Mean	Standard deviation	Range
Chronological age (years)	15.2	0.5	14.1 – 16.0
Years of formal training (years)	6.0	2.7	2.0 – 11.0
Maturity offset (years)	1.76	0.90	-0.11 – 3.36
Estimated age at PHV (years)	13.50	0.87	11.97 – 15.13
Stature (cm)	176.9	11.9	155.1 – 197.2
Body mass (kg)	68.1	11.7	44.9 – 87.3
Sitting height (cm)	92.1	6.0	80.1 - 103.2
Leg length (cm)	84.0	7.3	61.8 – 97.4
Leg volume (L)	8.84	1.78	5.56 – 11.78

The difference (mean of mean differences as a percentage) between test sessions of concentric muscular actions were 4.6% (95% CI 0.2 – 9.2; $P < 0.05$; ES-*r*= 0.38) and 8.4% (95% CI 0.2 – 17.3; $P < 0.05$; ES-*r* = 0.42) for knee extension and flexion, respectively. For eccentric muscular actions, differences between sessions were 5.1 (95% CI -3.5 – 14.5; $P > 0.05$; ES-*r* = 0.26) and -1.9% (95% CI -10.3 – 7.3; $P > 0.05$; ES-*r* = 0.01) for knee flexion and extension, respectively.

Mean peak moment of force values for the second test session were higher than for the first session in all muscular actions with exception of eccentric knee extension (Table 5.2). Effects sizes of within subject variation were only moderate. The CV for concentric knee extension was 8.1% (95% CI 6.3 – 11.2), while CVs for other muscular actions ranged from 15.1% to 17.4%. The retest correlations ranged from 0.72 to 0.89.

Pairwise CVs between test sessions 2 and 3 for the subsample of eight athletes were 4.9% and 6.0% for concentric knee extension and flexion, respectively, and 3.9% and 5.3% for eccentric knee flexion and extension, respectively (Table 5.3). Corresponding ICCs ranged from 0.95 to 0.99.

Correlations between the variance in within-subject variation between the two test sessions with age, estimated APHV, years of formal training, body size, lower-body morphology (length and volume) and initial strength are presented in Table 4. Variance in within-subject variation for concentric knee extension was not associated with age, years of formal training, body size, lower-body morphology and initial strength. Mean differences between pairwise eccentric knee flexion knee were negatively correlated ($P<0.05$) with session one values of eccentric knee flexion and knee extension. Within-subject differences in mean differences between pairwise concentric knee flexion were correlated with training experience (*P*<0.05) and initial values of concentric knee flexion (*P*<0.01). Within-subject eccentric knee extension variation was significantly (*P*<0.05) correlated with CA, estimated APHV, stature, body mass and leg volume, but the correlations were only moderate.

Table 5.2. Reliability estimates of concentric and eccentric knee flexion and extension peak torque at 60 deg.s^{-1} measured in two sessions in adolescent basketball players .

	Session 1 Mean (SD)	Session 2 Mean (SD)	Mean Differences (95% CI)	CV (%) (95% CI)	ICC (95% CI)
n = 27					
knee ext con (Nm)	172.4 (36.9)	180.0 (37.2)	7.6 (0.2 – 14.9)	8.1 (6.3 – 11.2)	0.89 (0.77 – 0.95)
knee flex ecc (Nm)	220.0 (69.2)	230.2 (70.2)	10.0 (-5.9 – 25.9)	16.5 (12.8 – 23.0)	0.78 (0.58 – 0.90)
knee flex con (Nm)	95.5 (21.7)	102.5 (24.1)	7.2 (1.0 – 13.4)	15.1 (11.7 – 21.2)	0.74 (0.51 – 0.87)
knee ext ecc (Nm)	157.7 (41.0)	157.4 (49.0)	-0.3 (-13.1 – 11.9)	17.4 (13.4 – 24.5)	0.72 (0.47 – 0.86)

Flexion (flex); extension (ext); concentric (con); eccentric (ecc)

Table 5.3. Reliability estimates in the subsample of adolescent basketball players tested on a third occasion.

	CV (%) between Sessions 2 and 3 (95% CI)	ICC between Sessions 2 and 3 (95% CI)
n = 8		
knee ext con	4.9 (3.2 – 10.2)	0.95 (0.76 – 0.99)
knee flex ecc	3.9 (2.5 – 8.8)	0.99 (0.92 – 1.00)
knee flex con	6.0 (4.0 – 12.2)	0.95 (0.76 – 0.99)
knee ext ecc	5.3 (3.5 – 11.1)	0.97 (0.87 – 0.99)

Flexion (flex); extension (ext); concentric (con); eccentric (ecc)

DISCUSSION

Since statistical analyses revealed differences in reciprocal concentric and eccentric isokinetic assessments at 60º s^{-1} between two trials, overall variability in performance cannot be assumed to represent systematic bias (e.g. general learning effect) and random error (biological or mechanical variation) in adolescent basketball players. One familiarization session appeared to be sufficient to measure reliable data under the specified test conditions. Reliability values of replicate measurements after the familiarization session were consistent with CVs (<6.1%) and ICCs (≥0.88) reported in the literature (146, 202).

Studies of the reproducibility of isokinetic peak moments of force measurements are limited, specifically for eccentric actions. Retest correlations for concentric peak moment of force of knee extensors and flexors in boys aged 6–8 years tested in three sessions with 3 days of rest between sessions, using a velocity of 100 º s^{-1}, ranged from 0.85 to 0.95 (248).

Among pubertal (pubic hair stage 3) soccer players 13 years of age, ICCs for concentric and eccentric knee extensors and flexors of the dominant leg ranged from 0.85 (eccentric) to 0.98 (concentric) (249). Coefficients of variation of 4% and 9.9% for eccentric peak moment of force were noted in boys 11 years of age (253). It was suggested that reliability could have been improved by a familiarization session. Test-retest correlations in the present study after familiarization were consistent with range of values reported for concentric actions but higher than ICCs reported for eccentric muscular actions. Nevertheless, the reliability estimates from the familiarization session to the second test were lower than values reported in children, and exceeded the limit of values proposed for good reliability in isokinetic strength assessment (146, 202).

Table 4. Correlations between variance in within-subject variation between two trials of isokinetic muscular actions at 60 º s^{-1} with age, maturity status, years of formal training, body size, lower limb morphology and initial strength in adolescent basketball players.

	Mean differences between pairwise knee ext con	Mean differences between pairwise knee flex ecc	Mean differences between pairwise knee flex con	Mean differences between pairwise knee ext ecc
Age	0.25	0.29	0.18	0.41*
Age at PHV	-0.14	-0.09	-0.06	-0.38*
Years of formal training	-0.33	-0.37	-0.37*	-0.36
Stature	0.10	0.10	-0.01	0.41*
Body mass	0.19	0.22	0.04	0.47*
Leg length	0.07	0.05	-0.04	0.28
Leg volume	0.15	0.20	0.11	0.39*
Trial 1 knee ext con	-0.33	0.02	-0.28	0.11
Trial 1knee flex ecc	-0.02	-0.43*	-0.28	0.08
Trial 1 knee flex con	-0.11	-0.24	-0.62**	0.10
Trial 1 knee ext ecc	-0.08	-0.42*	-0.35	-0.09

** $P < 0.01$;* $P \leq 0.05$; Flexion (flex); extension (ext); concentric (con); eccentric (ecc)

Few studies have analyzed possible learning effects during day-to-day testing of isokinetic strength. No differences in concentric peak moment of force in the knee extensors and flexors at 60 º s^{-1} were noted in adult men and women (247), but comparable data for eccentric knee muscular actions in general and specifically for younger subjects or athletes are lacking. Differences between the first and second test sessions in the adolescent basketball players and the reliability estimates for the familiarization session (*n* = 8) suggested a need to account for either systematic bias and/or random error in both concentric and eccentric muscular actions when testing young athletes inexperienced in isokinetic strength testing. The reproducibility in isokinetic strength might be related to biological variation.

Several factors affecting reliability have been noted in the literature (202, 254). At the speed used in the present study isokinetic dynamometry is a valid and reliable testing tool (255). All measurements were made by a single experienced observer. Reliability estimates of the observer for the used protocol, based on repeated measurements in 13 subjects (university students, age 21.1 ± 3.1), were: concentric knee extension, CV=4.1% and ICC= 0.98; concentric knee flexion, CV=4.1% and ICC=0.98; eccentric knee extension, CV=5.2% and ICC=0.97; eccentric knee flexion, CV=4.8% and ICC= 0.97. In order to control potential effects of time-of-day, replicate data were obtained at the same time of day within ±30 min (256). Therefore, it is possible to assume that within-subject variation in the adopted protocol of isokinetic strength assessment is mainly related to subject-specific factors.

Factors related to subjects, particularly specific issues in pediatric populations, and assessment conditions that may influence dynamometric measurements of extremity muscles have been addressed in the literature (146, 149, 257). Potential factors include variation in chronological age per se, body size (stature and body mass), limb dominance, presence of impairment, and athletic background; variation in biological maturity status is an additional consideration. Body size, in particular body mass, apparently influences the magnitude of isokinetic moment of force production in youth populations (253). Muscle mass has also been indicated as a relevant covariate in the interpretation of isokinetic strength in youth (258), but intra-subject variation does not appear to be related with this measure. It is possible that individual differences in maturity status may influence strength through its effect on body size and muscle mass. Within a given age group of adolescent boys, those advanced in maturation are, on average, taller and heavier and have a larger muscle mass than boys later in maturation (14). To our knowledge, no study has apparently addressed the possible contribution that chronological age per se, late adolescent growth in muscle mass (peak rate of growth in muscle mass occurs on average after peak height velocity) and accumulated effects of training to reliability estimates in isokinetic dynamometry.

Age, estimated maturity status, training experience and body size were the variables correlated with mean within-subject variation between two sessions of isokinetic strength of the hamstrings muscles assessed at 60 ^{o} s^{-1} (concentric knee flexion and eccentric knee extension) and in particular for eccentric contractions (Table 5.4). The results highlight the importance of age, maturation and body size in the consideration of reliability of assessments of knee flexion muscles in adolescent basketball players. As for assessment of quadriceps muscles (concentric knee extension and eccentric knee flexion), within-subject variation in the concentric action was smaller than in the other muscular actions, and closer to reported values in literature. Moreover, within-subject variation in eccentric actions was negatively related to performance values in the familiarization session in both eccentric knee actions. Therefore, higher reliability estimates between the familiarization session and second test may be related to higher values of strength in this muscle group.

The issue of maturity-associated variation in isokinetic strength performance has not received much attention (149). Some evidence indicated an increase in concentric knee extension and flexion with age in boys and girls, athletes, but without statistically controlling for inter-individual variability in growth and maturation in the analysis (40, 171, 259). This is relevant because short-term power outputs improve with age during adolescence independently of pubertal status (14). It is likely that maturity exerts an influence on isokinetic strength performance via body size and muscle mass. Within a given age group of adolescent boys, those advanced in maturation are, on average, taller and heavier and have a larger muscle mass than boys later in maturation (14). Some limited data for male adolescent soccer players boys an independent maturity effect on isokinetic indicators in the knee joint, albeit the limitations of the use of self-reported sexual maturation (260). Overall, the one interested in assessing lower-body isokinetic strength should consider biological inter-individual variation and fitness level as factors that significantly affect measurement reliability. On the other hand, learning effects, i.e. systematic bias, seem to diminish after familiarization session, allowing more reliable data in adolescent basketball players.

CONCLUSIONS

A familiarization session may improve reliability of assessment when using concentric and eccentric knee isokinetic strength testing at 60º s^{-1}, and improve the evaluation of the effectiveness of strength training programs or clinical assessments of adolescent basketball players. Intra- and inter-individual differences in chronological age, maturity status and accumulated experience are potential factors that should be considered when using knee isokinetic strength testing at 60º s^{-1}, in particular for the assessment of the hamstrings muscular actions.

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CHAPTER 6

Normalising maximal short-term performance to body dimensions in adolescent athletes

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Introduction: Several determinants of short-term power outputs are related to body dimensions in youth. Hence, body dimensions on anaerobic performance should be measured in analyses of short-term power performance in youth to permit appropriate interpretations of factors that influence performance. The aim of this study was to examine the influence of body dimension on short-term performance using body mass (BM), fat-free mass (FFM) and estimated lower-limb volume (LLV) as separate scaling factors in young athletes aged 14 to 16 years.
Methods: Subjects included 152 adolescent male athletes (91 basketball and 61 roller-hockey players) 13.9 to 16.5 years (15.3± 0.6 years). Stature and BM were measured. FFM and LLV were estimated anthropometrically. Short-term power outputs were measured with the Wingate Anaerobic Test [peak power (PP) and mean power (MP)]. Common size b exponents for BM, FFM, and LLV were calculated using nonlinear allometric modeling. Residual size correlations were calculated using Pearson product-moment correlations to assess the independence of body dimensions (stature, BM, FFM, LLV) of the power function ratios, including commonly expressed power outputs by BM^{-1} and recommended allometric exponent of 0.67 (Jaric et al 2005).
Results: The estimates for size exponents (95% CI) from the separate allometric models for PP and MP were, respectively: BM 0.87 (0.76 – 0.99) and 0.85 (0.75 – 0.95), FFM 0.75 (0.62 – 0.89) and 0.75 (0.63 – 0.86) and LLV 0.81 (0.70 – 0.93) and 0.78 (0.68 – 0.89). Both PP and MP expressed by BM allometric exponents showed no residual size correlation with all body dimension variables. Both PP and MP expressed by FFM and LLV allometric exponents presented no residual correlation to their respective body dimension variables, but presented substantial residual size correlations to other size variables, indicating that FFM and LLV did not correctly partition out the influence of body dimensions. Short-term power normalisation per unit of BM was not independent of body dimensions ($0.07 < r < 0.25$) systematically penalising young athletes with larger body dimensions. Similarly, the exponent 0.67 was not independent of body dimensions ($0.20 < r < 0.36$), and penalised individuals with smaller body dimensions.
Discussion/Conclusion: Body mass was the most valid allometric denominator to remove the influence of body dimensions on cycle-ergometer short-term power output in this sample of adolescent athletes heterogeneous for body size and composition. Expression of power outputs in BM^{-1} and $BM^{-0.67}$ may provide a biased short-term power estimate, since the influence of body dimensions was not completely partitioned and indexes tended to differentially favor young athletes with extreme body dimensions.

Keywords: Adolescents, athletes, allometry, Wingate Anaerobic Test

INTRODUCTION

Movement patterns in team-sports are characterized by short burst, predominantly short-term maximum intensity activities (e.g. basketball). However, less attention has been provided to maximal short-term power output compared to long-duration performance (49).

Determinants of short-term power output, i.e., muscle quantity, quality, endurance and neuromuscular activation and musculoskeletal architecture, in young athletes in the context of changes associated with growth, maturation and perhaps training (166). Consequently, the influence of body dimensions on short-term exercise should be controlled to allow appropriate interpretations of the factors that influence young athletes´ short-term power performance.

Maximal short-term power outputs are commonly expressed as a ratio standard, or per kilogram of body mass (BM), despite the theoretical and statistical limitations of widely addressed yet largely ignored (173-175). Thus, allometric models, which have been shown to be more appropriate for partitioning body size effects from physiological variable or performance (175), have been used to partition size variables on short-term power outputs in children and adolescents (121, 122, 150, 170, 187), but do not appear to have been used in studies involving young athletes.

Therefore this study examined the influence of body dimension on maximal short-term performance using BM, fat-free mass (FFM) and estimated lower-limb volume (LLV) as separate scaling factors in young athletes aged 14 to 16 years.

METHODS

One hundred and fifty-two adolescent male players, 13.9 to 16.5 years (mean age 15.26 ± 0.56), volunteered for this study. Informed written consent was obtained from athletes and their parents or legal guardians. All participants were engaged in formal training and competition for at least two years (obtained by interview).

Anthropometric measurements included stature and BM. The young athlete’s FFM (261) and LLV (210) were estimated based on anthropometry. Intra-observer technical errors of measurement for the anthropometrical measures were reported elsewhere (262).

The athletes completed the 30-s WAnT test on a friction-loaded cycle ergometer (Monark 824E, Monark AB, Vargerg, Sweden) with resistance set at 0.075 kg (0.74 N) BM. Measurements included peak power (PP, highest mechanical power generated any 5-s period, watts), mean power (MP, average for the 30-s period, watts) (208). Details about procedures and reliability of the WAnT were previously reported (262).

Descriptive statistics for all variables were calculated. Non-linear allometric modeling ($\mathrm{Ln}\ Y = \mathrm{Ln}\ a + b \cdot \mathrm{Ln}\ X + \mathrm{Ln}\ \varepsilon$) was used to derive b exponents to model the relationship between power outputs and body dimensions. Power function ratios (Y/X^b) for each of the scaling denominators were calculated. Residuals analysis was checked via the correlation between the absolute residual and the independent body size variable (Ln BM, Ln FFM and

Ln LLV). If the influence of body size has been removed, the correlation should not be different from zero, regardless of whether they are statistically significant (175).

RESULTS

Characteristics of the total sample of youth basketball players are shown in Table 6.1.

Table 6.1. Descriptive statistics for the total sample (*n* = 152).

	Mean	Standard deviation	Range
Stature. cm	174.4	9.4	150.1 – 199.0
Body mass. kg	65.7	10.9	41.6 – 104.5
Fat-free mass. kg	54.7	8.9	33.1 – 73.5
Lower-limb volume. L	8.73	1.51	5.56 – 14.69
WAnT peak power. watts	613	112	357 – 978
WAnT mean power. watts	523	88	312 – 799

The regression output for the allometric models is summarized in Table 6.2. Correlations between WAnT power outputs and body size descriptors were large and significant (p < 0.01). Overall, the point estimates for the size exponent from the separate allometric models were similar for both WAnT power outputs, and the body size descriptors scaling exponents had a small range (0.75 – 0.87).

Table 6. 2. Allometric modeling of WAnT power outputs for body size variables.

	Body-size descriptor	b	(95% CI)	*R*	R^2
Peak power					
	Body mass	0.87	(0.76 – 0.99)	0.78	0.60
	Fat-free mass	0.75	(0.62 – 0.89)	0.68	0.46
	Lower-limb volume	0.81	(0.70 – 0.93)	0.75	0.56
Mean power					
	Body mass	0.85	(0.75 – 0.95)	0.81	0.65
	Fat-free mass	0.75	(0.63 – 0.86)	0.72	0.52
	Lower-limb volume	0.78	(0.68 – 0.89)	0.77	0.60

Regressions diagnostic showed that the assumption of homocedasticity of residuals was achieved in the log-linear regressions (Figure 6.1), given the near zero correlations between absolute residuals with the predictor variables (Ln BM, Ln FFM and Ln LLV).

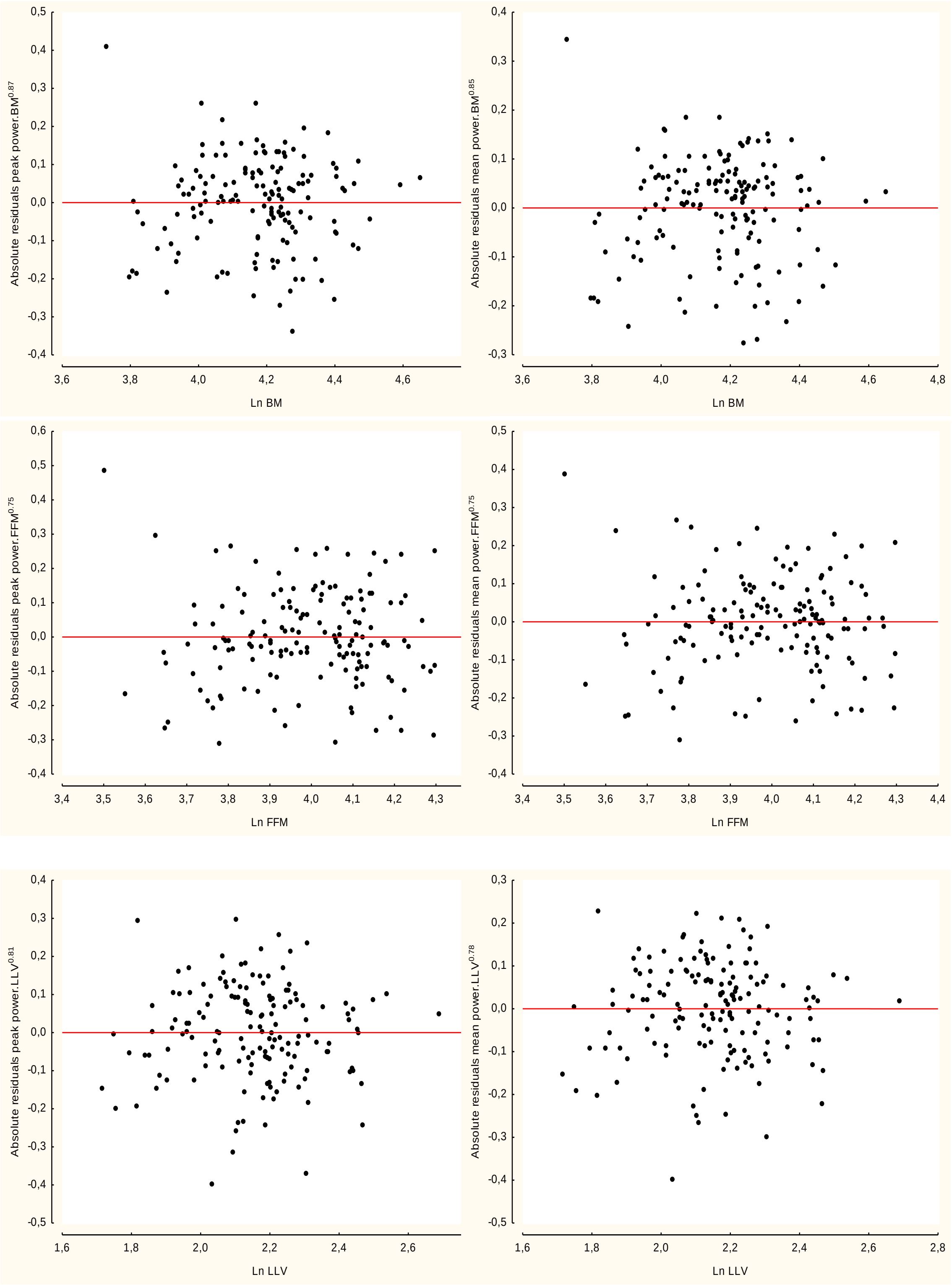

Figure 6.1. Pattern of absolute residuals resulting from allometric models vs. size descriptors Ln is natural log. Solid line, zero line.

Both PP and MP expressed by BM allometric exponents showed no residual size correlation with all body dimension variables. Both PP and MP expressed by FFM and LLV allometric exponents presented no residual correlation to their respective body dimension variables, but presented substantial residual size correlations to other size variables (0.14 < r < 0.38). Short-term power normalisation per unit of BM was not independent of body dimensions (-0.25 < *r* <0.08) systematically penalising young athletes with larger body dimensions. Similarly, the exponent 0.67 was not independent of BM (0.26 < *r* <0.32), and penalised individuals with smaller body dimensions.

Table 6.3. Relationship between allometric function (Y / X^b) and individual body size denominators (X).

	Body mass	Fat-free mass	Lower-limb volume
Peak power.$BM^{-0.87}$	-0.02	-0.01	0.08
Peak power.BM^{-1}	-0.18*	-0.15*	-0.08
Peak power.$BM^{-0.67}$	0.26*	0.23	0.32*
Mean power.$BM^{-0.85}$	-0.02	0.02	0.06
Mean power.BM^{-1}	-0.25*	-0.18*	-0.13
Mean power.$BM^{-0.67}$	0.26*	0.26*	0.32*
Peak power.$FFM^{-0.75}$	0.27*	-0.02	0.38*
Peak power.FFM^{-1}	0.02	-0.29*	0.17*
Mean power.$FFM^{-0.75}$	0.27*	-0.02	0.38*
Mean power.FFM^{-1}	-0.01	-0.34*	0.14
Peak power.$LLV^{-0.81}$	0.14	0.18*	-0.02
Peak power.LLV^{-1}	-0.08	-0.01	-0.26*
Mean power.$LLV^{-0.78}$	0.16*	0.22*	-0.03
Mean power.LLV^{-1}	-0.13	-0.02	-0.34*

** $P < 0.01$; * $P < 0.05$

DISCUSSION

Curvilinear power functions models (log-linear regressions) were an adjusted fit to both PP and MP data, since body size descriptor (BM, FFM and LLV) were largely correlated with the WAnT power outputs, b exponents derived for each size descriptor were markedly different from 1.0 and the models provided body size free scores of maximal short-term performance (Table 6.2). Power outputs of WAnT do not appear to increase in direct proportion to body size, i.e. is not proportional to body $size^{-1}$. However, it continues to be current convention to express physiological measurements, in particular power outputs, as a ratio standard, adjusting the function for body size (e.g., $watt.kg^{-1}$). The use of ratio standards has been criticized (173-175) due to the fact that spurious correlations, misinterpretation of the data and indirect conclusions can follow from use of the method.

The size exponents for PP and MP were higher than the theoretically predicted value of 0.67, based on theory of geometric similarity (190). These results conflict with previous data were short-term power outputs scaled to 0.67 using BM (175). The values of size exponents in this study may be explained in part by lower-limb muscles development at greater rate than that predicted by geometric similarity in young athletes, given the possible interactions between growth, maturation and training stimulus (193). Moreover, limitations of WAnT to assess in young people and young children may also contribute to the size exponents' deviations from theoretical values (122).

Body mass was the body size descriptor that had the highest correlation with PP and MP, and the short-term power outputs partitioned to BM were the only scaled outputs to demonstrate no spurious correlation to all used body size indicators. These results contrast with previous results that reported that lower-limb lean volume was the best predictor for cycling power outputs (170) in young boys, albeit non-athletes, and do not support the argument that it is inappropriate to use total body mass to standardize leg power in exercises where body weight is supported, such as cycling (263).

To conclude, this study confirms the importance of using allometric scaling to account for body size differences when interpreting maximal short-term performance in adolescent athletes.

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CHAPTER 7

Predictors of maximal short-term power outputs in basketball players 14-16 years

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Relationships between growth, maturation and maximal short-term power outputs were investigated in 94 youth basketball player 14-16 years. Data included chronological age (CA), skeletal age (SA), years of training; body dimensions, estimated thigh volume, a running-based short-term exercise assessed by the Line-drill test (LD), the Bangsbo sprint test (BST), and short-term muscle power outputs with the Wingate Anaerobic Test (WAnT). Multiple linear regression analyses were used to estimate the effects of CA, skeletal maturity (SA/CA), years of training experience, body size and lower-limb volume on short-term performance in the LDT, BST and WAnT, respectively. Explained variances differed between cycle-ergometry outputs (52%-54%) and running test performances (23%-46%). The independent effects of predictors were small in the fatigue scores of the WAnT (4%) and the BST (11%). Skeletal maturity, body mass and leg length were primary predictors for all maximal short-term power output measures. Leg length was more relevant as a predictor than stature in the WAnT outputs, while stature and body mass appeared in the model with the running tests as dependent variable. Maximal short-term running abilities were also sensitive to years of training. In summary, skeletal maturation, body size and thigh muscle mass explained moderate to large proportions of the variance on maximal short-term performances of adolescent basketball players. The results highlight the importance of considering maturity status in evaluating the maximal short-term power outputs of adolescent athletes.

Keywords: maturation, growth, lower limb volume, repeated sprint ability, Wingate test.

INTRODUCTION

Movement patterns in basketball rely on short, intense and repeated episodes of activity that require rapid changes in direction (24, 25). Although the majority of play time in basketball is devoted to aerobic activities (25, 32), the ability to produce maximal-intensity efforts is crucial given the intermittent nature of the sport (25). Performance in 30-s all-out sprint tests was a significant predictor of playing time in youth (33) and adult (34) basketball players. However, relatively little is known about short-term power output of male basketball players, especially during adolescent years (31, 35).

Maximal short-term power-output is defined as the highest mechanical power that can be produced during exercise of up to 30 s duration, with the time period depending on the force or load against which the individual has to work and organization of the acceleration (49). The ability to produce cycling or running based short-duration maximal sprints and the capacity to repeat maximal short-term efforts has potentially important physiological implications for many team-sports given the intermittent nature of activities during a competition (35, 52, 53).

The issue of maturity-associated variation in maximal short-term power output has not received much attention (14). There is also the need to consider de determinants of short-term power output, i.e., muscle quantity, quality, endurance and neuromuscular activation and musculoskeletal architecture, in young athletes in the context of changes associated with growth, maturation and perhaps training (166). Maximal short-term power outputs during adolescence are related to body size (49). A combination of variables related to body size (stature, leg length, body mass, lean body mass, leg volume and total muscle mass) explained up to 92% of variance in peak power assessed by the WAnT in young males (86, 120)**.** Further, estimated lean leg volume was strongly associated with short-term power output in youth (Doré et al. 2000). Available data also suggest that factors of qualitative nature should be considered in determining short-term power output (167).

The preceding observations were largely based on males spanning late childhood through adolescence who were not regularly involved in organized competitive sport. Relationships between morphological factors and short-term maximal performance in young athletes engaged in sport-specific training programs merit more detailed consideration. Although elite adolescent athletes within a sport tend to be relatively homogeneous in training history, functional capacity and sport-specific skills, variation in size and maturity status may be considerable during adolescence (36). Adolescent basketball players demonstrate this pattern in addition to potential variation by position within the sport (89). As such, adolescent basketball players may provide a useful model for evaluating relationships among variation in body size, biological maturation and maximal short-term performances. The purpose of this study was, therefore, to examine the relationships between growth and maturation status, on one hand, and maximal short-term power outputs, on the other hand, in adolescent basketball players 14 to 16 years of age.

METHODS

The sample included 94 male basketball players, 14.0 to 16.0 years. Players volunteered for the study and were of Portuguese (n=88) and African (n=6) ancestry. All participants were classified as under 16 (U16) by the *Federação Portuguesa de Basquetebol* (Portuguese Basketball Federation) and were engaged in formal training and competition for at least two years. The study was approved by the *Scientific Committee* of the *Faculty of Sport Science and Physical Education* of the *University of Coimbra* and registered in the *Portuguese Foundation for Science and Technology* [PTDC/DES/70918/2006]. Participants were informed about the nature of the study and were also informed that participation was voluntary and that they could withdraw at any time. Players and their parents or legal guardians provided informed written consent.

Participants were instructed not to eat for at least 3-h and not to drink coffee or beverages containing caffeine for at least 8-h before testing. Assessments were performed at the same hours of the day (6:00 to 7:00 PM for field tests, 3:00 to 6:00 PM for laboratory tests). Subjects wore similar clothing and the same footwear on each testing occasion. All testing procedures were completed within 30 days with at least 48-h between testing sessions.

Chronological age (CA) was calculated to the nearest 0.1 year by subtracting birth date from date of hand-wrist radiographs. The Fels method (84) was used to estimate skeletal maturity. The method utilizes specific criteria for each bone and ratios of linear measurements of epiphyseal and metaphyseal widths as observed/measured on a radiograph of the left hand and wrist. Ratings were entered into a program (Felshw 1.0 Software) to derive skeletal age (SA) and standard error of estimate. The assessments were made by a single observer (HMC) trained by an expert (RMM). Twenty-two radiographs (~20%) were assessed independently on two occasions to determine intra-observer reliability. The mean difference between replicate assessments of SA was 0.22 years with a technical error of measurement of 0.10 years. The estimates were similar with other studies with young athletes (95, 102, 201). SA was divided by CA (SA/CA ratio) to provide an indicator of skeletal maturity at the time of the study. A ratio above one indicated SA was in advance of CA while a ratio below one indicated SA lags behind CA.

Years of training was obtained by interview and confirmed in the online database of the *Federação Portuguesa de Basquetebol* (264). Anthropometric dimensions were taken by a single experienced observer following standard procedures (221). Stature and sitting height were measured with a portable stadiometer (Harpenden model 98.603, Holtain Ltd, Crosswell, UK) to the nearest 0.1 cm. Leg (subischial) length was estimated as stature minus sitting height. Body mass was measured with a portable balance (Seca model 770, Hanover, MD, USA) to the nearest 0.1 kg. Circumferences, measured at the gluteal furrow (the highest possible horizontal circumference), mid thigh (the largest possible mid thigh circumference) and minimum circumference above the knee; and partial lengths, between each circumference location, of the dominant leg were used to estimate total thigh volume (210). The method has often been used in studies with youth populations (150, 167, 170, 187). Based on 18 participants measured twice within one week, intra-observer technical errors of measurement were 0.54 cm for stature, 0.74 for sitting height, 0.88 kg for body mass, 0.29 to

0.74 cm for limb circumferences and 0.16 to 0.46 cm for limb lengths. The estimates were within the range reported for intra- and inter-observer errors for youth (200). A pilot study of the estimation of thigh volume indicated correlations ranging from 0.88 to 0.90 between the anthropometric protocol and dual-energy X-ray absorptiometry in 23 athletes (20.5 ± 1.2 years old). There was no heteroscedasticity but the anthropometric method tended to overestimate lower-limb volumes by 6.4% to 7.2% compared with estimates based on dual-energy X-ray absorptiometry (unpublished results).

After a standardized warm-up, athletes completed the 30-s WAnT test on a friction-loaded cycle ergometer (Monark 824E, Monark AB, Vargerg, Sweden) that was interfaced with a microcomputer and calibrated for pedal speed and applied resistance. Resistance was set at 0.075 kg (0.74 N) body mass. The WAnT test began with minimal resistance (basket supported) at 60 rev·min^{-1}. On the command "go", the resistance was abruptly applied and the computer was activated simultaneously. Athletes remained seated during the test and were verbally encouraged to give an all-out effort throughout the test. Measurements included peak power (PP, highest mechanical power generated any 5-s period, watts), mean power (MP, average for the 30-s period, watts) and fatigue index (FI, peak power minus lowest power divided by peak power) (208). Coefficients of variation based on replicate tests in 20 subjects were 2.8%, 3.2% and 8.7% for PP, MP and FI, respectively.

Running based maximal short-term performance in field conditions was measured by Line Drill Test (LD) and Bangsbo Sprint Test (BST). In the LD protocol subjects ran 140 m as fast as possible in the form of four consecutive shuttle sprints of 5.8, 14.0, 22.2 and 28.0 m on a regular basketball court. Details and reliability of the LD have been reported (265). The BST (266) included seven consecutive sprints (about 35-m sprint with a slalom) with a recovery period of 25 s between sprints during which the subject ran/walked from the end line back to the starting line. Time was measured with photoelectric cells (Globus Ergo Timer Timing System, Codogné, Italy). Test scores included the fastest sprint (i.e. speed), total time for the seven sprints (total sprint time, seconds) and percentage decrement among sprints. The percent sprint decrement was calculated as follows:

$$(\text{Total sprint time} / \text{Ideal sprint time}) \times 100) - 100),$$

where ideal sprint time is the best sprint time, usually the first or second sprint, multiplied by seven (50, 206). It has been recommended that participants who failed to achieve at least 95% of the time of the best sprint in the first run be excluded in order to avoid pacing during the test (46, 50). All players met the inclusion criterion. The protocol is highly reliable (135).

Coefficients of variation for the BST based on replicate tests in 15 subjects were 1.5%, 1.2% and 22.2% for the best sprint, total sprint time and percent sprint decrement, respectively.

Descriptive statistics (means and standard deviation) for CA, SA, SA/CA ratio, anthropometric dimensions, thigh volumes and performance variables were calculated for the sample. The assumption of normality was checked by the Kolmogorov-Smirnov test with Lilliefors' significance correction, and by visual inspection of normality plots. When assumptions were violated, log-transformations were performed to reduce non-uniformity of error. Multiple linear regression (backward method with the stepping criteria for removal of $P < 0.10$) was used to estimate the relative contributions of CA, skeletal maturity status (SA/CA ratio), years of formal training, stature, body mass, leg length and thigh volume to variation in maximal short-term performance measures. The method reduces collinearity among the independent variables making them more stable predictors.

RESULTS

Characteristics of the total sample are summarized in Table 7.1. The sample of basketball players was, on average, advanced in SA compared to CA. Estimates of the relative contribution of CA, skeletal maturity status, years of formal training, stature, body mass, leg length and thigh volume to maximal short-term tests performance are given in Table 2.

The independent variables explained approximately 23% of variance in the LD and 44% and 46% of the best sprint time and total sprint time in the BST. Advanced skeletal maturity ($P < 0.001$), training experience ($P < 0.05$) and stature ($P < 0.05$) were positive predictors while body mass ($P < 0.001$) had a negative influence on LD performance. Predictors were the same for the two components of BST: CA, advanced skeletal maturity status, years of training, leg length and height had a positive influence on sprint performance, while body mass had a negative influence. In contrast, only 11% of variance in the percentage sprint decrement was explained. CA, leg length and thigh volume were significant predictors of percentage sprint decrement.

The independent variables explained 52% and 54% of the variation in peak and mean power, respectively. Advanced skeletal maturity, leg length and body mass were significant predictors of the two cycle-ergometry indicators of maximal short-term performance. On the other hand, only 4% of the variance in the WAnT fatigue index was explained. Delayed skeletal maturity explained a small but significant ($P < 0.05$) portion of the variance in the fatigue index.

Table 7.1. Descriptive statistics for the total sample (*n* = 94).

	Mean	Standard deviation	Range
Chronological age, years	15.12	0.53	13.91 – 15.96
Skeletal age, years	16.75	1.00	13.58 – 18.00
SA/CA ratio, #	1.11	0.06	0.92 – 1.21
Years of training, years	5.8	2.4	2 -11
Stature, cm	177.0	10.9	150.1 – 206.9
Mass, kg	67.4	12.9	44.6 – 127.3
Sitting heigth, cm	93.1	5.6	75.4 – 103.2
Leg length, cm	88.6	6.6	61.8 – 104.7
Thigh volume, L	5.11	1.14	3.04 – 9.58
Line Drill test, s	31.75	2.09	28.43 – 41.68
BST best sprint time, s	6.92	0.49	6.14 – 8.25
BST total sprint time, s	50.16	3.86	43.87 – 61.17
BST percent sprint decrement, %	3.5	1.9	0.8 – 9.9
WAnT peak power, watt	603	118	357 – 978
WAnT mean power, watt	517	96	312 – 799
WAnT fatigue index, %	29.7	5.7	17.0 – 43.0

DISCUSSION

The contribution of years of sport-specific training, CA, skeletal maturity status (SA/CA ratio), body size and estimated leg length and thigh volume to concurrent assessments of maximal short-term performance among adolescent basketball players was considered. Advanced skeletal maturity status (SA in advance of CA), estimated leg length and body mass were among significant predictors for four of the seven indicators of short-term high-intensity exercise – best sprint time and total sprint time with the BST as well as peak and mean power in the WAnT (Table 7.2). Advanced skeletal maturity and stature were positively related with LD. Chronological age, years of training and stature were significant predictors for three of the short-term high-intensity exercise indicators, while estimated thigh volume appeared as a significant predictor for only one variable: percentage of sprint decrement score in the BST. Leg length was more relevant than total stature in the cycle-ergometer power outputs, while stature and body mass were included in the final models that explain variance in the running tests (which required displacement of the body through space).

Table 7.2. Predictors of short-term performance estimated R^2 in adolescent basketball players.

	R^2	Adjusted R^2	*P*	Predictors	Standardized *β* coefficient	*P*
Line drill[1]	0.28	0. 23	< 0.001	Years of training	0.23*	< 0.05
				Maturity	0.46**	< 0.001
				Stature	0.33*	< 0.05
				Body mass	-0.60**	< 0.001
BST best sprint time[1]	0.47	0.44	< 0.001	Age	0.22*	= 0.01
				Maturity	0.48**	< 0.001
				Years of training	0.24**	< 0.01
				Leg length	0.25	= 0.06
				Stature	0.33*	< 0.05
				Body mass	-0.78**	< 0.001
BST total sprint time[1]	0.49	0.46	< 0.001	Age	0.24**	< 0.01
				Maturity	0.45**	< 0.001
				Years of training	0.24**	< 0.01
				Leg length	0.34*	= 0.01
				Stature	0.30*	= 0.05
				Body mass	-0.79**	< 0.001
BST percent sprint decrement[1]	0.15	0.11	< 0.01	Age	0.18	= 0.09
				Leg length	0.39**	= 0.01
				Thigh volume	-0.23*	< 0.05
WAnT peak power	0.53	0.52	< 0.001	Maturity	0.20*	< 0.05
				Leg length	0.23*	= 0.01
				Body mass	0.45**	< 0.001
WAnT mean power	0.56	0.54	< 0.001	Maturity	0.23**	< 0.01
				Leg length	0.25**	< 0.01
				Body mass	0.43**	< 0.001
WAnT fatigue index	0.05	0.04	< 0.05	Maturity	-0.21*	< 0.05

[1]Signs are reversed since a lower time on the running tests indicates a better performance.

** $P < 0.01$; * $P < 0.05$

The growth characteristics of this sample of Portuguese adolescent basketball players were consistent with other reports with heterogeneous samples of young male athletes (36, 267). Variation in body size was considerable (Table 1) but mean statures and body masses exceeded age-specific 75th percentiles of U.S. reference data (268). The current sample of basketball players was, on average, advanced in skeletal maturity expressed as the ratio of SA and CA (Table 7.1), although inter-individual variation was considerable. The data were consistent with observations on adolescent basketball players based on assessment of pubic hair (89). The literature about skeletal maturation of youth basketball players is limited. However, the presence of a significant number of players advanced in skeletal maturation among 14-15 year old players in the present study may reflect selective criteria of the sport (selection or exclusion) in developmental programs (36), as already noted in basketball (Drinkwater et al. 2008) and soccer (201).

The independent variables in the regression model explained 52% and 54% of variance for peak and mean power from the WAnT, respectively, emphasizing the importance of body size and muscle mass (quantitative factors) to variance in maximal power in the 30-s cycle-ergometer test. However, the explained variances in the present study were lower than previously reported for the WAnT (120, 123, 166, 269, 270) or Force-velocity Test (170). These studies, however, largely considered children and adolescents not training for sport; they had, on average, statures and body masses comparable to age-specific reference medians. The results would seem to suggest, therefore, that other factors (i.e., training, genotype) may interact in the expression of short-term power outputs in young athletes, specifically adolescent basketball players. The metabolic profile of WAnT test is highly anaerobic (131, 271); it has been demonstrated that energy is supplied mostly by glycolysis (~50%) and phosphorylcreatine (PCr) breakdown (~30%) with a minor aerobic component (~20%) (131). However, neither the availability of anaerobic energy nor the rate of anaerobic energy release seems to limit performance during the WAnT, indicating that the rate of ATP utilization may be the performance-limiting factor during the 30 s all-out cycling performance (272). Short-term maximum intensity performance, absolute and relative to body mass, is lower in children than adolescents and adults. It has been suggested that limitations of glycolysis, PCr breakdown and oxidative re-phosphorylisation confine short-term maximum performances throughout pubertal development (125).

The limitations of ratio standards (e.g., Watt.kg^{-1} body mass, Watt.L^{-1} lean leg volume) to remove potentially spurious effects associated with body size has been noted for some time (174). Body mass has been the most used size variable when modeling power outputs, but it has been argued that other dimensions can serve as alternatives when using allometric scaling to compare individuals (181, 186, 273). The results of the backward regression analysis (Table 2) indicate that body mass, leg length and skeletal maturity status are the most relevant variables to partition the effects of body dimensions on cycling power outputs among adolescent basketball players.

There is a lack of valid, reliable and standardized methods of assessing maximal short-term power outputs in children and adolescents (49). The WAnT has been used extensively and in a variety of settings in children and adolescents and was highly reliable and sensitive (127). Meanwhile, the specificity of the WAnT for athletes in non-cycling sports has not been yet established. In an effort to more closely match short-term maximal-intensity efforts related to the demands of basketball performance, the experimental approach included a basketball-specific short-term maximal running protocol. The LD is considered a valid and reliable measure of all-out exercise with changes of direction during approximately 30-s in 14 to 16 years-old basketball players and showed a moderate association with WAnT (126, 265). This suggests that the running field protocol may measure, to some extent, the same anaerobic properties as the all-out 30-s cycling test. In fact, it has been reported that the 30-s maximal effort shuttle run was a strenuous effort for 10 to 14 years-old boys and girls; no differences were observed in peak blood lactate after the shuttle run protocol and WAnT (274, 275). The results of the regression analysis indicate that maximal short-term exercise with changes of direction with an approximate duration of 30-s was related to training experience, skeletal maturity status, stature and body mass; however, only a moderate portion of variance is explained by the independent variables (23%). Performance in this basketball-specific test may be limited largely by the rate of ATP utilization, given the cost of generating force or alterations in the storage and recoil of elastic energy imposed by 180º directional changes that require deceleration and acceleration.

Several sport-specific protocols have been proposed for the evaluation of maximal-intensity performance, in particular dealing with repeated-sprint ability, for team sports such as basketball (134-136). Considering the movement patterns and intermittent nature of basketball, the assessment of the ability to perform maximal short-sprints repeatedly has logical validity and may be amenable to specific physiological interpretation. Anaerobic ATP production during a single short-duration sprinting (< 10-s) is provided by PCr degradation and anaerobic glycolysis (141), but the relative contribution of anaerobic glycogenolysis to performance in subsequent sprints throughout the test is reduced, which is partially explained by an increase in aerobic metabolism (51). However, metabolic profiles of repeated-sprint ability tests are strongly dependent of sprint and recovery duration (144, 145). Sport-specific training adaptations may also contribute to the physiological responses to repeated sprint ability. It has been recently shown that performance of 10 sprints of 15 m with 30-s of recovery was independent of maximal oxygen consumption in 16-17 years-old basketball players (53).

The regression models explained 44% and 46% of variance for best sprint time and total sprint time in the BST, respectively, in the present study of adolescent basketball players. The positive standardized coefficients of skeletal maturity status and stature and negative coefficient of body mass suggested that players who were advanced in maturity and were taller with less body mass attained better performances in the repeated-sprints test. It has been suggested that repeated-sprint ability improves during maturation of highly trained youth football players (42). However, analyses of the effects of age on repeated-sprint ability controlling for maturity status are lacking. Years of training contributed positively to performance in repeated maximal shot-term efforts, suggesting that intermittent maximal performances may be sensible to the accumulation of basketball-specific training stimulus. Of interest, older CA was significant predictor in only the fastest sprint and total sprint times in the BST.

The decline in performance from the best to worst, either in a continuous period of maximal effort or a repeated-sprint test, has been commonly labeled as a fatigue index, although the usefulness of fatigue scores has been questioned (136, 207). Indices of fatigue on either the cycle-ergometer and repeated-sprint tests have moderate levels reliability (127, 206, 276). Practical interpretation of fatigue scores is also problematic (207). Only small portions of variance in fatigue scores based on both the WAnT (4%) and BST (11%) were explained by the independent variables. The results add to concerns expressed about the utility of such scores.

Skeletal maturation probably influences maximal short-tem performance through associated variation in somatic features including size per se and muscle mass and composition (58). Skeletal maturation, however, is not necessarily related to neuromuscular maturation. Nevertheless, boys show clearly defined adolescent spurts in an agility shuttle run, speed of plate tapping and vertical jump which may perhaps suggest neuromuscular maturation during adolescence (71). There are also adolescent changes in the cerebral cortex and neural pathways associated with motor function (14) which may influence neuromuscular characteristics and performance at these ages.

Potentially confounding factors in explaining the moderate to large relationship of maximal short-term outputs with training experience, growth characteristics, body size and lower-body morphology in adolescent basketball players include maturity-related variation in short-term muscle power outputs and sprinting ability, the non-linear improvement in anaerobic energy supply during the adolescent growth spurt, the trainability of muscle power during adolescence, and the established relationship between body size and power. Given these considerations, is it problematic to extrapolate results from adolescent to adult athletes (13).

In summary, using the same predictors, concurrent assessments of maximal short-term performance were explained by different models. Biological maturation entered almost all outputs derived from the three protocols with the exception of the decrement score in repeated sprints. Consequently, future research on maximal short-term performance in adolescent athletes should consider variation related to maturation whether the protocol requires displacement of the body or cycling. Years of training experience was also a significant predictor of the running tests and failed to enter in models that explained peak and mean power from the WAnT suggesting, perhaps, that 140-m shuttle run and sprints may be specific to basketball. Nevertheless, care should be exercised when interpreting or comparing the results of this study given the narrow range of variation in CA and skeletal maturity status, as well as the over-representation of subjects with extreme values for body size compared to the reference.

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CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

CHAPTER 8

Age-related variation of maximal short-term effort after controlling for size and maturation in adolescent athletes

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Background: Adolescence is characterized by increments in body size and physical performance.
Aim: Variation of short-term performance of adolescent basketball players (n=93, 14-16 years) in relation to years before and after age at estimated peak height velocity (PHV) and variation in body size was considered.
Methods: Data included chronological age, estimated age at PHV, training experience; stature, body mass (BM), free-fat mass (FFM) and estimated lower-limb volume (LLV) by anthropometry; and short-term power outputs derived from the Wingate Anaerobic Test (WAnT). Nonlinear allometric modeling was used to partition the variation in body size. Pearson´s correlations were used to estimate the associations between distance to PHV (maturity offset) and training experience with absolute and scaled estimates of short-term power.
Results: Absolute WAnT increase linearly (PP, r = 0.70; MP, r = 0.72) through the interval of rapid growth of the adolescent growth spurt and were related mainly to body and muscle mass. Nevertheless, a residual significant positive influence of chronological age per se on maximal short-term power outputs remains independent of body size.
Conclusion: Allometric modeling to partition size may reveal other potentially meaningful factors in the development of short-term performance in adolescent athletes.

Keywords: youth athletes, allometry, Wingate Anaerobic Test, maturity offset, basketball

INTRODUCTION

Participation in many team sports involves movements characterized by short bursts of predominantly maximum intensity activities (e.g. basketball, soccer or handball). Maximal short-term power-output is defined as the highest mechanical power that can be delivered during an exercise of up to 30-s duration, with the time period depending on the force or load against which the individual has to work and acceleration (49). Maturity-associated variation in short-term performances during male adolescence has not received much attention (123). Absolute short-term power outputs increase with growth and maturation and are likely influenced by growth in body size and muscle mass (14). It was hypothesized that growth-related improvements in short-term power outputs among young athletes are a function of increasing body size or qualitative changes in the structural and functional capacities independent of body size or both.

Maximal short-term power outputs are commonly expressed as a ratio standard or per kilogram of body mass (watt.kg^{-1}), despite theoretical and statistical limitations (174, 175). Alternate statistical models to create a “size-free” expression of maximal short-term power outputs have been recommended. Linear regression and allometric scaling (log-linear regression) techniques have been used to investigate relationships between lean upper-leg volume and short-term power in adults (277-279). Linear regression techniques have also been used to the interpret relations between lean leg volume and maximal short-term performance in children (274). Allometric models, which have been shown to be more appropriate for partitioning body-size effects from physiological variable or performance (175), have also been used to partition the influence of size variables on short-term power outputs in children and adolescents (121, 150, 170). Allometric models apparently have not been used systematically in studies involving young athletes (115).

Variation in short-term power outputs across adolescence has been studied in the general population (49). Cross-sectional studies detailing the physiological characteristics of young basketball athletes are rather limited, in particular dealing with all out performance (22, 37, 52, 235, 262). These studies generally include are within an age range typically associated with talent identification programs and sport-specific intensive training programs inclusion (i.e., 14–16 yr), but, with few exceptions (37, 262), maturity status information is lacking. Therefore, studies dealing with growth-related changes in short-term performance among adolescent basketball players are needed to provide evidence-based information in order to allow coaches to sustain appropriate training decisions for basketball.

The purpose of this study was to examine short-term performance in relation to time before and after estimated age at peak height velocity (PHV) in adolescent basketball players. Changes in short-term effort were also evaluated taking into account corresponding changes in body weight and fat-free mass using allometric scaling.

MATERIALS & METHODS

Subjects

The sample included 93 male basketball players, 14.0 to 16.0 years. The players volunteered for the study and were of Portuguese (n=87) and African (n=6) ancestry. All participants were classified as under 16 (U16) by the *Federação Portuguesa de Basquetebol* (Portuguese Basketball Federation), and were engaged in formal training and competition for at least two years. Years of training was obtained by interview and confirmed in the online database of the *Federação Portuguesa de Basquetebol* (237).

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 (194). 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.

Maturity status

Chronological age (CA) was calculated to the nearest 0.1 year by subtracting birth date from date of testing. Age at peak height velocity (APHV) was estimated with the maturity offset protocol (69). The technique estimates time before or after (PHV) from CA, stature, body mass, sitting height and estimated leg length (stature minus sitting height). Negative values indicate time before PHV and positive values indicate time after PHV. Negative offset values were added to and positive offset values were subtracted from CA to estimate APHV.

Anthropometry

All measurements were taken by a single experienced observer following the procedures described in Lohman et al. (221). Stature and sitting height were measured with a portable stadiometer (Harpenden model 98.603, Holtain Ltd, Crosswell, UK) to the nearest 0.1 cm. Leg (subischial) length was estimated as stature minus sitting height. Body mass (BM) was measured with a portable balance (Seca model 770, Hanover, MD, USA) to the nearest 0.1 kg. Triceps and subscapular skinfold were used measured and used to estimate percent body fat (%BF) using maturation- and race-specific equations for adolescent boys (261). Fat-free mass (FFM) was estimated: FFM = (100 - %BF) / 100 · BM.

Lower-limb volume (LLV) of the dominant leg (210) was estimated anthropometrically using the following dimensions: circumferences at the gluteal furrow (maximum horizontal), mid-thigh (maximum), above the knee (minimum), around the knee (patella level, maximum), below the knee (minimum), calf (maximum) and ankle (minimum); and lengths between the level of each circumference from the gluteal furrow to the ankle; and sum of the six partial lengths. Although the protocol is valid (210, 212), it tended to overestimate LLV (approximately 6%) compared estimates based on dual-energy X-ray absorptiometry in 37 athletes 13 to 22 years of age. Correlation between estimated volumes ranged between 0.91 and 0.96 (under review).

Eighteen players were measured twice within one week. Intra-observer technical errors of measurement were 0.54 cm for stature, 0.74 cm for sitting height, 0.88 kg for body mass, 0.7 – 0.9 mm for skinfolds, 0.29 to 0.74 cm for limb circumferences and 0.16 to 0.46 cm for calculated limb lengths. The estimated errors were within the range reported for intra- and inter-observer errors for a variety of studies (200).

Wingate anaerobic test

Athletes were instructed not to eat for at least 3 h and not to drink coffee or beverages containing caffeine for at least 8-h before testing. All assessments were performed at the same hours of the day (3:00 to 6:00 pm). Athletes wore similar clothing and the same footwear on each testing occasion.

After a standardized warm-up, athletes completed the 30-s WAnT test on a friction-loaded cycle ergometer (Monark 824E, Monark AB, Vargerg, Sweden) that was interfaced with a microcomputer and calibrated for pedal speed and applied resistance. Resistance was set at 0.075 kg (0.74 N) body mass. The WAnT test began with minimal resistance (basket supported) at 60 $\text{rev}\cdot\text{min}^{-1}$. On the command "go", the resistance was abruptly applied and the computer was activated simultaneously. Athletes remained seated during the test and were verbally encouraged to give an all-out effort throughout the test. Measurements included peak power (PP, highest mechanical power generated any 5-s period, watts), mean power (MP, average for the 30-s period, watts) (208). Coefficients of variation based on replicate tests in 20 subjects were 2.8% and 3.2% for PP and MP, respectively.

Statistical analysis

Descriptive statistics for CA, experience/training, anthropometric dimensions, estimated APHV and short-term performance were calculated. Before allometric analysis, Pearson correlation coefficients were calculated to examine linearity between body dimensions (BM, FFM, LLV) and power outputs. Allometric equations, $Y = a \cdot X^b \cdot \varepsilon$, where *a* is the intercept of the regression line on the Y axis and *b* is the slope of the line were used to model the relationship between short-term power outputs and body dimensions. Values of *a* and *b* were derived from linear regressions of the logarithmic regression transformations, in the form of $\log Y = \log a + b \cdot \log X + \log \varepsilon$, where Y was the dependent variable (PP or MP) of short-term power outputs (natural logarithms, i.e., Log PP and Log MP) and body size descriptors (Log BM, Log FFM and Log LLV).

Subsequently, regression diagnostics were performed by checking the assumption of homoscedasticity of residuals in the log-linear regressions using correlations between residuals converted to absolute values with the predictor variables (Log BM, Log FFM and Log LLV). The association between these power function ratios and the body size scaling denominators were then calculated using Pearson correlations. If the allometric model was successful in partitioning out the influence of body size, the correlation between the derived power function ratio and the size variables would approach zero, i.e., there should be little or no residual size correlation (175). Correlations that did not approach zero, regardless of whether they were statistically significant, suggest that the power function ratio was not been completely successful in rendering short-term power outputs independent of body dimensions.

Pearson correlations were calculated between short-term power indicators (absolute values and allometrically scaled) and maturity offset and training experience. 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 ($r > 0.9$) after Hopkins (227).

RESULTS

Characteristics of the total sample of youth basketball players are shown in Table 8.1. All maturity offset values were positive except four, indicating that the sample was beyond the age at maximum growth rate in height during the adolescent spurt.

The regression output for the allometric models is summarized in Table 8.2. Correlations between WAnT power outputs and indicators of body size were high ($p < 0.01$). Overall, the point estimates for the size exponent from the separate allometric models were similar for both WAnT power outputs, and the scaling exponents for indicators of body size had a small range (0.81 – 0.88).

Correlations between PP and MP allometrically scaled for each indicator of body size showed no spurious correlations between power outputs expressed by $BM^{-0.88}$ and the observed size variables ($0.00 < r < 0.08$). For the PP and MP expressed by $FFM^{-0.85}$, the correlation was near zero for FFM, but significant low positive correlations were observed for BM ($r = 0.22$ for PP and $= 0.21$ for MP, $p < 0.05$), and moderate for LLV ($r = 0.31$ for PP and $r = 0.33$ for MP, $p < 0.01$). A similar trend was observed for short-term power outputs scaled for LLV. No correlation was observed for LLV, but low correlations were noted for BM ($r = 0.15$ for PP and $r = 0.14$ for MP, $p > 0.05$) and FFM ($r = 0.24$ for PP, $p < 0.05$ and $r = 0.27$ for MP, $p < 0.01$).

Table 8.1. Descriptive statistics for the total sample (*n* = 93).

	Mean	Standard deviation	Range
Chronological age, yrs	15.17	0.54	13.92 – 15.96
Estimated age at peak height velocity, yrs	13.54	0.72	11.97 – 15.57
Maturity offset, yrs	1.62	0.84	-0.82 – 3.36
Years of training, yrs	5.87	2.37	2.00 – 11.00
Stature, cm	176.7	10.6	150.1 – 199.0
Body mass, kg	66.5	11.1	44.6 – 104.5
Sitting height, cm	91.7	5.2	75.4 – 103.2
Fat-free mass, kg	56.4	9.2	34.8 – 73.3
Lower-limb volume, L	8.88	1.56	5.56 – 14.69
WAnT peak power, watt	605	118	357 – 978
WAnT mean power, watt	519	96	312 – 799

Figure 8.1 illustrates the studied relationships between the WAnT power outputs and estimated time before and after APHV (maturity offset). The scatter data indicated a high correlation between short-term power expressed in absolute terms and estimates time before and after PHV (PP $r = 0.70$ and MP $r = 0.72$, $p < 0.01$). Interestingly, the relationship between power outputs and maturity offset were best fitted with the exponential function, with an apparent acceleration between approximately 1 and 1.5 years after PHV. Short-term power outputs allometrically scaled for BM and maturity offset were correlated (PP $r = 0.20$ and MP $r = 0.21$, $p = 0.05$) but low. Corresponding correlations between maturity offset and estimates of maximal short-term performance allometrically partitioned for FFM were also significant but low (PP $r = 0.16$ and MP $r = 0.15$, $p < 0.05$). When PP and MP were allometrically scaled for LLV, the magnitude of correlations with maturity offset was significant and higher compared with other indicators of body size (PP $r = 0.38$ and MP $r = 0.41$, $p < 0.01$). The regression lines between power outputs scaled by BM ($p \leq 0.05$) and LLV ($p < 0.01$) were different from zero. Neither absolute WAnT power outputs nor short-term power scores controlled for body size were significantly correlated with years of training in basketball.

Table 8.2. Allometric modeling of WAnT power outputs for body size variables.

	Body-size descriptor	b	(95% CI)	*r*	R^2
Peak power					
	Body mass	0.88	(0.73 – 1.04)	0.76	0.57
	Fat-free mass	0.85	(0.67 – 1.02)	0.71	0.50
	Lower-limb volume	0.81	(0.65 – 0.98)	0.72	0.52
Mean power					
	Body mass	0.88	(0.73 – 1.02)	0.78	0.61
	Fat-free mass	0.85	(0.69 – 1.01)	0.75	0.56
	Lower-limb volume	0.82	(0.67 – 0.96)	0.76	0.57

Table 8.3. Relationship between allometric function (Y / X^b) and individual indicators of body size (X).

	$PP\cdot BM^{-0.88}$	$MP\cdot BM^{-0.88}$	$PP\cdot FFM^{-0.85}$	$MP\cdot FFM^{-0.85}$	$PP\cdot LLV^{-0.81}$	$MP\cdot LLV^{-0.81}$
Body mass	0.00	-0.01	0.22*	0.21*	0.15	0.14
Fat-free mass	0.06	0.08	-0.01	0,00	0.24*	0.27**
Lower-limb volume	0.07	0.08	0.31**	0.33**	-0.01	-0.02

** $P < 0.01$; * $P < 0.05$

DISCUSSION

An allometric approach was used to evaluate the relationship between time before and after estimated APHV and short-term maximum intensity performance among adolescent basketball players. Indicators of body size (BM, FFM and LLV) were largely correlated with the WAnT peak and mean power, and curvilinear power functions models (log-linear regressions) provided an adjusted fit to both PP and MP, i.e., maximal short-term performance independent of body size (Table 8.2). The results showed an increment of short-term power outputs across adolescence which was also apparent when body size is partitioned out by allometric scaling. When analyzed independently of body size, increases across adolescence appeared to be unrelated to training experience.

The non-linear allometric modeling procedures were statistically appropriate to account for differences in body size, since *b* exponents derived for each indicator were markedly different from 1.0. Although studies reporting body size exponents for both PP and MP, particularly in samples of young athletes are limited (121, 277-279), WAnT variables do not appear to increase proportionally to body size. Peak power expressed in watts per unit of body mass is, nevertheless, often used in some studies although the use of ratio standards has several limitations (174, 175). This may contribute to potential misinterpretation of data.

The size exponents for PP and MP power were higher than the theoretically predicted value of 0.67 based on theory of geometric similarity (190). This observation is interesting since evidence has shown that short-term power outputs scale to 0.67 using either BM (175) and lean leg volume (280) in adult women. It has been argued that the use of a body size exponent of b = 0.67 is appropriate for homogeneous samples, i.e. similar training background, age and body dimensions (281). It is possible that the higher body size exponents may be explained by lower-limb muscular development at greater rate than that predicted by geometric similarity in young athletes, given the possible interactions among growth, maturation and training stimulus. The wide range of body stature and mass and the relatively homogeneous maturity status may be additional factors. Hence, generalizations from the present sample to other youth populations may not be warranted. It has also been argued that the deviation of size exponents from theoretical values may be a function of the limitations of WAnT with children and adolescents (122).

Maturity offset may not be a sufficiently sensitive indicator of maturity status. Variation in maturity offset and in turn estimated APHV in the present sample was relatively narrow compared with the range of variation reported in longitudinal studies determining APHV (14, 65, 71). The standard deviations for APHV in the present study (Table 1) was slightly higher than values reported in studies where the protocol was used, but all are lower than standard deviations derived from longitudinal studies which modeled individual height records (65). Limitations of the offset protocol with young female gymnasts have been noted (70) and this may also apply to other samples of athletes. In the present sample of basketball players, only four were late in estimated APHV, which is consistent with skeletal and sexual maturity status observed in this sample (37, 262). Most of the basketball players were advanced in skeletal maturation which may reflect selective criteria (selection or exclusion) of developmental programs in the sport (36). Thus, possible limitations of the maturity offset protocol in samples of adolescent athletes should be considered.

It has been suggested that body mass is not the unique body size dimension for use in scaling variables of relevance to exercise physiology that systematically vary with size (273). Moreover, short-term muscle power function may be confounded by variability in body size and composition. When analyzing the interrelationships of scaled WAnT indicators with each indicator of body size, BM had the highest correlation with PP and MP, and the short-term power outputs partitioned to BM were the only scaled outputs to demonstrate no spurious correlation with all indicators of body size. This results contrast with previous studies that reported lean lower-limb volume as the best predictor for cycling power outputs in young boys (170), albeit non-athletes, and do not support the argument that it is inappropriate to use total body mass to standardize leg power in exercises where body weight is supported, such as cycling (263).

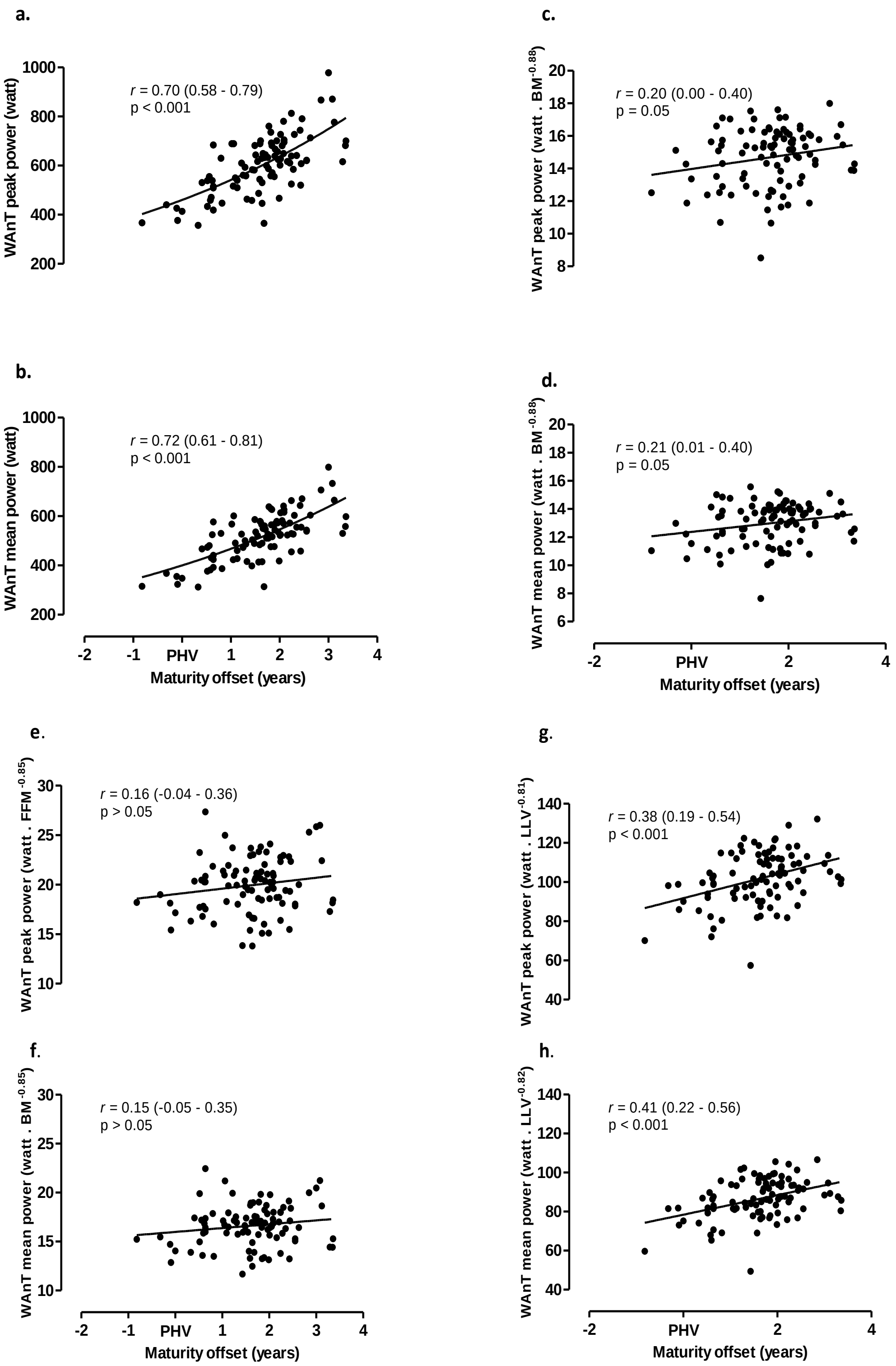

Figure 8.1. Relationships between the WAnT power outputs and estimated time before and after age at PHV (maturity offset). (A) WAnT absolute peak power *vs* maturity offset; (B) WAnT absolute mean power *vs* maturity offset; (C) WAnT peak power scaled for body mass (BM) *vs* maturity offset; (D) WAnT mean power scaled for body mass (BM) *vs* maturity offset; (E) WAnT peak power scaled for fat-free mass (FFM) *vs* maturity offset; (F) WAnT mean power scaled for fat-free mass (FFM) *vs* maturity offset; (G) WAnT peak power scaled for lower-limb volume *vs* maturity offset; (H) WAnT mean power scaled for lower-limb volume (LLV) *vs* maturity offset.

The variation in absolute short-term power outputs was largely correlated with maturity offset, revealing a trend of accentuated non-linear increase of absolute maximal short-term performance one year after PHV. The accentuated increase in absolute PP and MP absolute may be related to adolescent spurts in BM, FFM and perhaps regional muscle mass, since maximal growth in BM during adolescence in boys generally occurs, on average, after PHV. Corresponding data for the adolescent spurt in FFM are limited and based on annual increments in contrast to individually modeled longitudinal observations (14). Longitudinal data for static lower-body strength peaked, on average, about one year after PHV and maintained a similar rate of growth for the next two years (98). Although PP and MP increased in cross-sectional samples of boys classified as prepubertal, pubertal and mature (120), chronological age varied within and among the three maturity groups and was not statistically controlled in the analysis. This is relevant because maximal short-term performance improves with age during adolescence independently of pubertal status (14).

When power outputs were partitioned for size variables, the magnitude of correlations with maturity offset decreased significantly and linear relationships were observed (Figure 8.1). The results indicated that the increments in absolute short-term power outputs relative to time before and after APHV were influenced mainly by body size and muscle mass. However, it is of interest that there were significant residual correlations between WAnT scaled for BM and LLV and maturity offset. Differences from the zero line in the regressions also indicated a maturity effect independent of body size. The results may reflect a positive interaction of other factors including genetic variation in size and WAnT (164), age related-qualitative changes and inter-individual muscular characteristics (48, 49), and possibly training. Although no association was noted between years of formal training and WAnT power outputs in this study, but it is likely that experience expressed in years is not a sufficiently sensitive indicator of training, i.e., intensity and regularity. Longitudinal research is needed to provide a better understanding of improvements in short-term performance across puberty and the growth spurt.

In summary, this study confirms the importance of allometric scaling to account for body size differences when interpreting changes in maximal short-term performance in adolescent basketball players. The results demonstrated that variation in WAnT power outputs was apparent when expressed relative to estimated time before and after APHV and was mostly mediated by variation in body dimensions. The consideration of factors affecting maximal short-term performance is of relevance in the context of youth basketball, especially for talent identification, sport selection and prediction of success.

ACKNOWLEDGMENTS

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CHAPTER 9

Age-related variation in lower-limb isokinetic strength controlling maturation in late adolescent basketball players

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The relationships of knee joint isokinetic strength with distance to peak height velocity (PHV) were examined in 14-to 16 years old basketball players, considering allometric scaling for body mass (BM) and thigh volume (TV). Data included chronological age, estimated age at PHV (maturity offset); stature, BM and estimated TV by anthropometry; and the maximal moments of force of concentric (CON) and eccentric (ECC) knee extensions (KE) and flexions (KF) at 60 $^{o}\cdot s^{-1}$. Polynomial regression analyses and Pearson´s correlations were used to examine the relationships between the maximal moments of force, absolute and scaled scores, with maturity offset. Linear relationships were observed between the absolute values of KE_{CON} and KF_{ECC} maximal moments of force with offset ($0.31 \leq R^2 \leq 0.50$). As for absolute values KF_{CON} and KE_{ECC} maximal moment of force, quadratic relationships were observed with maturity offset. The trend of relationships between maximal moments of force with maturity offset was quadratic ($0.03 \leq R^2 \leq 0.20$, controlling for BM; $0.29 \leq R^2 \leq 0.40$, controlling for TV). The results indicate that dimensional changes cannot account for all variation related to the distance to PHV in isokinetic strength performance at 60 $^{o}\cdot s^{-1}$ in 14 to 16 years-old basketball players.

Keywords: maturation, basketball, anthropometry, allometric scaling, moments of force, adolescence

INTRODUCTION

Movement patterns in team-sports (e.g. basketball, soccer), involve short, intense and repeated episodes of activity and rapid changes in direction, accelerations or jumps (25, 282) that require lower-limb muscle strength. Strength corresponds to maximal force generated (in N) or moments of force (N·m) developed by a muscle or muscle group during maximal voluntary contraction under a given set of conditions (54).

Isokinetic dynamometry is commonly used for the assessment of dynamic muscle functions in both research and sports environments (146). Isokinetic assessment provides information about maximal dynamic muscular contraction when the velocity of the movement is controlled and maintained constant. Maximum moments of force in concentric muscular actions appear to be consistently favored as a measure of isokinetic leg strength, referring to the single highest moment of force output of the joint produced by the muscle action as the limb moves through a range of motion (146).

Isokinetic maximal force production in concentric muscular actions increases with age in child and adolescent non-athletes (168, 169, 241) and athletes (39, 40, 45, 171, 260, 283). Strength is affected by body size (40, 283, 284) so that it may be difficult to distinguish variation due to age per se from that due to size. Inter-individual variation in biological maturity status (skeletal maturation, pubertal status) is an additional factor affecting growth in size and function especially during pubertal years (14, 58). Increments in maximal moment of force also depend upon neuromuscular maturation during adolescence (283). In contrast to concentric strength testing, assessments of eccentric muscular actions have been relatively under-utilized in youth non-athletes and athletes even though sport-specific movement patterns frequently require eccentric muscular actions.

It is apparent that the evaluation of muscular force needs to be expressed relative to variation in body size (285). Adjustment for body size is often performed using standard ratios, despite theoretical and statistical limitations (174, 175). As such, allometric modeling has attracted the attention of researchers (45, 286, 287). Techniques of allometric scaling are detailed elsewhere (175); nevertheless, linear regression and allometric scaling (log-linear regression) have been shown to be appropriate for partitioning body size effects from a physiological variable or performance (175). These strategies have not, however, been consistently used to partition size variables on isokinetic strength outputs in children and adolescents (168, 288).

Mid- and late-adolescence in males, about 14-16 years, is often considered as a decisive period for prediction of success in team sports, in general, and particularly in basketball (13). The purpose of this study was to examine the influence age related variation in knee joint isokinetic concentric (CON) and eccentric (ECC) muscular actions (extension and flexion) controlling for individual differences in maturity status and using an allometric scaling approach for the adjustment for body size.

MATERIALS AND METHODS

Subjects

The sample included 55 male basketball players, 14.0 to 16.0 years. The players volunteered for the study and were of Portuguese (n=51) and African (n=4) ancestry. All participants were classified as under 16 (U16) by the *Federação Portuguesa de Basquetebol* (Portuguese Basketball Federation), and were engaged in formal training and competition for at least two years. The study was approved by the *Scientific Committee* of the *Faculty of Sport Science and Physical Education* of the *University of Coimbra* and registered in the *Portuguese Foundation for Science and Technology*. Participants were informed about the nature of the study and also that participation was voluntary and that they could withdraw from the study at any time. Players and their parents or legal guardians provided informed written consent.

Participants were instructed not to eat for at least 3-h and not to drink coffee or beverages containing caffeine for at least 8-h before testing. Assessments were performed at the same hours of the day (3:00 to 6:00 PM). Subjects wore similar clothing and the same footwear on each testing occasion. All tests were completed within 30 days with at least 48-h between testing sessions.

Age and maturity status

Chronological age (CA) was calculated to the nearest 0.1 year by subtracting birth date from date of testing. Age at peak height velocity (PHV) was estimated with the maturity offset protocol (69). The technique estimates time before or after PHV using a sex-specific equation that incorporates CA, stature, body mass, sitting height and estimated leg length (stature minus sitting height). Negative offset values indicated time before PHV and positive values indicated time after PHV. Negative offset values were added to and positive offset values were subtracted from CA to estimate APHV.

Anthropometry

Anthropometric dimensions were taken by a single experienced observer following standard procedures (221). Stature and sitting height were measured, respectively, with a portable stadiometer (Harpenden model 98.603, Holtain Ltd, Crosswell, UK) and sitting height table (Harpenden, Holtain Ltd, Crosswell, UK) to the nearest 0.1 cm. Leg (subischial) length was estimated as stature minus sitting height. Body mass (BM) was measured with a portable balance (Seca model 770, Hanover, MD, USA) to the nearest 0.1 kg. Circumferences at the gluteal furrow (highest possible horizontal circumference), mid-thigh (largest possible mid-thigh circumference) and lower thigh (minimum circumference above the knee), and lengths between each circumference level were measured and used to estimate total thigh volume of the dominant leg (210). The method has often been used in studies with youth (170, 187).

Based on 18 participants measured twice within one week, intra-observer technical errors of measurement were 0.54 cm for stature, 0.74 for sitting height, 0.88 kg for body mass, 0.29 to 0.74 cm for limb circumferences and 0.16 to 0.46 cm for limb lengths. A pilot study of the estimation of thigh volume indicated correlations ranging from 0.88 to 0.90 between the anthropometric protocol and dual-energy X-ray absorptiometry in 23 athletes (20.5 ± 1.2 years old). The anthropometric method tended to overestimate lower-limb volumes by 6.4% to 7.2% compared with estimates based on dual-energy X-ray absorptiometry (unpublished results).

Isokinetic dynamometry assessment

Isokinetic assessments were completed within a one week period that included a familiarization and testing sessions with at least 48-h between sessions (Carvalho et al, under review). Isokinetic assessment of reciprocal KF and KE muscular actions were made using a calibrated dynamometer (Biodex System 3, Shirley, NY, USA) at angular velocity of $60^{o}\cdot s^{-1}$. The subject performed a 10 min cycling warm-up on a Monark cycle ergometer (Monark 814E, Varberg, Sweden) with minimal resistance (basket supported) at 60 $rev\cdot min^{-1}$ and 2 min of static stretching of the hamstring and quadriceps muscles. The athlete was then placed in a seated position adjusted according to manufacturer guidelines in a standardized 85^{o} hip flexion from the anatomical position. Reciprocal muscular actions in the dominant leg were assessed. The lever arm of the dynamometer was aligned with the lateral epicondyle of the knee and the force pad was placed approximately 3 to 5 cm superior to the medial malleolus with the ankle in a plantigrade position. Range of motion during testing was set using voluntary maximal full extension (0 ^{o}) to 90 ^{o} of knee flexion. Cushioning was set using a hard deceleration (according to manufacturer guidelines) and therefore, 90 ^{o} constituted the range of motion tested. At the beginning of each session, the participant was asked to relax the leg so that passive determination of the effects of gravity on the limb and lever arm could be accounted for. The participant was instructed to firmly grasp the hand grips at the sides of Biodex System 3 seat during the test procedure. In CON actions, the participant was instructed to push the arm lever during extension and pull during flexion as hard and fast as possible; in ECC actions, the subject was instructed to resist the lever arm during knee extension (KE) and flexion (KF) as hard as possible. Extension was undertaken first in both muscular action modes. Each subject performed five continuous maximal repetitions. The order of testing started with CON actions, followed by a 90 s period of rest before the performance of the ECC actions. Visual feedback of moment versus time was provided during the test, but no verbal feedback was given (148). Maximal KF and KE moments of force from the best repetitions in both CON and ECC muscular actions were retained and expressed as N·m.

Statistical analysis

Statistical analyses were performed using SPSS version 17.0 software (SPSS, Chicago, IL). Descriptive statistics for CA, years of formal training, maturity offset, estimated APHV, body size and isokinetic measures were computed for the total sample. The assumption of normality was checked by the Kolmogorov-Smirnov test with Lilliefors' significance correction, and by visual inspection of normality plots.

Allometric equations, $Y= a \cdot X^{b} \cdot \varepsilon$, where a is the intercept of the regression line on the Y axis and b is the slope of the line were used to model the relationship between maximal moments of force and body size. Values of a and b were derived from linear regressions of the logarithmic regression transformations, in the form of log Y = log a + b · log X + log ε, where Y was the dependent variable of maximal torque outputs (natural logarithms, e.g., Log CON_{KF}) and body size (e.g., Log BM).

Regression diagnostics were performed by checking the assumption of homocedasticity of residuals in the log-linear regressions using correlations between residuals converted to absolute values with the predictor variables (Log BM; Log TV). The association between these power function ratios and body size scaling denominators were then calculated using Pearson's correlations. If the allometric model was successful in partitioning the influence of body size, the correlation between the derived power function ratio and size variables would approach zero, i.e, there should be little or no residual size correlation (175). Correlation coefficients that do not approach zero, regardless of whether they are statistically significant, suggest that the power function ratio was not completely successful in rendering moments of force independent from body size.

Polynomial regression analyses (linear and quadratic) and Pearson correlations were used to examine relationships between the maximal moments of force in CON and ECC muscle actions, absolute and allometically scaled scores, and the distance to age at PHV (maturity offset). Correlations between years of formal training in the sport and moments of force and torque outputs were also analyzed. Significance level was set at $p < 0.05$. The coefficient of determination, R^2, provides an indication of the explained variance achieved by the variables by the regression models. Correlations were interpreted as follows: trivial ($r < 0.1$), small ($0.1 < r < 0.3$) moderate ($0.3 < r < 0.5$), large ($0.5 < r < 0.7$), very large ($0.7 < r < 0.9$) and nearly perfect ($r > 0.9$) and perfect ($r = 1$) (227). Significance was set at $p<0.05$. Statistical analyses were performed using SPSS version 17.0 software (SPSS, Chicago, IL).

RESULTS

Characteristics of the sample are shown in Table 9.1. With the exception three participants, all maturity offset values were positive, indicating that the sample was beyond the age at maximum growth rate in height during the adolescent spurt.

The point estimates for the BM and TV exponents from the separate allometric models of isokinetic maximal moments of force in 14 to 16 years-old basketball players are summarized in Table 9.2. Correlations between the derived power function ratio and the size variables showed no residual size correlation ($-0.05 \leq r \leq -0.02$, $p > 0.05$, for BM; $-0.05 \leq r \leq -0.03$, $p > 0.05$, for TV), and visual inspections of absolute residuals from the linear models *vs* size descriptors showed no heteroscedasticity, indicating that the allometric model was successful in partitioning out the influence of BM and estimated active thigh muscle volume.

Table 9.1. Descriptive statistics for the total sample (*n* = 55).

	Mean	Standard deviation	Range
Chronological age, years	15.13	0.47	14.06 – 16.04
Age at peak height velocity, years	13.35	0.80	11.76 – 15.13
Maturity offset, years	1.82	0.84	-0.11 – 3.89
Years of training, years	5.89	2.37	2.00 – 11.00
Stature, cm	179.6	11.6	155.1 – 206.9
Body mass, kg	68.3	12.8	44.9 – 127.3
Sitting height, cm	93.0	5.4	80.1 – 103.2
Thigh volume, L	5.14	1.25	3.04 – 9.58
Isokinetic maximal moments of force at 60º.s^{-1}			
CON_{KE}, Nm	180.2	37.7	98.6 – 257.9
ECC_{KF}, Nm	231.8	62.5	118.0 – 382.7
CON_{KF}, Nm	108.3	28.7	56.3 – 213.1
ECC_{KE}, Nm	164.7	42.9	79.6 – 269.0

Knee flexion (KF); Knee extension (KE); concentric (CON); eccentric (ECC)

Table 9.2. Allometric modeling of isokinetic maximal moments of force for body size variables.

	Body-size descriptor	b	(95% CI)	*r*	*R*^{2}
CON_{KE}					
	Body mass	0.82	(0.58 – 1.07)	0.68	0.46
	Thigh volume	0.49	(0.28 – 0.70)	0.54	0.29
ECC_{KF}					
	Body mass	0.99	(0.66 – 1.31)	0.64	0.42
	Thigh volume	0.51	(0.23 – 0.79)	0.45	0.20
CON_{KF}					
	Body mass	0.92	(0.61 – 1.24)	0.63	0.39
	Thigh volume	0.62	(0.37 – 0.87)	0.56	0.32
ECC_{KE}					
	Body mass	1.15	(0.86 – 1.44)	0.74	0.54
	Thigh volume	0.71	(0.45 – 0.96)	0.61	0.37

Knee flexion (KF); Knee extension (KE); concentric (CON); eccentric (ECC)

Figures 9.1 and 9.2 illustrate the relationships between the isokinetic maximal moments of force for reciprocal KF and KE in CON and ECC muscular actions, expressed in absolute values and as the derived power function ratio, with maturity offset. Linear relationships were observed between the $\mathrm{CON}_{\mathrm{KE}}$ and $\mathrm{ECC}_{\mathrm{KF}}$ maximal moments of force expressed in absolute terms with estimated offset from PHV. The trend of relationships between absolute values $\mathrm{CON}_{\mathrm{KF}}$ and $\mathrm{ECC}_{\mathrm{KE}}$ maximal moment of force with maturity offset was quadratic. The explained variance between absolute isokinetic maximal moments of force and maturity offset ranged from 0.31 and 0.50.

The magnitude of associations between maximal moments of force scaled for BM with maturity offset was small ($0.03 \leq R^2 \leq 0.20$) and significant only for $\mathrm{ECC}_{\mathrm{KE}}$. The trend of relationships was quadratic and indicated increases in isokinetic strength for approximately two years after PHV. Significant quadratic associations were also observed in the relationships between maximal moments of force scaled for TV and maturity offset, ($0.29 \leq R^2 \leq 0.40$; $p < 0.001$).

DISCUSSION

The present study examined the influence of age on variation in isokinetic strength variables in late adolescent basketball players, matching individuals for variation in estimated time before or after age at PHV. As expected, basketball players presented a wide range of variation in body size. Given the observed correlation between BM and TV and isokinetic maximal moments of force in the knee joint, allometric modeling was used to partition size differences. Although the range of variation in estimated time before and after PHV was limited, time from PHV significantly influenced both CON and ECC isokinetic maximal strength at 60 $^{\mathrm{o}}\cdot\mathrm{s}^{-1}$ in the basketball players. Controlling separately the influence of BM and estimated active thigh musculature with allometric scaling reduces but does not totally remove maturity offset associated variation on isokinetic strength in both muscular actions. Thus, dimensional changes do not account for all differences in isokinetic strength performance at 60 $^{\mathrm{o}}\cdot\mathrm{s}^{-1}$ in 14 to 16 years-old basketball players.

The growth characteristics of this sample of Portuguese adolescents were consistent with other reports with heterogeneous samples of young male basketball players (36, 37, 267). Although variation in body size was considerable (Table 9.1), mean stature and body mass exceeded age-specific 75th percentiles of U.S. reference data (268), consistent with the importance of body size in basketball selection (31).

Only three basketball players were estimated as before age at PHV; by inference, the sample as a whole was at and beyond PHV. The standard deviation of estimated age at PHV

(13.3±0.8 years) based on maturity offset was similar to those for the three longitudinal samples upon which the protocol was developed (69) and in the range of those based on individually fitted height data in several longitudinal studies (61). Longitudinal data that span the adolescent growth spurt in basketball players are limited. Estimated peak velocity of growth in height of 15 “very tall” youth basketball players in France appeared to occur at about 13.0 years of age (289), which was similar to the estimate for the current sample of players based in maturity offset.

The adequacy and appropriateness of allometric scaling was demonstrated by the near-zero relationships between the scaled isokinetic outputs and size variables and examination of residuals which showed a normal distribution (not shown). The assumptions of linearity and homogeneity of variance of the log-transformed dependent variables were also met (173).

Isokinetic strength outputs are often expressed as a ratio standard to adjust for variation in body size (171, 259, 260). However, spurious correlations, potential misinterpretation of the data, and inaccurate conclusions are limitations of the ratio method (173-175), especially when applied with children and adolescents. Samples of young athletes not only include inter-individual variability in body size and composition, but also contrasting training backgrounds, level of performances, and biological maturation. Results of allometric modeling indicated b exponents in relation to maximal isokinetic moments of force ranging from 0.82 to 1.15 (Table 2) for body mass; the exponents fluctuated above and below the theoretically predicted value of 1.0 value based on theory of geometric similarity (190, 287) and are within the limits of in the 95% confidence interval. This is consistent with reported body size exponents for isokinetic peak torque in other samples of young athletes (45). On the other hand, estimates for the thigh volume exponents from the separate allometric models of isokinetic maximal moments of force ranged from 0.49 to 0.71, which were lower than the theoretically predicted value of 1.00. Values of body size exponents may be explained in part by lower-limb muscle development at greater rate than that predicted by geometric similarity in young athletes, given the possible interactions among growth, maturation and training (193). Thus, generalizations of the observed size exponents to other youth populations need to be made with care.

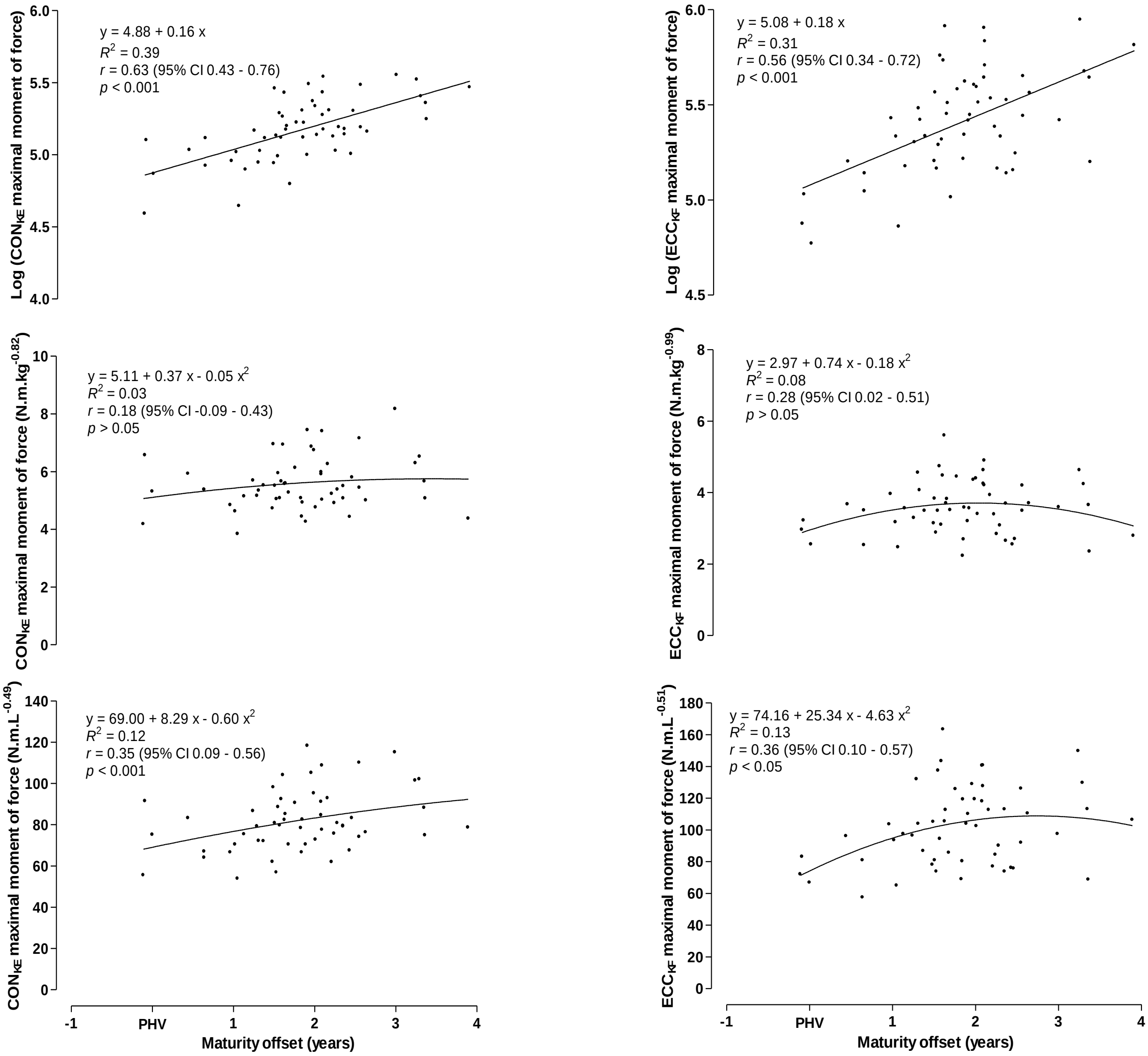

Figure 9.1. Relationships between the isokinetic maximal quadriceps muscles maximal moments of force, in c1oncentric and eccentric actions, with estimated time before and after age at PHV (maturity offset).

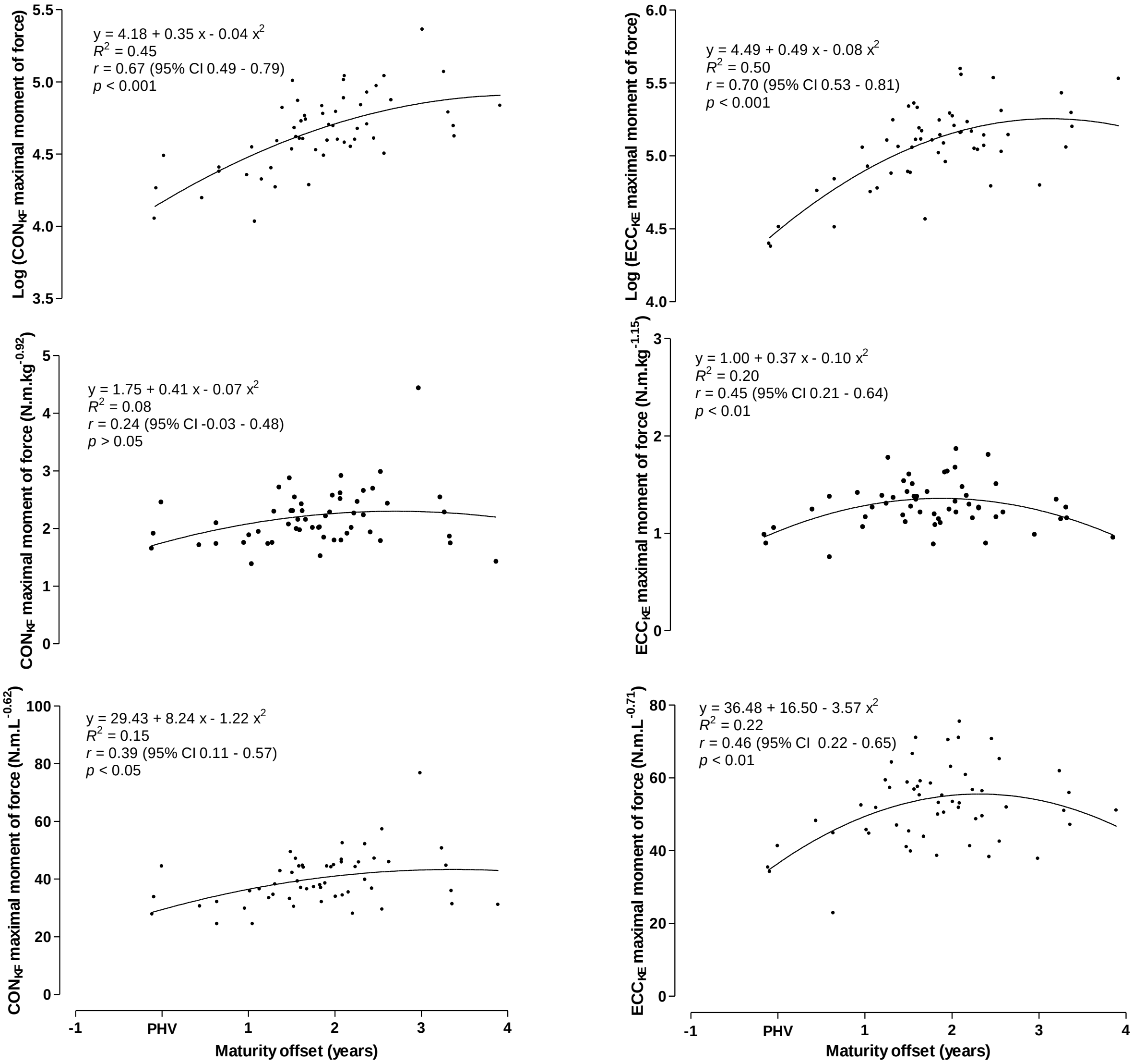

Figure 9.2. Relationships between the isokinetic maximal hamstring muscles maximal moments of force, in concentric and eccentric actions, with estimated time before and after age at PHV (maturity offset).

Most available data youth populations is focused on isometric actions, whereas information on variability in dynamic muscle function related to physical growth and biological maturation has not been fully addressed (149). Available data consider age-related variation in isokinetic strength in athletes, but do not control for inter-individual differences in the timing of the growth spurt (40, 171, 283). The observations on adolescent basketball players indicated a trend of linear increase in isokinetic strength of both quadriceps muscular actions, i.e. CON$_{KE}$ and ECC$_{KF}$, with age after PHV. Corresponding increases in hamstring muscle actions under isokinetic conditions i.e. CON$_{KF}$ and ECC$_{KE}$, tended to reach a plateau approximately two years after PHV. Overall, the results suggested an influence of age per se on lower-limb isokinetic strength outputs when individual variability is aligned on the time before or after PHV; growth in strength occurred for about 2 years after the estimated age at PHV. The variation may be due to the influence of sport-specific training seeing as late adolescence corresponds to period of more intensive sport specialization. The results were generally consistent with observations longitudinal observations on growth in lower body strength. Peak velocity of growth in lower body static strength occurred, on average, 1 year after PHV and maintained a similar rate of growth in the following 2 years (98). This trend may be related to adolescent growth spurts in body mass and free-fat mass, since maximal growth in body mass and muscle mass in boys generally occurs after PHV (14). The distinction between the linear trend of isokinetic quadriceps strength values and the quadratic pattern with a plateau observed approximately 2 years beyond PHV for hamstring muscles may indicate potential concern for knee joint stability. It may lead to imbalances in the relationship of agonist and antagonist forces in the thigh.

The continued increases in isokinetic maximal torque in both quadriceps and hamstring muscles after the estimated age at PHV were partially removed after controlling for BM and TV, separately. These observations were consistent with the general assumption that somatic growth is the major influence on strength during childhood and adolescence, especially the changes in the quantity of muscle (290). However, the quadratic patterns noted when body size variation was allometrically controlled suggested that even during the later stages of adolescent growth neuromuscular development may an additional influence.

The present study demonstrated that lower-limb isokinetic strength at 60 $^{\circ}\cdot s^{-1}$ in CON and ECC muscular actions in late adolescent basketball players is influenced by inter-individual variation in estimated time before or after PHV. The influence of estimated time from age at PHV on isokinetic strength performance was partially reduced when overall mass and estimated thigh muscle were allometrically scaled, which suggested that dimensional changes do not account for all of the variation in isokinetic strength performance at 60 $^{\circ}\cdot s^{-1}$ in 14 to 16 year-old basketball players.

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CHAPTER 10

General discussion

The interest on talent identification, selection and development by researchers has rise considerable in the last twenty years. This fact derives from the importance that national sporting associations frequently seek to identify young athletes who have the highest likelihood of success (13). Hence, structured talent identification and development programs have been adopted for several sports, including in team sports, particularly in the last decade (17-22, 44, 235, 236, 291).

Multidimensional approach to talent identification

Several factors contribute to expert performance, thus it has been recommended multidimensional approaches to study talent identification, selection and development in sport (18), and additionally it is advocated that measures should represent specific demands of the sport in question (292). In team sports, studies dealing with the relation between multidimensional performance characteristics and performance level have been observed in basketball (22, 289, 293, 294), field-hockey (17, 236), handball (21), soccer (16, 19, 20, 44, 295, 296), roller-hockey (unpublished observations), rugby (297, 298) and volleyball (299).

Testing the elite young athlete

Elite athletes in a given age group tend to be homogenous and the procedures used to evaluate physiological performance to need to be sensitive to distinguish individuals. In general, the studies on youth talented athletes explore the application of sport-specific protocols, and in some cases protocols were developed (300, 301). Similarly to non-athletes populations, the assessment of long-term performance is more widespread in studies with athletes, and mostly applying field tests. Meanwhile, the participation in many team sports involves predominantly movements characterized by repeated short bursts, mostly maximum intensity activities (24, 25, 282, 302). Maximal short-term power output is noted to be important to performance in basketball (303, 304), and concurrent testing procedures may have reliability and construct validity limitations to assess performance of adolescent basketball players. In chapter 4 we demonstrated that a commonly used exercise, adopted also as testing procedure, i.e. 140-m Line-drill test, is a sport-specific reliable test for short-term performance and sensitive to distinguish adolescent players by competitive level. The test presents itself as a protocol of interest to coaches, sport scientists and others involved in the selection and development of youth basketball players. This has been noted in literature with the increase of the interest in the test in basketball related research (22, 52, 126, 304, 305).

Protocols, data quality and confounding factors

The sources of intra-observer variability in isokinetic strength assessment in the knee joint have been addressed in literature (146, 247-249, 256). However, it has been noted that familiarization sessions may be needed in children and adolescents, with particular concerns in eccentric muscular actions (149), and the lack of control of learning effects may inner the validity of interpretations on isokinetic data on human muscle function (146). In Chapter 5, age, biological maturation, training experience, body size, lower-body morphology and initial strength performance were examined as correlates to intra-individual variability in adolescent athletes. The results highlight the importance of age, maturation and body size in the consideration of reliability of assessments of isokinetic knee joint muscles actions at $60^{o} \cdot s^{-1}$ in adolescent athletes. The results suggest that attention should take when considering eccentric actions in isokinetic assessment of the knee joint in athletes, confirming the concerns previously raised (149). This indicates the need of familiarization session to improve reliability of assessment of dynamic muscular function of thigh muscles. In this study was observed a decrease of intra-individual variability in a small subsample after a familiarization session, within the limits of intra-observer error reported in literature(146).

Despite multidimensional approaches, the focus of the studies in young athletes is mostly on morphological characteristics and physiological performance, but the consideration of the confounding effects introduced by maturation have not been systematically considered (13). In chapters 8 and 9, the age-related influence on maximal short-term power and strength performance was aligned to estimated PHV. The results indicate that a large variability in age-related variation on maximal short-term performance is accounted to maturation when individual are matched by the moment of maximum growth in stature during adolescence. The results are consistent with the suggestions that maturity associated variation on maximal short-term performance is mainly mediated by increases in body size (14), i.e., overall body mass and appendicular muscle mass. This may reflect the asyinchronism of the development of body mass and muscle mass during adolescence growth spurt, delayed on average by one year to PHV (63, 65, 66). Interestingly, not all variability accounted to maturation on maximal short-term power outputs is attributable to inter-individual differences in size. Significant correlations (see figure 8.1) remain between WAnT power outputs when allometrically scaled for body size indicators, indicating that adolescent growth spurt may enclose genetic variation in size and WAnT (164), age related-qualitative changes and inter-individual muscular characteristics (48, 49).

Age variation and alignment for PHV

Other limitation of the applying of a large set of protocols to assess young athletes performance resides in possible limitation of these assessments, in particular field based assessments, to provide deeper insights in important neuromuscular mechanisms. The analysis of isokinetic strength outputs aligned for PHV provides intriguing results. Data reported previously on age-related effects is based on concentric muscle action of knee extensors and flexors, using ratio standards to control body size effects as did not consider possible maturity-associated variation (171, 259, 306). The trend of improvements of quadriceps and hamstrings after PHV seem to be distinct. Quadriceps muscles increases have a linear trend with age (i.e., increases in muscle size and function with growth and with accumulation of training exposure), as hamstrings muscle increases with age tend to reach a plateau approximately two to three years after PHV, particularly in eccentric actions. Normalizing inter-individual variability in whole and lower-limb size, the increases in thigh muscle strength may be attributed to dimensional changes with growth and to neuromuscular maturation, possibly increases in the myelination (307) and propagation velocity of motor neurons (308), along with the ability to activate a greater percentage of available motor units (309). It seems plausible to consider that training exposure, in the particular case of basketball, may be a major contributor to age related changes in lower-limb strength after pubertal development. Therefore, the distinction in the development patterns for quadriceps and hamstrings muscles observed may indicate potential concern for knee joint stability. It suggests that the accumulation of basketball training stimulus and/or increases of intensity and loads associated with the development of optimal physiological conditions to performance in the sport may lead to imbalances in the relationship of agonist and antagonist forces in the thigh.

Performance outputs: indicators, limitations and predictors

Further analysis of the thigh muscles isokinetic outputs should consider the examination of the ratio between hamstrings by quadriceps maximal moments of force. Normative values in the relationship between hamstrings by quadriceps ratio have been suggested as reference for thigh muscle balance (310, 311). The use of these ratios is widespread in literature for the assessment of muscle balance (253, 259, 312-314), but it should be noted that the variables, whether reciprocal or functional ratios (315), are based on maximal moments of force. Given the observed distinct trends of development in isokinetic thigh strength with age after PHV, assessing muscle balance may be important, but independently, the peak moment ratios and angle specific moment curves provide only a limited amount of information since it fails to take account the angle at which the moment is produced (316).

Overall, the preceding observations highlight the importance of considering maturation in the factors affecting maximal short-term performance being of relevance in the context of youth basketball, especially for talent identification, sport selection and prediction of success. Additionally, the consideration of laboratory based assessment may provide important information about the neuromuscular function in young athletes.

Normalisation for variation in size

Maximal power and strength measures are related with body size, composition and lower-limb muscular mass (49, 149). Another interesting debate in the literature is focused on the appropriateness of control for whole-body size or to appendicular segments, given their logical contribution to non-weight bearing movements, or observed tendency to body mass independence in sprint running efforts (172, 192, 317). The measurement of appendicular segments composition, in particular in the lower-limb, has several procedures available, but it may limitations on the use of these procedures in extensive samples (see Chapter 3). Therefore, lower-limb volume estimates by anthropometry have been proposed (210) and validated in adults (210-212) and children (318), and used in several studies with maximal short-term performance in youth populations (150, 167, 170, 187, 274, 319). The validity of the athropometrical method in athletes is not established in literature. Cross-validation analysis of lower-limb volume estimates by anthropometry (practical method) with dual-energy X-ray absorptiometry method as criterion demonstrated a tendency for overestimate lower-limb volumes by anthropometry. Correlation and range of variation between practical and criterion methods indicated that the anthropometrical method is a valid method to quantify lower-limb volumes in male and female athletes. The method is practical when more expensive and complex techniques are not available. Additionally, predictive models were tested including age, body size and lower-limb skinfolds to increase the precision of LLV estimates using anthropometry. It was observed an increase in the accuracy of the estimates volumes, both for male and female subjects.

Allometric or power function modeling has been noted to be theoretically, physiologically, and statistically superior to alternative scaling models (175), but debate about appropriateness of mathematical model as well as the value of the adopted size indicator remains actual. The use of allometric modeling to remove the influence of body size on physiological variables as not been systematic in young athletes. The values of the mass exponents derived from allometic models in the present study demonstrate that short-term performance is not proportional to body size, consequently highlighting the need to use allometric scaling to interpret data in late adolescent athletes. Also, the assyncronisms present in pubertal development associated with possible muscle mass development induced by training stimulus may explained the consistency of the present results with the observations that indicate limitations in the application of geometric similarity in adults (193).

CHAPTER 11

Main conclusions

It is possible to summarize the present research project in a short number of main conclusions:

- Validity of anthropometric lower-limb volumes estimation, as well as predictive models that included anthropometric volumes estimates plus age, body size and lower-limb skinfolds was established for both for male and female athletes;
- The Line-Drill test revealed to be a useful protocol to coaches, sport scientists and others involved in the selection and development of youth basketball players. This test has the ability to provide reliable data, sensitiveness to distinguish young athletes;
- Intra-individual variability in concentric and eccentric knee isokinetic strength testing at 60º s^{-1} indicates the need for familiarization session. Additionally, the consideration of chronological age, maturity status and accumulated experience are potential factors that may reduce the attainment of optimal performance;
- This study confirms the importance of allometric scaling to account for body size differences when interpreting changes in maximal short-term performance in late adolescent basketball players;
- Biological maturation, body size dimensions, lower-limb volume and years of training explained differently the variation in concurrent assessments of maximal short-term performance. Overall, biological maturation entered almost all outputs derived from the three protocols, highlighting the need to consider variation related to maturation whether the protocol requires displacement of the body or cycling;
- The variation in maximal short-term muscle power and isokinetic strength outputs was mostly mediated by variation in body dimensions and this was evident when expressed relative to estimated time before and after age at PHV. Dimensional changes do not account for all of the variation in maximal short-term performance, indicating that neuromuscular maturation needs to be considered in these efforts among late adolescent basketball players.

It is expected children and adolescents to be taller, heavier, stronger and faster with age, in particular when engaged in sports training programs. Therefore, the main conclusion of the present study is that the effects of biological maturation and body size on maximal short-term performance need to be accounted appropriately, whether in research or in the context of youth basketball.

LIMITATIONS OF THE STUDY

The present study in a sample of young basketball players, as with any other cross sectional study, only provides suggestive evidence concerning the causal relationship between variables during growth. In particular, in chapters 8 and 9 are characterized average short-term power outputs and isokinetic strength developmental patterns displayed by adolescent basketball players differing in estimated maturity timing and age. Consequently, the true magnitude of performance changes that might effectively occur between and within individuals with growth and maturation cannot be described. While estimates of somatic maturity used to align individual for PHV have merit in that they do not require invasive procedures, care is warranted in utilizing predicting age at PHV from anthropometrical variables (70). Also, only male, late adolescent basketball players were evaluated here. Thus, caution should be taken when applying the present results to groups of younger basketball players, in particular pre-pubertal athletes. Additionally, it would be of interest to verify if the results of the present study have similar trends similar groups of female players.

Basketball may be categorized as a strength-related sport, where performance is influenced by strength, but it is not a critical factor that directly limits performance (250). The specificity of testing with isokinetic dynamometry in basketball may be questioned, as no information is available about the correlation between isokinetic performance and physiological or biomechanical parameter and athletic performance in basketball. Then again, isokinetic assessment has been noted useful in other team sports, such as soccer (320-322) and roller hockey (unpublished observations). Additionally, it was only considered one testing angular velocity, (i.e., “slow velocity”, $60^{o}\cdot s^{-1}$), based on concerns noted to executing eccentric muscular actions at “high” velocities, and in pediatric populations (149, 250, 323). Consequently, inferences about isokinetic strength development cannot be extended to higher angular velocities.

CHAPTER 12

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