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Relations of muscle strength and body mass when performing different vertical jumps

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Abstract
Introduction. Sports result largely depends on body dimensions and the development of motor skills. Aim of Study. The aim of the study was to examine the relationship between body mass and muscle strength test results when performing different variants of vertical jumps. Material and Methods. Sixty selected senior basketball players participated in the study. According to the criterion of the position played in the team, the respondents were divided into two groups. One group consisted of external players (n = 30), while the other group comprised internal players (n = 30). Results. In both groups of subjects, low correlation coefficients were obtained between body weight and results of indirect muscle strength assessment tests (0.00; –0.05; –0.00; –0.02), as well as weak correlation coefficients between results of direct muscle strength assessment tests and body weight (0.44; 0.36; 0.41; 0.38). In the group of external players in the tests for the direct assessment of muscle strength allometric exponents b = 0.82 and b = 0.74 were recorded, while for internal players in these tests allometric exponents b = 0.73 and b = 0.72 were obtained. Tests for the indirect assessment of muscle strength in the group of external players gave allometric exponents b = 0.09 and b = –0.00, while in the group of internal players the exponents were b = –0.10 and b = –0.25. Conclusions. This study showed that the results in the tests for the direct assessment of muscle strength when performing fast movements are dependent on body mass, while those in tests for the indirect assessment of muscle strength when performing fast movements do not depend on body mass.

KEYWORDS: basketball players, body dimensions, allometric scaling, fast movements.

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Introduction

The sports result largely depends on the athlete's body dimensions and the development of motor skills. Successful movement and solving motor tasks are influenced not only by body dimensions, but also by other factors, such as gender, age and body composition [4, 10, 14, 18, 22, 30, 32]. Of these factors, the influence of body dimensions on motor ability needs to be especially emphasized, because physical growth and development largely determine the level of development of motor and functional abilities [12]. Previous studies concerning all body dimensions specifically analyzed the effect of body weight and body height on motor abilities [12-34]. The athletes with larger body dimensions show greater muscular strength and they will overcome a higher external load compared to those with smaller body dimensions. It is common to say in a description of a body that it is twice as large as another, making no distinction in terms of body length, surface area and volume. At the same time, the important fact is forgotten that the lengths, surface areas and volumes for bodies of similar dimensions do not scale proportionally. For the two bodies, being geometrically similar, but of different dimensions, it cannot be claimed that they are the same, because the ratio of surface area and volume changes significantly with the dimension of the body [2]. Initially, studies were conducted that referred to the effect of body dimensions on strength in weightlifters. Hoffman researched the influence of body weight on muscle strength in the 1930s and came up with the so-called Two-thirds power law. Comparing the abilities of weightlifters characterized by different body dimensions, he determined the so-called Hoffman formula. Ten years later, Austin considered the $m^{2/3}$ exponent to be insufficiently accurate, thus he set up the Austin formula, which involved the $m^{3/4}$ exponent [2]. The unexpected results in weightlifting were explained by those researchers by scaling strength with body weight. In the lower weight categories the weight of the lifted load increases proportionally with the body weight of competitors, while this growth is significantly slower in heavier competitors. The reason lies in the scaling of muscle strength with $m^{2/3}$, i.e. heavier competitors, in relation to their own weight, are relatively weaker than lighter competitors. More recently the effect of the dimensions of the locomotor system on human motor abilities has been investigated in many studies [12-34]. The influence of body dimensions on the mechanics of movements is referred to as scale effects, thus bringing a mechanical quantity that describes the movement in connection with a certain dimension of the body is called scaling [12]. Among researchers opinions are divided when it comes to the effect of body dimensions on motor abilities. Some authors consider body dimensions and motor abilities to be linearly dependent and in the normalization of results they use the method of proportional scaling, with the obtained results presented per kilogram of body weight [9, 10]. On the other hand, other authors are of an opinion that type of normalization is not adequate and in a number of studies they have proven the nonlinear dependence of body dimensions and motor abilities [14-25]. There are two models in normalizing the results. The theoretical model in examining the influence of body dimensions on the locomotor system is based on the assumption that two bodies are basically the same, with differences found only in their dimensions. It is based on the concept of geometric similarity and is referred to as geometric scaling [1]. When the results of research are normalized in relation to body weight by applying proportional scaling, different exponents are obtained in different groups of motor ability tests. Since the topic of this paper is connected with testing the effect of body weight on the manifestation of muscle strength when performing fast movements, only exponents for normalization of results in tests of direct and indirect assessment of muscle strength when performing fast movements will be presented. Two models are most often used in the normalization of results. According to the theoretical model, tests for the direct assessment of muscle strength are normalized with $m^{2/3}$ and the theoretically predicted value for results normalization is $b = 0.67$ [1, 7]. Tests for the indirect assessment of muscle strength when performing fast movements do not depend on body dimensions. If the movement is performed with a maximum jump, the test results are proportional to the surface area of the muscle and the length of its shortening, and they are inversely proportional to body weight. In a study of Marković and Jarić [19], recorded results indicate that strength during the vertical jump is related to body dimensions, while the jump height in the same tests remained independent of body dimensions. It should be noted that some studies have confirmed that transverse body dimensions, relative to body size, grow faster than longitudinal body dimensions. This assumption is confirmed by the theory of elastic similarity. According to this theory, muscle strength and power should be proportional to $m^{0.75}$, not to $m^{0.67}$ [15, 16, 20, 25-27]. In order to more precisely normalize the results of the tests, an experimental model, known in practice as allometric scaling, is often applied in practice [14, 15, 34]. By applying allometric scaling, the obtained results of motor tests do not depend on body dimensions. The basic idea of this study arose from the assumption that the effects of scaling are manifested differently in people of different body dimensions. Nevill et al. [25] when comparing well-trained athletes with physically inactive individuals confirmed that body composition between subjects was not geometrically similar. They concluded that in both groups of subjects body circumferences and body segments, in locations of greater muscle mass and adipose tissue, grow at a faster rate than that predicted by geometric similarity. On the other hand, in the area of the head and joints the growth of the volume of the body segments is slower than the geometric similarity predicts. Bazett-Jones et al. [2] noted a test dependence of muscle force and torque on body mass of different allometric exponents in men and women. Applying the obtained exponents he normalized the results and successfully neutralized the influence of body weight on the manifestation of motor abilities. Starting from the assumption that the effects of scaling are manifested differently in people of distinctly different narrow dimensions, the aim of this study is to examine the relationship between body mass and muscle strength tests when performing different vertical jumps in two groups of basketball players of different body dimensions.

Material and Methods

Study participants

A total of 60 senior elite basketball players participated in this study. They were divided into two equal groups based on the position they play in the team. One group of basketball players consisted of 30 outside players (11 pointguards, 10 shooting guards and 9 small forwards) with an average age of 25.21 ± 4.11 years, body mass 86.91 ± 7.78 kg, body height 191.38 ± ± 6.22 cm and body fat percentage 10.83 ± 3.27% (Mean ± SD). The other group comprised 30 inside players (14 power forwards and 16 centers) with an average age of 24.10 ± 4.28 years, body mass 102.28 ± ± 6.73 kg, body height 204.16 ± 3.37 cm and the percentage of body fat 13.20 ± 3.02% (Mean ± Std.Dev). Regarding the research methodology it is important to note that the recommendation is that the number of participants in such research should be 5-10 times higher than the number of tested variables [21]. In this study, four variables were tested on a sample of thirty subjects, which satisfies the prescribed recommendations. All the participants have been playing basketball professionally and participate in the highest ranking basketball competitions in Bosnia and Herzegovina. The criteria for inclusion were as follows: players who joined the first team for at least six months, players who played at least one half-season before testing, all players went through the preparation period with the team, without injuries in the last six months. Exclusion criteria were as follows: players in the recovery phase from some form of acute or chronic injuries, players in the process of rehabilitation and basketball players who did not complete the entire preparation period.

Study organization

Testing was performed by the same experienced examiner at the Laboratory for isokinetic testing, the Faculty of Physical Education and Sport in Banja Luka, Bosnia and Herzegovina. The laboratory was air-conditioned and room temperature was held between 22-24ºC. Testing was performed between 9.00 am and 14.00 pm. The morphological characteristics of the subjects was assessed on the basis of data obtained by measuring body height, body mass and percentage of body fat. Body mass (kg) and subcutaneous adipose tissue (%) of the subjects were measured by the method of bioelectrical impedance (TANITA BC418) accurate to 0.1 kg, while for body height (cm) an altimeter (Seca, Germany) accurate to 0.5 cm was used. The measurements were performed in accordance with the instructions of the International Association of Anthropometric Measurements (ISAK). A force platform (Globus Ergo Tesys System 1000, Force plate – Mega twin plates, Italy) was used to assess muscle strength when performing a vertical jump. In the vertical jump tests the countermovement jump (CMJ) and squat jump (SJ), the maximum jump height (cm) and the maximum displayed power (W) in the concentric phase of the jump (CMJP and SJP) were measured. Test results expressed in the maximum jump height in centimeters (cm) represent an indirect estimate of muscle strength (CMJ; SJ), while test results obtained in the concentric phase of a vertical jump expressed in watts (W) represent a direct estimate of muscle strength (CMJP; SJP). After a ten-minute warm-up on a bicycle ergometer (Monark) and dynamic stretching, the subjects performed two tests in three attempts, with a 10-second break between repetitions. The break between tests was 5 min. The best achieved values in the tests were taken for analysis. The CMJ test was performed with isolated hands on the hips. The subject was in a normal upright position, after which he descended to the semi-squat position (the angle of the thighs and lower legs was approximately 90°) and without stopping, at the point of changing the direction of movement, performed the maximum vertical jump [11]. The SJ test was performed with isolated hands on the hips. The subject was in a normal upright position, after which he descended to the semi-squat position (the angle of the thighs and lower legs was approximately 90°), maintained this position for three seconds, and after the signal performed a maximum vertical jump [11]. To obtain data in the CMJP and SJP test a force platform was used, where muscle strength was calculated as the product of the vertical component of the reaction force and the velocity of the center of body mass. The jump height in the CMJ and SJ tests was determined as the displacement of the center of mass of the body calculated from the vertical component of the reaction force and body mass. Based on the duration of the flight, the maximum jump height was calculated in the CMJ and SJ tests (the flight time method). A standard formula was used to calculate the jump height ($h = v_{take\text{-}off}^2/2g$). Muscle strength in the tests was expressed as the product of the vertical component of the ground reaction force (GRF) and the velocity of the center of mass of the body ($P = F \times v$) [1]. Measurement on the force platform requires precise adherence to the test technique (both feet should leave and touch the platform at the same time, the knees in the jump take a stretched position, the torso remains in the stretched position). According to the theory of geometric similarity, muscle strength and power are proportional to the cross-sectional area of the muscle, which is proportional to body weight graded to 2/3 (b = 0.67). An allometric scaling model was used to normalize muscle strength relative to body mass. The equation representing allometric scaling is

$$a = S / m^b \quad (1)$$

where (a) the index of motor abilities, (S) motor ability, (m) body mass, and (b) the allometric exponent [13]. By applying equation (1) each motor ability (S) can be represented as a function of body dimensions (m):

$$S = a \cdot m^b \quad (2)$$

where (a) is a constant multiplier, and (b) is an allometric exponent.
By logarithmic transformation of equation (2), the regression line equation is obtained:

$$log(S) = log(a) + b \cdot log(m) \rightarrow \quad (3)$$

where parameter (a) represents the segment and parameter (b) is the slope coefficient of the regression line. Using regression analysis, the method of least squares, the values of parameters (a) and (b) are calculated, which determines the relationship between motor abilities and body dimensions.

Statistical analysis
The obtained data were processed by descriptive and comparative statistical procedures. Within the descriptive statistics for all variables are determined, i.e. arithmetic mean and standard deviation. Within comparative statistics the following were applied: simple linear regression analysis (least squares method) to determine parameter a, which represents the segment, and parameter b, which represents the slope coefficient of the regression line, based on which the correlation between the results of motor skills and body mass tests is assessed. All the collected data were processed using the statistical program Statistics SPSS version 20.0.

Ethical approval
The research was approved by the Ethics Commission of the Faculty of Sports and Physical Education, University of Banja Luka in accordance with the Declaration of Helsinki [35].

Informed consent
All the participants were first informed about the study, the purpose and goal of the research and possible consequences were explained to them. Also the procedure and the course of the testing itself were explained to the participants. Prior to the survey, each participant signed a consent form to participate. For this research the consent and approval of the head coach and the president of the club were obtained and after that testing was started.

Results

Table 1 shows the basic descriptive parameters (Mean ± ± SD) of vertical jump variables for basketball players divided based on their positions in the team.

Table 1. Vertical jumps of basketball players divided based on their positions in the team

Variables	Outside players	Inside players
	Mean ± SD	Mean ± SD
CMJ (cm)	36.53 ± 4.56	31.83 ± 2.79
CMJP (W)	4494.12 ± 735.50	4810.90 ± 587.65
SJ (cm)	35.26 ± 4.31	30.33 ± 2.89
SJP (W)	4415.94 ± 732.80	4635.60 ± 568.30

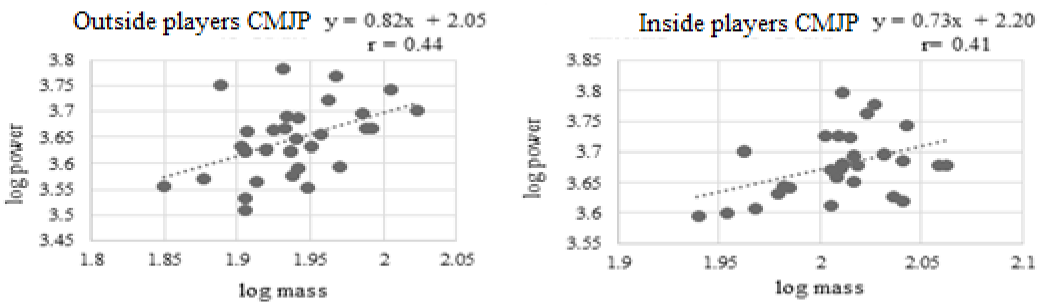
Note: CMJ – countermovement jump, CMJP – countermovement jump power, SJ – squat jump, SJP – squat jump power

Table 2 presents the relationship between the logarithmic results of tests for motor abilities of outside and inside players of senior age with body weight. In both groups of subjects low correlation coefficients (0.00; –0.05; –0.00; –0.02) were obtained between body mass and indirect muscle strength assessment tests, as well as moderate correlation coefficients between direct muscle strength assessment tests and body weight (0.44; 0.36; 0.41; 0.38).

Table 2. Correlation of results from tests of motor abilities of outside and inside players with body weight

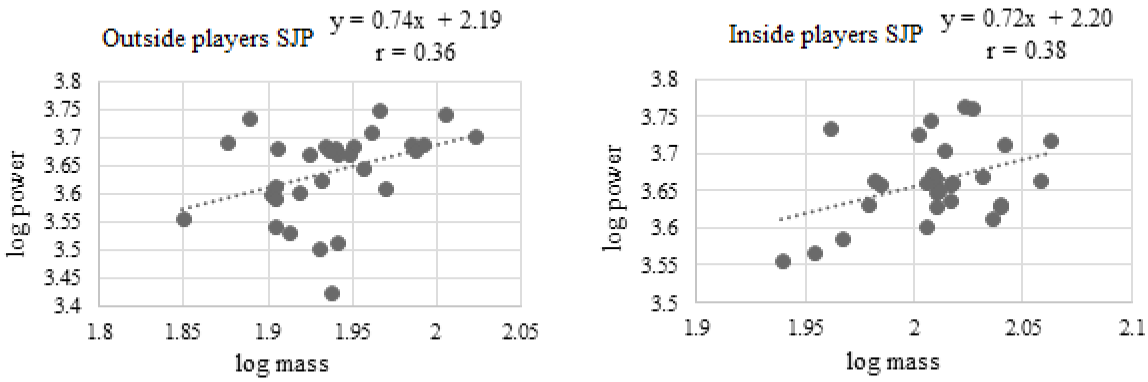
		Outside players				Inside players			
		CMJ	CMJP	SJ	SJP	CMJ	CMJP	SJ	SJP
m	*a*	1.37	2.05	1.56	2.19	1.70	2.20	1.98	2.20
	b	0.09	0.82	–0.00	0.74	–0.10	0.73	–0.25	0.72
	r	0.00	0.44*	–0.05	0.36*	–0.00	0.41*	–0.02	0.38*

Note: CMJ – countermovement jump, CMJP – countermovement jump power, SJ – squat jump, SJP – squat jump power, *a* – segment, *b* – slope coefficient of regression line, m – body mass, *r* – correlation coefficient
* $p < 0.05$



Note: CMJP – countermovement jump power

Figure 1. Relationship between logarithmic results of body mass and manifested muscle strenght in concentric phase of the countermovement jump in outside and inside players



Note: SJP – squat jump power

Figure 2. Correlation between logarithmic results of body mass and expressed muscle strenght in the concentric phase of squat jump in outside and inside players

In the group of outside players allometric exponents b = 0.82 and b = 0.74 were obtained in the tests for the direct assessment of muscle strength (Figure 1, Figure 2). In inside players allometric exponents b = 0.73 and b = 0.72 were obtained in direct muscle strength assessment tests (Figure 1, Figure 2). Regarding the tests for the indirect assessment of muscle strength in the group of outside players allometric exponents b = 0.09 and b = –0.00 were recorded, while in the group of inside players it was exponents b = –0.10 and b = –0.25 (Table 2).

Figures 1 and 2 show the correlation between the logarithmic results of body mass and the expressed muscle strength in the concentric phase of the CMJ and SJ in outside and inside players. The slope coefficient of the regression line corresponds to the allometric exponent that determines the relationship between muscle strength and body mass.

Discussion

Using an experimental model in data normalization allometric exponent b was determined, which shows the correlation of test results for different vertical jumps and body weight. The basic assumption is that muscle strength manifested in the concentric phase of vertical jumps is dependent on body mass, while the height of vertical jumps is independent of body mass. When testing the relationship between motor skills and body dimensions, attention must be paid to other factors, such as gender, age, physique and level of physical fitness [13]. Guided by these recommendations, the participants in our study did not differ significantly in terms of age, they are of the same sex, approximately similar level of training, while body composition and low percentage of adipose tissue did not negatively affect the manifestation of motor skills. This study involved selected basketball players, whose body height, body weight and percentage of adipose tissue approximately correspond to the values of top European basketball players [7, 28, 33]. The study results in the CMJ and SJ tests indicate that in both groups of the participants low correlation coefficients were obtained between body mass and indirect muscle strength assessment tests, as well as moderate correlation coefficients between direct muscle strength and body mass assessment tests (Table 2). The obtained results are consistent with the results of other researches. Nedeljković et al. [22] recorded moderate correlation coefficients (from 0.21 to 0.56) between body weight and various motor ability tests. In all muscle strength tests a statistically significant association with body weight was confirmed. In the same study an average value of allometric exponent b = 0.55 was obtained. Another study reported a low correlation coefficient between the tests for the indirect assessment of muscle strength and body mass (–0.03) [18]. In the same study in the tests for the direct assessment of muscle strength when performing rapid movements a slightly lower allometric exponent (b = 0.57) was obtained compared to the theoretically predicted value (0.67). In the continuation of the research of the same problem, Marković and Jarić [17] tested the connection between the tests for the direct assessment of muscle strength in the vertical jump and body weight before and after the normalization of the data. Prior to normalization, a moderate positive association between muscle strength and body mass was observed. After data normalization the correlation coefficients decreased. Regarding allometric exponents in the CMJP test, a smaller allometric exponent was recorded for inside players (b = 0.73) compared to outside players (b = 0.82). This result can be explained by the higher proportion of adipose tissue in the body composition of players playing in inside positions. Folland et al. [5] confirmed that with the increase of the fat component in the human body the value of the allometric exponent recorded in relation to body weight decreases. Different allometric exponents between the tested groups can also occur due to significant differences in body weight and body height of outside and inside players. In the SJ test very similar allometric exponents were obtained. For outside players exponent b = 0.74 was obtained, while for inside players it was b = 0.72. In both groups of subjects different allometric exponents were recorded in relation to the theoretically predicted value for this group of tests (b = 0.67). Taking into account the results in both tested groups and both vertical jump tests, the mean value of the allometric exponent is b = 0.75, which is slightly higher than the theoretically predicted value determined by the theory of geometric similarity. It should be emphasized that the obtained mean value of the exponent coincides with the value predicted by the theory of elastic similarity ($m^{0.75}$). Discrepancies between the values of allometric exponents and the theoretically predicted value (0.67) may be the result of markedly different body dimensions of the examined basketball players in relation to the average population, which was most often the sample in such research. Regarding the tests for the indirect assessment of muscle strength in the CMJ test exponents b = 0.09 for the group of outside players and b = –0.10 for the group of inside players were obtained. In the SJ test exponent b = –0.00 was recorded in the group of outside players, while b = –0.25 was obtained in the group of inside players. The mean value in both tests and in both tested groups is b = –0.08, which is very close to the theoretically predicted value of b = 0. As expected for this group of tests, it was confirmed that the results do not depend on body weight and that they do not need to be normalized in order to eliminate the influence of body dimensions. Marković and Jarić [18] used an experimental approach to normalize the tests for the indirect assessment of muscle strength in relation to body weight to obtain a mean value of the allometric exponent b = 0.07, which is approximately the mean value of the exponent obtained in our study. Although some research results indicate a moderate positive association between movement speed and body dimensions [31], the results of our study are consistent with the data reported by Nedeljković et al. [22], in turn confirming the findings of Marković and Jarić [18] that indirect muscle strength assessment tests when performing rapid movements does not depend on body mass.

Conclusions

Among other factors, body dimensions significantly affect the manifestation of motor abilities. The influence of body mass on motor abilities was most often examined. In both groups a nonlinear relationship was confirmed between body mass and results in direct muscle strength assessment tests when performing vertical jumps. On the other hand, there was no correlation between body mass and muscle strength in the tests for the indirect assessment of muscle strength when performing the same tests. In the tested groups different allometric exponents were obtained in the tests for the direct assessment of muscle strength. The same exponents also differed from the theoretically predicted value for this group of tests. In the tests for the indirect assessment of muscle strength, approximately similar allometric exponents were obtained, which did not differ in relation to the theoretically predicted value. This study represents only a small part of the problem related to the effects of scaling. A special contribution of this research is that selected basketball players were tested, with different body dimensions and different body dimensions in relation to the average population. The conclusions of this study can be used in future research to examine the effect of body dimensions on different groups of motor skills tests.

Conflict of Interest

The authors declare no conflict of interest.

References

1. Aasa U, Jarić S, Barnekow-Bergkvist M, Johansson H. Muscle strength assessment from functional performance tests: role of body size. J Strength Cond Res. 2003;17:644--670.
2. Bazett-Jones MD, Cobb CS, Muktan NJ, Susan E, Cashin ES, Earl EJ. Normalizing hip muscle strength: establishing body-size-independent measurements. Arch Phys Med Rehabil. 2011;92(1):76-82.
3. Dalleau G, Belli A, Viale F, Lacour JR, Bourdin M. A simple method for field measurements of leg stiffness in hopping. Inter J Sports Med. 2004;25:170-176.
4. Davies MJ, Dalsky GP. Normalizing strength for body size differences in older adults. Med Sci Sports Exerc. 1997;29(5):713-717.
5. Folland JP, McCauley TM, Williams AG. Allometric scaling of strength measurements to body size. Eur J Appl Phys. 2008;102:739-745.
6. Frontera WR, Hughes VA, Fielding RA, Fiatarone MA, Evans WJ, Roubenoff R. A cross-sectional study of muscle strength and mass in 45- to 78-yr-old men and women. J Appl Phys. 1991;71:644-650.
7. Gerodimos V, Manou V, Kellis E, Kellis S. Body composition characteristics of elite basketball players. J Hum Mov Stud. 2005;49:115-126.
8. Glatthorn JF, Gouge S, Nussbaumer S, Stauffacher S, Impellizzeri FM, Maffuletti NA. Validity and reliability of Optojump photoelectric cells for estimating vertical jump height. J Strength Cond Res. 2011;25(2):556-560.
9. Hakkinen K, Komi PV, Alen M. Effect of explosive type strength training on isometric force and relaxation-time, electromyographic and muscle fibre characteristics of leg extensor muscles. Acta Phys Scand. 1985;125(4):587--600.
10. Ioakimidis P, Kellis E, Gerodimos V, Manou V, Kellis S. Allometric Scaling of Isokinetic Peak Torque in Young Basketball Players. Athens: Pre-olympic Congress; 2004.
11. Jarić S, Mirkov D, Marković G. Normalizing physical performance tests for body size: a proposal for standardization. J Strength Cond Res. 2005;19(2):467--474.
12. Jarić S. Biomechanics of human locomotion with the basics of sports medicine. Beograd: Dosije; 1997.
13. Jarić S. Muscle strength testing: use of normalization for body size. Sports Med. 2002;32(10): 615-631.
14. Jarić S. Role of body size in the relation between muscle strength and movement performance. Exerc Sport Sci Rev. 2003;31(1):8-12.
15. Kleiber M. Body size and metabolic rate. Physiol Rev. 1947;27:511-541.
16. Kleiber M. Body size and metabolism. Hilgardia. 1932;6:315-353.
17. Marković G, Jarić S. Is vertical jump height a body size independent measure of muscle power? J Sport Sci. 2007;25:1355-1363.
18. Marković G, Jarić S. Movement performance and body size: the relationship for different groups of tests. Eur J Appl Phys. 2004;92:139-149.
19. Marković G, Jarić S. Scaling of muscle power to body size: The effect of stretch – shortening cycle. Eur J Appl Phys. 2005;95:11-19.
20. McMahon TA. Muscles, reflexes, and locomotion. Princeton: Princeton University Press; 1984.
21. Nedeljković A, Mirkov D, Božić P, Jarić S. Tests of muscle power output: the role of body size. Inter J Sports Med. 2009;30(2):100-106.
22. Nedeljković A, Mirkov D, Marković G, Jarić S. Tests of muscle power output assess rapid movement performance when normalized for body size. J Strength Cond Res. 2009;23(5):1593-1605.
23. Nevill AM, Bate S, Holder RL. Modeling physiological and anthropometric variables known to vary with body size and other confounding variables. Am J Phys Anthropol. 2005;128(S41):141-153.
24. Nevill AM, Ramsbottom R, Williams C. Scaling physiological measurements for individuals of different body size. Eur J Appl Phys. 1992;65:110-117.
25. Nevill AM, Stewart AD, Olds T, Holder R. Are adult physiques geometrically similar? The dangers of allometric scaling using body mass power laws. Am J Phys Anthropol. 2004;124:177-182.
26. Nevill AM. Scaling, normalizing, and per ratio standards: an allometric modeling approach. J Appl Physiol. 1995;79:1027-1031.
27. Nevill AM. The need to scale for differences in body size and mass: an explanation of Kleiber's 0.75 mass exponent. J Appl Phys. 1994;77:2870-2873.
28. Ostojić SM, Mazić S, Dikić N. Profiling in basketball: physical and physiological characteristics of elite players. J Strength Cond Res. 2006;20(4):740-744.
29. Schmidt-Nielsen K. Scaling: why is animal size so important? Cambridge: Cambridge University Press; 1984.
30. Siff MC. Supertraining. 6th ed. Denver: Supertraining International; 2004.
31. Vanderburgh PM, Katch FI, Schoenleber J, Balabinis CP, Elliott R. Multivariate allometric scaling of men's world

indoor rowing champion performance. Med Sci Sports Exerc. 1996;28:626-630.
32. Vanderburgh PM, Mahar MT, Chou CH. Allometric scaling of grip strength by body mass in college-age men and women. Res Q Exerc Sport. 1995;66(1):80-84.
33. Vaquera A, Santiago S, Gerardo VJ, Morante JC, Vicente GT. Anthropometric characteristics of Spanish professional basketball players. J Hum Kinet. 2015; 46:99-106.
34. Winter EM. Scaling: partitioning out differences in size. Pediatric Exer Sci. 1992;4:296-301.
35. World Medical Associations declaration of Helsinki ethical principles for medical research involving human subjects. JAMA. 2013;310(20):2191-2194.